UNIVERZITET U NOVOM SADU
FAKULTET TEHNIČKIH NAUKA

UNIVERSITY OF NOVI SAD
FACULTY OF TECHNICAL SCIENCES

Norbert L. Harmati

OPTIMIZACIJA ENERGETSKIH PERFORMANSI ADMINISTRATIVNIH ZGRADA U FUNKCIJI KORISNIČKOG KOMFORA

ENERGY PERFORMANCE OPTIMIZATION OF ADMINISTRATIVE BUILDINGS IN THE FUNCTION OF OCCUPANT COMFORT

DOKTORSKA DISERTACIJA
DOCTORAL DISSERTATION

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Doktorsku disertaciju posvećujem svom ocu
Lorantu Harmatiju dipl. inž. maš.

The doctoral dissertation is dedicated to my father
Lorant Harmati Dipl.-Ing. Mech.

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Тип документације, **ТД**:		Монографска публикација
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Врста рада, **ВР**:		Докторска дисертација
Аутор, **АУ**:		Норберт Л. Хармати, мастер инжењер архитектуре
Ментор, **МН**:		Проф. емеритус др Радомир Фолић (ментор 1) Проф. др Золтан Мађар (ментор 2)
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Место и адреса, **МА**:		21000 Нови Сад, Трг Доситеја Обрадовића 6
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Предметна одредница/Кључне речи, **ПО**:		Енергетска перформанса, динамичка енергетска симулација, кориснички комфор, Фангеров модел, Енерџиплус
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Doktorska disertacija

Proširen izvod

Sadržaj

Apstrakt

Istraživanja u doktorskoj disertaciji zasnovana su na određivanju visoko efikasnog rešenja za unapređenje energetskih performansi višespratnih administrativnih zgrada u umerenim klimatskim uslovima sa posebnim naglaskom na postizanju i održavanju prihvatljivih unutrašnjih mikroklimatskih standarda i termičkog komfora korisnika. Metode za unapređenje su istražene sa stanovišta kompleksne višekriterijumske optimizacije uz primenu najsavremenije tehnologije dinamičke energetske simulacije.

Razvijena metodologija za vrednovanje i unapređenje energetskih performansi u funkciji korisničkog komfora imaće mogućnost široke primene na višespratnim administrativnim zgradama u cilju formulisanja efikasnih metoda za poboljšanje energetskih performansi i unapređenja unutrašnjih mikroklimatskih uslova u zgradama. Formulisam model poseduje fleksibilnost i adaptibilnost za dalji razvoj i primenu u različitim klimatskim uslovima.

Ključne reči: Energetska performansa, dinamička energetska simulacija, korisnički komfor, Fangerov model, EnergyPlus

Doktorska disertacija Proširen izvod

Poglavlje 1 **Uvod**

Predmet i problem istraživanja

Svetska energetska potrošnja je u stalnom porastu sa zahtevom zadovoljenja sve većih energetskih potreba. Enormnu energetsku potrošnju čini ozbiljnom nedostatak prirodnih resursa i prisustvo uzajamnog povećanja ekološke neravnoteže. Republika Srbija trenutno spada u zemlje koje karakteriše enormna ne-efikasna energetska potrošnja u građevinskom sektoru. Najveći procenat energije se dobija iz neobnovljivim izvora, dok većina zgrada nije prilagođena efikasnim energetskim zahtevima. Porast energetske potražnje, pritisak javnosti zbog globalnog zagrevanja, zaštita životne sredine i povećanje troškova energenata postavlja ključna pitanja u cilju rešavanja nastalih problema.

Savremene metode u oblasti unapređenja energetskih performansi zgrada svrstavaju kriterijume za zadovoljavanje korisničkog komfora među najznačajnije. Termički komfor korisnika je stanje svesti koje izražava fizičko zadovoljstvo u okruženju. Važnost postizanja i održavanja unutrašnjeg komfora u administrativnim zgradama se manifestuje u ostvarenju zdravog i prijatnog radnog okruženja, koje takođe poboljšava produktivnost zaposlenih. Međutim, percepcija komfora je subjektivna i gotovo je nemoguće da se u potpunosti zadovolji termički komfor svakog pojedinca, već treba težiti ka postizanju povoljnih mikroklimatskih uslova definisanih prema evropskim i američkim standardima sa ciljem zadovoljenja više od 95% korisnika u zgradama prema predviđenoj najvišoj kategoriji korisničkog komfora.

Predmet istraživanja je analiza mogućnosti unapređenja energetskih performansi tipičnih višespratnih administrativnih zgrada. U tom cilju razvijena je metodologija procene stanja i potrebnih intervencija za unapređenje energetskih performansi tipičnih energetski ne-efikasnih administrativnih zgrada. Suština istraživanja je utvrđivanje količine energije koju administrativna zgrada zahteva u funkciji postizanja i održavanja zdravog i prijatnog radnog okruženja. Razvijena metodologija će biti prikazana i proverena na primeru devetoetažne kule Fakulteta tehničkih nauka u okviru Univerzitetskog kompleksa u Novom Sadu.
Zahtevi korisničkog komfora su:

- Vizuelni komfor; kvalitet prirodne svetlosti u radnom prostoru;
- Termički komfor; temperatura vazduha, relativna vlažnost vazduha, brzina kretanja vazduha,
- Kvalitet vazduha;
- Zvuk i akustika.

Prema navedenim zahtevima korisničkog komfora definisaće se kriterijumi za optimizaciju koji su:

- Kvalitet svetlosti u radnom prostoru;
- Interval oscilacije temperature vazduha;
- Prosečna temperatura zračenja površina;
- Interval oscilacije relativne vlažnost vazduha.

Kvalitet vazduha i akustika se ne istražuje u disertaciji iz razloga što kriterijumi za postizanje ispravnog čistog vazduha zavise od efikasnosti i održavanja sistema za ventilaciju i prečišćivača vazduha. Pored toga, proučavanje akustike u prostorijama administrativnih zgrada zavisi od geometrija prostorija i strukture primenjenih materijala u konstrukciji.

Istraživački predmet i problem doktorske disertacije se zasniva na:

1. Detaljnoj proceni energetskih zahteva tipične energetski ne-efikasne i ne-rehabilitovane administrativne zgrade izgrađene na teritoriji Novog Sada. Problem proučavanja je administrativni objekat sa velikom

površinom zastakljenosti fasade devetoetažne kule Fakulteta tehničkih nauka. Na referentnoj zgradi izvršiće se potrebne analize primenom metode geometrijskog i parametarskog modelovanja u programima Revit[1] i OpenStudio[2], a zatim konverzijom informacija u matematički model u programu EnergyPlus[3] za procenu energetskog opterećenja. Razvijena metodologija za određivanje i vrednovanje energetskih performansi imaće mogućnost široke primene na administrativnim zgradama u cilju formulisanja efikasnih metoda za poboljšanje energetskih performansi, korisničkog komfora i termičkih karakteristika omotača.

2. Utvrđivanju kvantitativnog i kvalitativnog uticaja parametara za zadovoljavanje korisničkog komfora u administrativnim zgradama. U okviru metodologije koja će biti razvijena osnovni cilj je definisanje i proračunavanje ukupnih energetskih zahteva objekta na godišnjem nivou radi postizanja i održavanja korisničkog komfora. Krajnji rezultat je redukcija energetskih zahteva uz održavanje termički komfornog i zdravog radno okruženja.
3. Utvrđivanju optimalnih mera za rekonstrukciju, rehabilitaciju i unapređenje energetske performanse administrativnih zgrada u funkciji zahteva korisničkog komfora formulisanjem visokog kvalitetnog rešenja za umerene klimatske uslove.

Potreba za istraživanjem

Nastanak ekološke neravnoteže je stogo povezana sa svetskim energetskim zahtevima koje se zadovoljavaju putem eksploatacije neobnovljivih energetskih rezervi. Prema podacima Međunarodne agencije za energiju zgrade prekoračuju 40% od ukupne svetske potrošnje a emituju skoro 1/3 CO_2 na svetskom nivou. Zahtevi energije za grejanje i hlađenje zgrada obuhvata najveći deo ukupnih troškova. Porast energetske potražnje, pritisak javnosti zbog globalnog zagrevanja, zaštita životne sredine i povećanje troškova energenata postavlja kritična pitanja. Optimizacija energetskih performansi prema klimatskim karakteristikama je preduslov za unapređenje i osavremenjavanje građevinskog sektora. Problemi u energetskom sektoru na globalnom nivou se izražavaju prema sledećim stavkama:

- Eksploatacija neobnovljivih izvora energije (nafta, ugalj, gas) ima ograničen vek;
- Nedovoljna primenljivost savremenih održivih tehnologija za proizvodnju energije;
- Zagađenje životne sredine je povezano sa globalnim zagrevanjem koje dovodi do promene klime;
- Tržište i ekonomske krize utiču na porast cena fosilnih energenata na regionalnom i svetskom nivou.

Republika Srbija uz navedene globalne energetske probleme ima mnogo više razloga za pridavanje veće pažnje energetskoj efikasnosti zbog sledećih razloga:

- Srbija uvozi preko 40% energenata, što je svrstava u izuzetno uvozno zavisnu državu;
- Potrošnja energije u zgradama je među najvećima u Evropi što značajno utiče na privredu i životni standard građana;
- Energetski sistemi opstaju na granici izdržljivosti, jer nema dovoljno sredstava za izgradnju novih i održavanju postojećih postrojenja, što za posledicu ima česte havarije i velike gubitke tokom transporta energije;
- Zagađenje vazduha i voda je naročito izraženo u velikim gradovima.

Obim i struktura energetskih rezervi i resursa Srbije su veoma nepovoljni. Rezerve kvalitetnih energenata kao što su nafta i gas čine svega 1% od ukupnih. Preostalih 99% energetskih rezervi čine razne vrste niskokvalitetnog uglja. Lignit je procenjen sa učešćem od oko 90% u ukupnim bilansnim rezervama. Potrošnja energije u građevinskom sektoru Republike Srbije iznosi približno 40%. Administrativne zgrade sa loši omotačem su najveći potrošači.

Trenutno stanje u oblati

Evropa proizvodi 80% energije iz fosilnih goriva, vodećeg zagađivača životne sredine. Prema najnovijim podacima evropski troškovi se procenjuju na 570 milijardi € godišnje za uvoz nafte, gasa i uglja. U suprotnom, evropske cene za električnu energiju su među najvišima u svetu, što je zabrinulo širu javnost po pitanju ekonomske isplativosti

[1] Autodesk Revit Architecture 2012, License: Type; Standalone-Locked, ID; REVIT_F_S, Expiration; 02.04.2016., Student version
[2] NREL OpenStudio Version 1.0.0., 2013, Build no. 12393, Copyright © 2013 National Renewable Energy Laboratory
[3] EnergyPlus Version 7.2.0. Build no. 006., 2013, Copyright © 1996-2012 The Board of Trustees of the University of Illinois and The Regents of the University of California through Ernest Orlando Lawrence Berkeley National Laboratory. All rights reserved

prelaska energetske politike na nisko emisionu proizvodnju energije. Prema izveštaju Svetskog saveta za energiju pod nazivom "Klimatske promene: implikacije u energetskom sektoru", odgovornog urednika Nuthall-a ključna otkrića su sledeća (Nuthall 2014):

- Energetska potražnja je u globalnom porastu. Očekuje se povećanje potražnje, prvenstveno iz ekonomskih razloga i rastuće populacije.
- Klimatske promene će postaviti nove izazove za proizvodnju i transport energije. Progresivno globalno zagrevanje, povećan broj ekstremnih vremenskih neprilika i promena učestalosti padavina uticaće na proizvodnju i isporuku energije.
- Znatno smanjenje emisije štetnih gasova staklene bašte tokom proizvodnje energije može se postići različitim merama. Ovaj proces uključuje prevashodno smanjenje emisije CO_2 u procesu ekstrakcije i konverzije fosilnih goriva, zatim povećanje primene goriva sa nižom emisijom štetnih gasova (na primer prelazak sa uglja na gas), poboljšanje energetske efikasnosti u prenosu i distribuciji, povećanje korišćenja obnovljivih izvora i nuklearne energije, uvođenje sistema za skladištenje CO_2 i redukciju finalne energetske potrošnje.
- Jaka globalna politička akcija imala bi značajno učešće u energetskom sektoru. Globalna stabilizacija emisije štetnih gasova bi značla fundamentalnu transformaciju energetske industrije širom sveta u narednim decenijama.
- Intenziviranje investicija u nisko emisivne tehnologije biće ključni izazov za države.

Cilj istraživanja

Osnovna hipoteza je: da je moguće iznalaženje optimalnog rešenja za unapređenje energetskih performansi administrativnih zgrada u funkciji parametara korisničkog komfora i zdravog radnog okruženja za klimatske uslove na teritoriji Novog Sada.

Druga hipoteza je: da je moguće formulisati/izraditi proračunski model za efektivno unapređenje energetskih performansi administrativnih zgrada primenom višekriterijumske optimizacije i komparativne analize. Pored toga da je moguće formulisati pojednostavljen model za primenu u cilju redukcije energetskih zahteva s jedne i postizanja komfornog radnog okruženja s druge strane.

Zadatak je iznalaženje optimalnih mera za unapređenje energetskih performansi administrativnih zgrada u funkciji zahteva korisničkog komfora i zdravog radnog okruženja sa ciljem formulisanja rešenja visokog kvaliteta. Disertacija će istražiti mogućnost efektivnog unapređenja energetskih performansi administrativnih zgrada primenom:

- BIM tehnologije (eng. Building Information Modeling);
- Parametarskog visoko-detaljnog modelovanja; i
- Dinamičke energetske simulacije.

Cilj istraživanja je određivanje optimalne energetske performanse tipičnog energetski ne-efikasnog administrativnog objekta na teritoriji Novog Sada, koja se sastoji iz detaljne kritičke analize energetske performanse sa posebnim naglaskom na postizanju i održavanju unutrašnjeg korisničkog komfora. Rezultati istraživanja definisaće rešenja sa najpovoljnijim performansama za polazni model administrativne zgrade. Optimalni energetski modeli administrativnih zgrada razrađeni su u pojedinim razvijenim zemljama. Srbija još uvek ne poseduje optimalan model administrativnih zgrada za klimatske uslove na teritoriji Vojvodine. Poboljšanje energetskih performansi poslovnih objekata trebala bi da bude neodvojiva od komfora korisnika. Ovaj pravac poboljšanja značajno bi smanjio energetsku potrošnju u zgradama i otvori bi put ka racionalnom korišćenju energije, smanjenju emisije štetnih gasova i očuvanju životne sredine.

Formulisana metodologija za određivanje i vrednovanje energetskih performansi će biti pojednostavljena u cilju primenljivosti na administrativnim zgradama sa istim ili sličnim karakteristikama kako bi ponudila efikasne metode za poboljšanje energetskih performansi, korisničkog komfora i termičkih karakteristika omotača.

Pregled osnovne literature

Određivanje energetske performanse zgrada primenom energetske simulacije zahteva unos mnogih parametara kao što su konstrukcija, materijali, intervali zauzetosti, operacija sistema za grejanje hlađenje i ventilaciju, unutrašnja energetska opterećenja i klimatski podaci. Dinamička energetska simulacija zahteva detaljno definisanje svih delova numeričkog modela, jer je neophodno formulisanje virtuelnog okruženja, usaglašenog sa fizičkim zakonima. Nova generacija programa za energetsku simulaciju – EnergyPlus, koji je primenjen u disertaciji razvijen je od strane američkih inženjera i profesora iz Ministarstva za energetiku, Istraživačkog i razvojnog centra inženjera američke vojske, Univerziteta u Berkliju, Univerziteta Ilinois, Univerziteta u Oklahomi i kompanije GARD Analytics. (Strand 2000) EnergyPlus omogućava visoko detaljnu energetsku simulaciju, jer poseduje matematičke modele i termodinamičke modele koji modeluju fizičke osobine materijala, kretanje vazduha i prenos energije konvekcijom, kondukcijom i radijacijom. EnergyPlus omogućuje detaljno programiranje zgrada sa velikim brojem termičkih zona i mehaničkih sistema. U cilju analiziranja energetskih zahteva modela u određenim vremenskim intervalima, ovom tehnologijom omogućeno je formulisanje projektnih rešenja sa optimizovanom energetskom performansom.

Tema vezana za automatizaciju zgrada razrađena je od strane autora Wang u knjizi „Inteligentne zgrade i automatizacija u zgradama“ (Wang 2010) i autora Gevorkian u knjizi „Održivi energetski sistemi u arhitektonskom projektovanju“ (Gevorkian 2006). Teorija komfora u zgradama je razrađena u knjizi „Kako projektovati zdrave, efikasne i održive zgrade“ prema autorima Bokalders i Blok (Bokalders i Blok 2010). Pametne zgrade su značajna tema u poslednjoj deceniji u cilju razvoja visoko efikasnih rešenja. Kompleksnost ove teme leži u integraciji računarskih modela koji povezuju aktivnost korisnika sa operacijom zgrade kako bi se poboljšala efikasnost i funkcionalnost. Autor Sinopli opisuje pametne zgrade i njihovu funkcionalnost u knjizi „Pametne zgrade za arhitekte, vlasnike i konstruktere“ (Sinopoli 2010). Veoma značajan izvor o metodama energetskog proračuna zastupala je knjiga pod naslovom „Energetska simulacija u projektovanju zgrada“ autora Clarke koja analizira probleme matematičkih modela i pouzdanost rezultata iz numeričkih simulacija (Clarke 2001).

Doktorska disertacija pod nazivom „Klimatski uticaji na energetske zahteve Evropskih poslovnih zgrada“ od autora Schlenger sa Tehničkog univerziteta u Dortmundu, razvija i analizira uticaj klimatskih uslova na energetsku performansu poslovnih zgrada u centralnoj i severnoj Evropi (Schlenger 2009). Brojne disertacije su analizirane pre početka istraživačkog rada u cilju analize metodologije koja je korišćena iz oblasti građevinske energetike i teorije komfora (Petersen 2011) (Chan 2011) (Flodberg 2012) (Khazaii 2012) (Birchall 2011) (Janson 2010) (Artmann 2008) (Joelsson 2008) (Hansen 2006) (Wetter 2004).

Mnogobrojna istraživanja razrađuju optimizaciju energetskih performansi zgrada primenom različitih metoda i tehnika za analizu kako bi formulisale održive, energetski efikasne i ekonomski isplative zgrade (Blizzard and Klotz 2012) (Vuuren, et al. 2012) (Dylewski and Adamczyk 2012) (Gong, Akashi and Sumiyoshi 2012) (Yu, et al. 2012) (Lou, et al. 2012) (Roetzel, Tsangrassoulis and Dietrich 2014) (Bambrook, Sproul and Jacob 2011) (Milan, Bojesen and Nielsen 2012) (Sartori and Hestnes 2007) (Wang, Gwilliam and Jones 2009) (Pérez-Lombard, et al. 2011) (Pisello, Bobker and Cotana 2012) (Schein 2007) (Attia, Hamdy, et al. 2013) (Fumo, Mago and Luck 2010) (Gonzalez, et al. 2011) (Rabah, Emmanuel and Rafik 2015) (Rahman 2014) (Eui-Jong, et al. 2014).

Objavljena istraživanja iz teme disertacije o energetskim simulacijama, korisničkom komforu, sistemima za grejanje i klimatizaciju prezentovana su u sledećim publikacijama; (Harmati and Folić 2014) (Harmati, Folić and Magyar (no. 1) 2014) (Harmati, Folić and Magyar (no. 2) 2015) (Harmati and Jakšić 2014) (Harmati, Jakšić and Vatin. 2015) (Harmati and Magyar (no. 1) 2014) (Harmati and Magyar (no. 2) 2014) (Harmati and Magyar (no. 3) 2014) (Harmati and Magyar (no. 4) 2014) (Harmati and Magyar (no. 5) 2014).

Zgrade sa nultom energetskom potrošnjom zauzimaju danas ključnu temu razmatranja i istražuju se u brojnim studijama (Thalfeldt, et al. 2013) (Kolokotsa, et al. 2011) (Attia, et al. 2012) (Schimschar, et al. 2011) (Robert and Kummert 2012) (Marszal and Heiselberg 2011) (Lund, Marszal and Heiselberg 2011) (Kapsalaki, Leal and Santamouris 2012) (Adhikari, et al. 2012).

Kratak sadržaj poglavlja

Disertacija se sastoji od osam poglavlja.

U Poglavlju 1 prikazan je istraživački predmet, problem i navedeni ciljevi disertacije sa naznačenim značajem teme na globalnom nivou i u Srbiji. Prikazano je trenutno stanje u predmetnoj oblasti uz navedenu značajnu literaturu.

U poglavlju 2 prikazana je metodologija primenjena u istraživanju i prikupljena građe/materijali. Analizirani su podaci sa merenja na terenu, tehnička građa, prikupljeni energetski troškovi i ulazni klimatski podaci.

Poglavlje 3 predstavlja optimizaciju omotača zgrade u funkciji prostorne disperzije prirodne svetlosti, kvaliteta i jačine svetlosti. Geometrijski CAD model zgrade modelovan je primenom BIM tehnologije. Modeli su detaljno razrađeni u cilju sprovođenja mnogobrojnih simulacija u programu Radiance[4]. Rezultati su vrednovani prema definisanim kriterijumima radi određivanja efikasnih performansi prozora u zadatim klimatskim uslovima.

Poglavlje 4 predstavlja performativna rešenja za poboljšanje termičkih karakteristika omotača administrativnih zgrada u skladu sa evropskim standardima i srpskoj regulativi o energetskoj efikasnosti zgrada. Takođe su prikazana i terenska snimanja postojećeg omotača referentne zgrade.

U poglavlju 5 razrađuje se složenost projektovanja termičkog multi-zonskog modela i definišu se svi neophodni ulazni parametri u cilju pokretanja dinamičke simulacije u programu EnergyPlus. Detaljno su opisani ulazni podaci i metodologija proračuna koje sledi komparativna analiza i vrednovanje rezultata. Energetski zahtevi za ventilaciju su utvrđeni prema standardu EN 15251. Nalazi definišu visoko efikasna rešenja sa aspekta energetske performanse za zadate klimatske uslove.

U poglavlju 6 detaljno se obrazlaže optimalan model zgrade u funkciji parametara komfora. Fangerov model termičkog komfora se primenjuje za prethodno usvojeno rešenje sa aspekta energetske performanse u cilju određivanja i analize PPG i PPN indeksa. Istraga obuhvata mnogobrojne dinamičke simulacije u cilju određivanja oscilacionih intervala parametara komfora u programu EnergyPlus i predstavlja detaljnu obradu i analizu parametara. Krajnji rezultat formuliše najefikasnije rešenje sa aspekta korisničkog komfora u skladu sa evropskim standardima.

Poglavlje 7 predstavlja pregled svojstava najefikasnijeg rešenja prema prethodnim istraživanjima izloženim u poglavljima 3, 4, 5 i 6. Obrazlaže se efikasnost sistema za grejanje i hlađenje kod novoprojektovanih zgrada i predlaže se metoda za unapređenje sistema kod rehabilitacije postojećih administrativnih zgrada.

Poglavlje 8 obuhvata sažetak i završne napomene, ukazuje na mogućnost primene rezultata i predlaže pravce za dalja istraživanja.

Poglavlje 2 Metodologija i materijali

Metodologija

Primenjene naučno-istraživačke metode:

- Metoda analize i sinteze, i komparativna analiza;
  - Analiziraće se energetska potrošnja objekta kule Fakulteta tehničkih nauka (Pod+P+9) kao tipičnog energetski ne-rekonstruisanog značajnog potrošača među administrativnim objektima,
  - Sintetizuju se glavni aspekti koji utiču na energetske performanse zgrada.
- Indukcija i dedukcija;
- Metoda parametarskog modelovanja;
- Metoda numeričke simulacije;
- Apstrakcija i konkretizacija.

Kvantitativni pristup:

- Prikupljanje podataka mernim instrumentima (temperatura vazduha, relativna vlažnost vazduha i intenzitet prirodne svetlosti),
- Prikupljanje troškova energetske potrošnje od JKP Toplane Novi Sad i Elektrovojvodine.

Optimizacija:

- Višekriterijumska optimizacija;
  - Višekriterijumskom optimizacijom se formuliše najbolje rešenja iz niza mogućih rešenja u smislu više usvojenih kriterijuma,
  - Vrednosti kriterijumskih analiza dokazaće koliko je formulisan model kvalitetan prema zadatim alternativama. Optimizacijom će se odrediti najefikasnije rešenje prema definisanim kriterijumima.

[4] Desktop Radiance, Radiance CP Version 2.01, 2013, Lawrence Berkely National Laboratories, USA

Tehnike prikupljanja podataka:

- Merenja i snimanja na terenu, i prikupljena arhivska tehnička građa.

Materijali

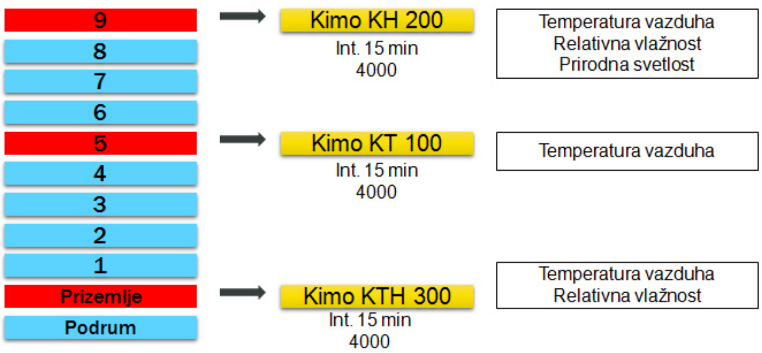
Klimatski podaci, urbanistički podaci, merenja

Klimatski podaci u dinamičkoj simulaciji čine skup podataka koji su sačinjeni iz dugoročnih merenja vremenskih uslova jedne lokacije. Dinamička energetska simulacija zahteva visoku detaljnost i veliki broj informacija o klimi. Pre pokretanja simulacije neophodna je konverzija klimatskih podataka u format sa EPW ekstenzijom kako bi se importovala u program EnergyPlus. U zavisnosti od detaljnosti simulacije neophodno je definisanje vremenskih intervala tokom procesa pripreme za konverziju podataka. Klimatski podaci za lokaciju grada Novog Sada preuzete su iz globalne meteorološke baze podataka Meteonorm 7[5] sa sedištem u Bernu, Švajcarskoj. Meteonorm je sveobuhvatan meteorološka satelitska baza koja omogućava pristup katalogu svih meteoroloških podataka u Evropi. Meteonorm je utemeljen na više od 25 godina iskustva u razvoju meteoroloških baza podataka (Meteotest 2014). Mesečni klimatološki podaci bili su dostupni za sledeće parametre: (Meteotest 2014) globalno zračenje, temperatura vazduha, vlažnost, padavine, broj dana sa padavinama, brzina i pravac vetra, sunčevo zračenje. Tabelaran i grafički prikaz klimatskih podataka je detaljno prikazan u **drugom poglavlju** disertacije na engleskom jeziku. Za referentnu administrativnu zgradu odabrana je kula Fakulteta tehničkih nauka, Univerziteta u Novom Sadu, iz razloga osobina objekta kao tipičnog ne-efikasnog značajnog potrošača na teritoriji Novog Sada. Drugi razlog za odabir istog bila je dostupnost tehničke dokumentacije i troškova energetske potrošnje. A treći razlog je zbog lokacije objekta u cilju svakodnevnog merenja i snimanja tokom šestomesečnog zimskog i letnjeg perioda. Fakultet tehničkih nauka čini deo Univerzitetskog kompleksa u naselju Liman 1 na obali Dunava. Orijentacija kule je – 30° od severne ose. Urbanistički plan naselja i Univerzitetskog kompleksa sa godišnjom trajektorijom sunca predstavljen je opširno u **drugom poglavlju** disertacije na engleskom jeziku.

Merenja su izvedena u cilju procene energetske potrošnje i mikroklimatskih uslova referentne zgrade tokom zimskog i letnjeg perioda 2014. godine. Podaci o daljinskom centralnom grejanju zabeleženi su u podstanici kako bi se ustanovio period operacije sistema i intenzitet grejanja. Merenje je izvedeno kako bi se utvrdila efikasnost sistema za grejanje i hlađenje, interval rada sistema i termička performansa spoljašnjeg omotača zgrade. Potrošnja energije u zimskom periodu merena je od 20. januara do 17. marta, dok je letnje merenje obavljeno od sredine jula do kraja avgusta. Referentna zgrada se snabdeva preko sistema daljinskog grejanja iz Novosadske toplane. Toplotna energija se prenosi preko radijatora koji se nalaze ispod prozora u svakoj kancelariji. Za hlađenje zgrade ne postoji centralizovan sistem, većina kancelarija poseduje klima uređaj koji se manualno podešava u zavisnosti od perioda zauzetosti radnog prostora.

Pomoću Kimo instrumenata mereni su parametri komfora u kancelarijama u cilju procene i vrednovanja kvaliteta radnog okruženja. Digitalni instrumenti su postavljeni na tri etaže referentne zgrade, kao što je prikazano na slici 1.

Celokupni rezultati merenja prikazani su u **drugom poglavlju** disertacije na engleskom jeziku i u **Prilogu A**. Slike 2, 3 i 4 prikazuju merenja iz prvog zimskog perioda od 20.01. do 03.02.2014. sa naznačenim intervalima parametara prema EN 15251.

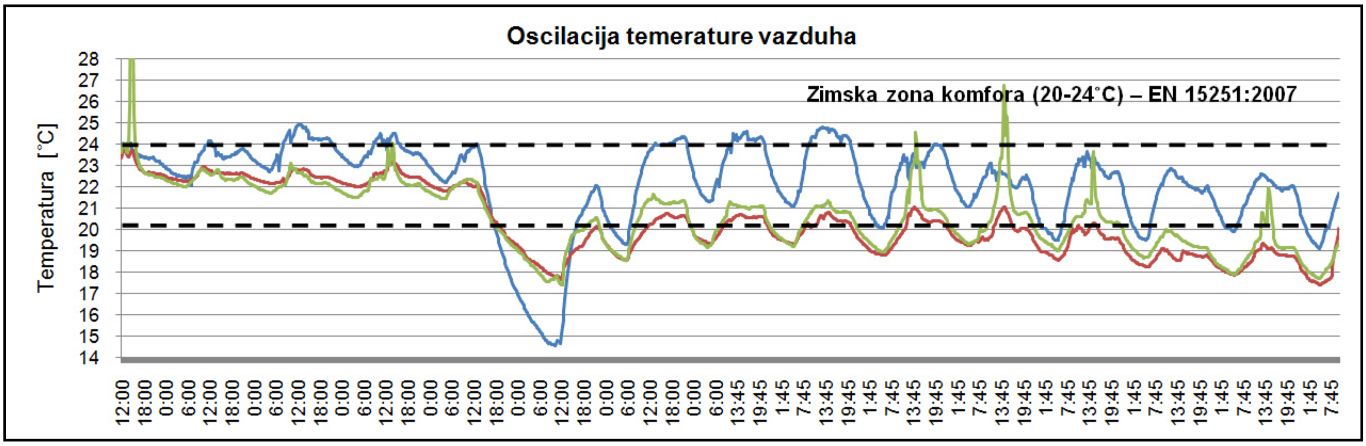


Slika 1. Postavljanje Kimo instrumenata

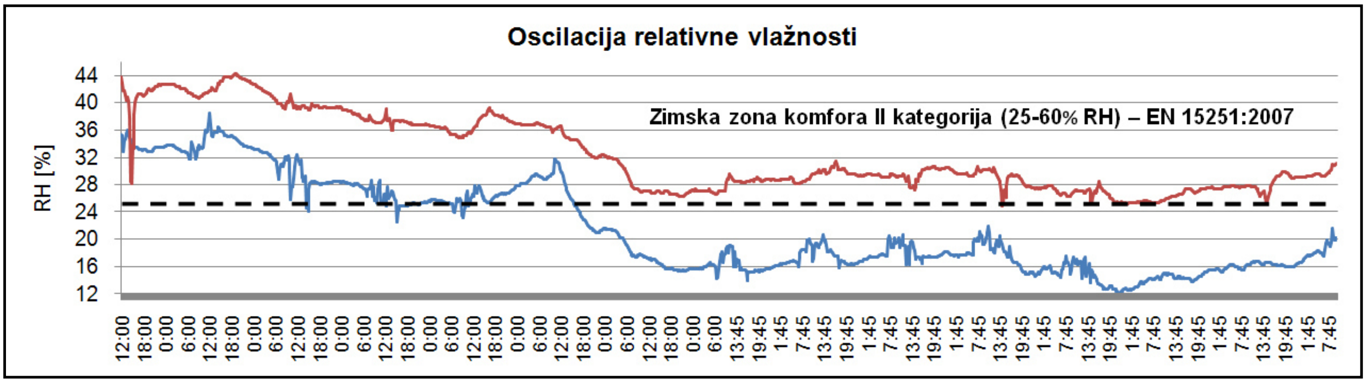
Analizirajući oscilaciju parametara komfora prema merenim podacima može se zaključiti da uprkos značajno visokoj energetskoj potrošnji koja je zabeležena u podstanici, standardi unutrašnjeg termičkog komfora nisu zadovoljeni u referentnoj zgradi. Temperaturna oscilacija vazduha, relativna vlažnost i intenzitet prirodne svetlosti su većinom u intervalima iznad ili ispod propisanih granica parametara komfora. Interval za temperaturu vazduha je od 20°C do 24°C, za relativnu vlažnosti od 25% do 60% (prema II kategoriji komfora propisanom u EN ISO 7730 2005). Minimalan uslov za intenzitet prirodne svetlosti je u intervalu od 350-500 lx. Troškovi energetske

[5] Meteonorm Version 7.0.22.8, 2014, License: registered for N. Harmati, tutorial licence, Copyright © 2012 Meteotest Genossenschaft, Bern, Switzerland

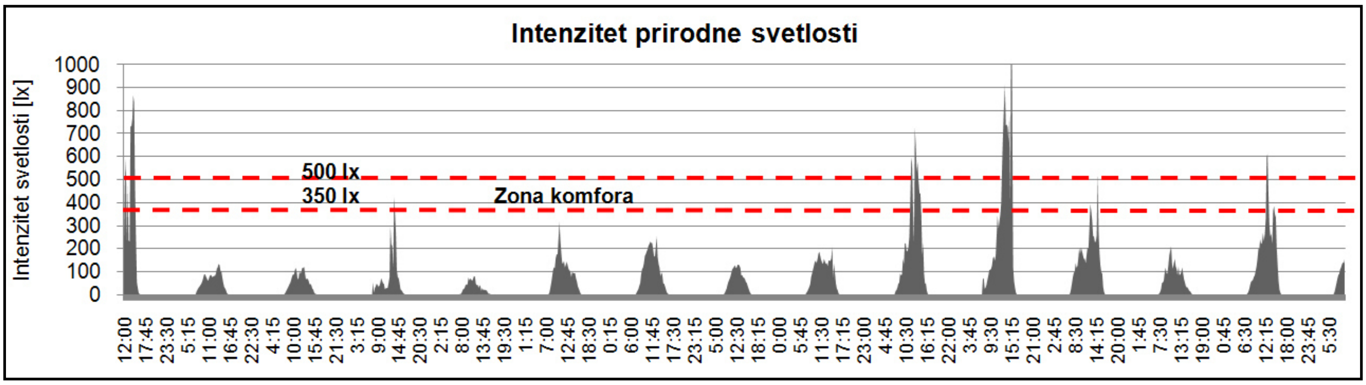
potrošnje za daljinsko grejanje i električnu energiju zgrade prikupljeni su od protekle tri godine 2013, 2012 i 2011. U tabeli 1 upoređeni su godišnji energetski troškovi referentne zgrade.



Slika 2. Oscilacija temperature vazduha; plava linija – prizemlje, crvena linija – 5. sprat, zelena linija – 9. sprat



Slika 3. Oscilacija relativne vlažnosti; plava linija – prizemlje, crvena linija – 5. sprat



Slika 4. Intenzitet prirodne svetlosti na 9. spratu

Tabela 1. Troškovi energetske potrošnje

Godišnja energetska potrošnja – grejanje i struja, administrativna zgrada – kula FTN						
Mesec	2011		2012		2013	
	Struja [kWh]	Grejanje [kWh]	Struja [kWh]	Grejanje [kWh]	Struja [kWh]	Grejanje [kWh]
I	19099	82306	19158	115993	19214	81610
II	18376	95210	14544	63473	17478	76527
III	18595	70106	21141	42323	18519	55891
IV	16918	31934	15870	1415	16918	52467
V	16486	/	16411	/	14375	/
VI	17519	/	19203	/	16706	/
VII	17947	/	20164	/	17078	/
VIII	16707	/	18402	/	16652	/
IX	18541	/	17014	/	14113	/
X	18009	18580	18883	9551	17245	21980
XI	19124	63268	18922	45003	15282	30005
XII	20398	80788	20111	61030	20230	60304
Ukupno	**217719**	**442192**	**219823**	**338788**	**203810**	**378784**
[kWh/m^2]	**63**	**128**	**64**	**98**	**59**	**110**

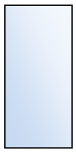
Poglavlje 3 CAD model, analiza zastakljenosti omotača i simulacija svetlosti

U trećem poglavlju se određuje optimalan procenat zastakljenosti omotača referentnog objekta u cilju postizanja kvalitetnog prirodnog osvetljenja u skladu sa zahtevima vizuelnog komfora u radnom prostoru. Optimizacija geometrije prozora i površine zastakljenosti ima dvostruku funkciju; omogućava adekvatnu prirodnu iluminaciju u radnom prostoru, a sa druge strane utiče i na ukupnu termičku performansu omotača i energetsku performansu zgrade. Optimizacija zastakljenosti objekta rezultuje u redukciji električne energije za veštačko osvetljenje i u redukciji energetskih zahteva za grejanje i hlađenje. Na osnovu detaljne numeričke simulacije utvrđuje se efikasna geometrija prozora i procenat zastakljenosti prema sledećim kriterijumima:

1. Analiza disperzije svetlosti (napredna svetlosna simulacija);
2. Određivanje faktora osvetljenja (analiza vizuelnog komfora);
3. Simulacija foto-električnog osvetljenja (senzorski sistem, učestalost električnog osvetljenja);
4. Analiza izloženosti solarnoj radijaciji (energetski dobici zračenjem).

Istraživanje obuhvata analizu geometrije prozora kao značajnog kriterijuma optimizacije omotača sa aspekta vizuelnog komfora. Disperzija svetlosti u enterijeru je simulirana i analizirana za tri geometrije prozora kao što je prikazano u tabeli 2.

Tabela 2. Geometrija fasadnih prozora

Kvadratni oblik	Horizontalni pravougaoni oblik	Vertikalni pravougaoni oblik
a x a 	a x b 	a x b 

Navedene geometrije prozora se zatim apliciraju na fasadi objekta sa različitim procentima zastakljenosti; 20%, 25%, 30% i polaznog modela 50%. Nakon formulisanja CAD (eng. Computer Aided Design) modela u programu Autodesk Revit Architecture sa različitim procentima zastakljenosti pristupa se unosu podataka i podešavanju napredne simulacije svetlosne disperzije u programu Radiance. Primenjene su sledeće dimenzije prozora, prikazane u tabeli 3.

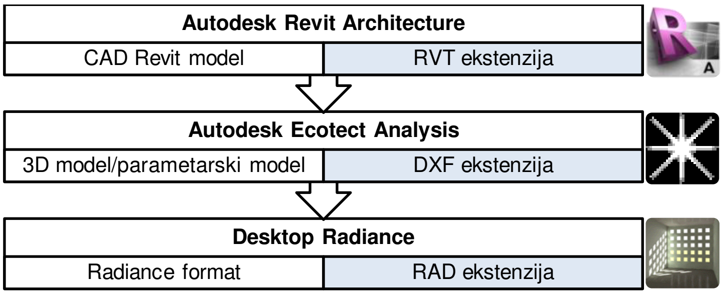
Tabela 3. Površina zastakljenosti i dimenzije prozora

Procenat zastakljenosti [%] Spoljašnja površina zida kancelarije 8.96 m^2	Površina zastakljenosti jedne kancelarije [m^2]	Površina jednog prozora [m^2]	Dimenzije prozora [m x m]
50 (referentna zgrada)	4.48	2.24	1.4 x 1.6
20	1.79	0.89	0.94 x 0.94; 0.64 x 1.40; 0.60 x 1.49
25	2.24	1.12	1.05 x 1.05; 0.80 x 1.40; 0.60 x 1.86
30	2.68	1.34	1.16 x 1.16; 0.96 x 1.40; 0.60 x 2.20
80 (referentna zgrada)	7.17	3.58	/ / 1.40 x 2.55

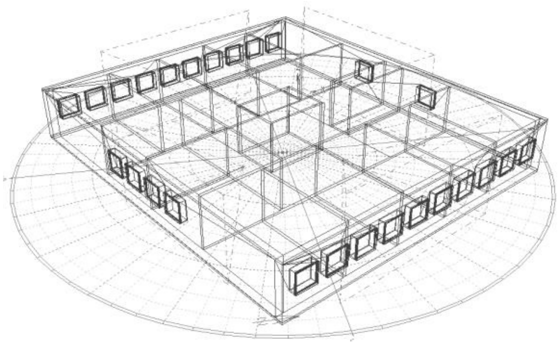
CAD model i konverzija formata

Konstruisano je deset zasebnih CAD modela u programu Revit u skladu sa prethodno navedenim proporcijama i dimenzijama zastakljenosti fasade. Kako bi se sprovela simulacija neophodno je konvertovati podatke geometrijskog modela u format koji je kompatibilan sa simulatorom Radiance. Metodologija konverzije prikazana je na slici 5. Uvezeni DXF modeli (slika 6) u Ecotect[6] za naprednu solarnu analizu treba da prevaziđu proces implementacije parametara kao što su hrapavost površina i osobine prozora. Hrapavost utiče na refleksiju svetlosti u unutrašnjem prostoru dok koeficijent transmisije zraka utvrđuje procenat propuštene svetlosti u zgradu.

[6] Autodesk Ecotect Analysis 2011, License: Type; Standalone-Locked, ID; ECOA_F_S, Expiration; 10.06.2016., Student version



Slika 5. Metodologija modelovanja i konverzija podataka



Slika 6. DXF model importovan u Ecotect program

Priprema modela za simulaciju u programu Radiance

Simulacija dnevnog osvetljenja je detaljno podešena i sprovedena u kontrolnoj tabli programa Radiance. Priprema simulacije je sprovedena u 9 koraka, koji su podeljeni u 5 kategorija:

1. Eksportovanje DXF modela u Radiance program sa RAD ekstenzijom;
2. Podešavanja osobina simulacije;
3. Postavljanje kamera i intervala ambijentalnog osvetljenja;
4. Definisanje preciznosti i detaljnosti proračuna;
5. Pregled i kontrola eksportovanih osobina simulacije u kontrolnoj tabli Radiance.

Detaljno podešavanje simulacije u programu Radiance za svaku kategoriju prikazano je u **trećem poglavlju** disertacije na engleskom jeziku. Disperzija dnevne svetlosti u enterijeru simulirano je primenom trostruke refleksije sa srednjim stepenom detaljnosti izlaznih podataka. Prostorna disperzija i intenzitet dnevne svetlosti analizirana je u intervalu od 0-1000 lx kao što je prikazano na slici 7.

Slika 7. Intervali intenziteta svetlosti u enterijeru

Rezultati simulacija

Simulacije su sprovedene na godišnjem nivou za sve moguće kombinacije geometrija prozora i procenata zastkljenosti iz prethodno navedene tabele 3. Analiza intenziteta i disperzije svetlosti zahtevala je 720 simulacija koje su zavisile od definisanog vremenskog intervala, uslova oblačnosti i orijentacije. Simulacije su sprovedene u intervalima od 4 sata radi analize intenziteta i disperzije dnevnog osvetljenja u kancelarijama tokom radnog vremena. Rezultati su analizirani u intervalima od 8.00h, 12.00h i 16.00h. U cilju vrednovanja vizuelnog komfora prema konstantnim granicama između 350 i 500 lx. Simulacije su sprovedene za 10 modela u vremenskim intervalima za svaki drugi mesec na godišnjem nivou za svaku orijentaciju. Rezultati su komparativno analizirani u funkciji disperzije i intenziteta sunčeve svetlosti koji su prikazani u **Prilogu B.** Odabrane simulacije su prikazane u tabeli 4.

Proračun faktora osvetljenja (FO), koji u najpovoljnijem slučaju iznosi 2.0 u radnom kancelarijskom prostoru je sproveden u skladu sa intervalima zauzetosti prostorija na godišnjem nivou. Za analizu koordinatnih tačaka definisan je geometrijski centar prostorija u kojima su pozicionirani virtuelni senzori za merenje intenziteta osvetljenja. Godišnja simulacija za određivanje prosečnog faktora osvetljenja izvedena je za sve prethodno navedene modele sa zahtevom da intenzitet osvetljenja iznosi najmanje 350 lx-a. Ukupan broj obavljenih simulacija je iznosio 16. Izračunavanjem faktora osvetljenja donesen je ključni argument u izboru optimalnog zastakljenja. Električno osvetljenje je analizirano u slučaju dva režima; režim automatskog uključivanja i isključivanja svetla, i režim prigušivanja svetla. Podešavanja režima i osobina prozora prikazana su u **trećem poglavlju** disertaciji na engleskom jeziku. Svi simulirani scenariji su predstavljeni u **Prilogu C.** Simulacija je predstavila procenat nepotrebne električne rasvete na godišnjem nivou u zgradi. Usvojen procenat zastakljenosti za sve orjentacije prikazan je u tabeli 5.

Tabela 4. Odabrani rezultati simulacije

Datum/vreme Karakteristike neba		20% zastakljenost	25% zastakljenost	30% zastakljenost	50% referentni model
Sept/12h Sunčano nebo	Istok				
	Jug				
	Zapad				
Jul/16h Sunčano nebo	Istok				
	Jug				
	Zapad				

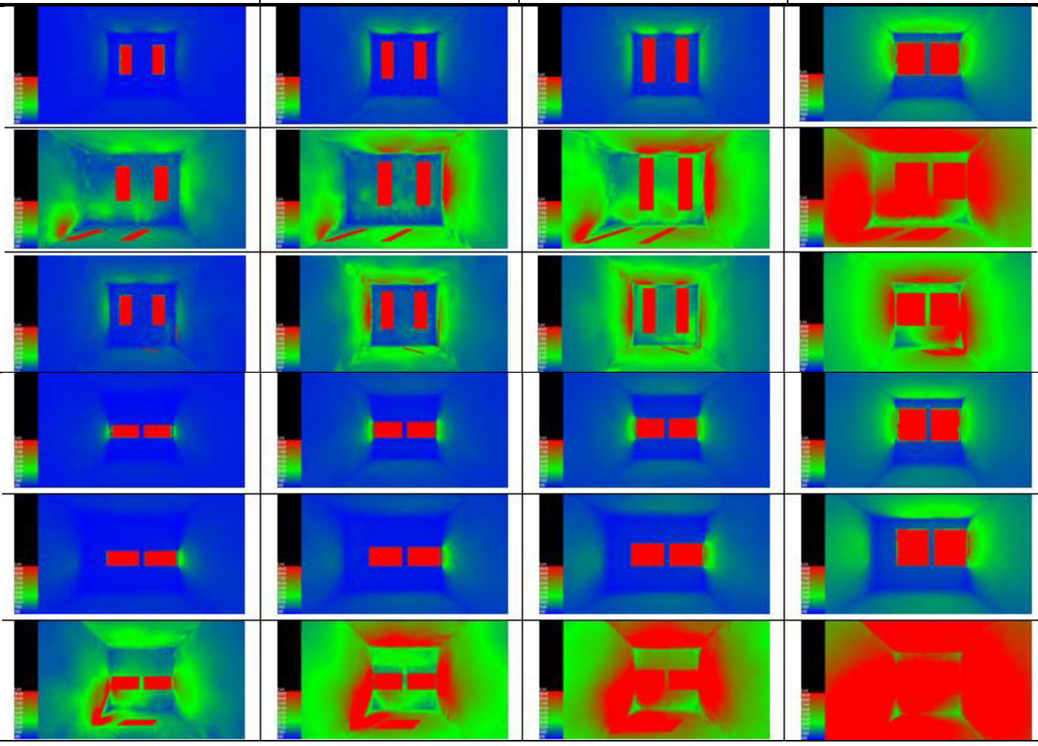
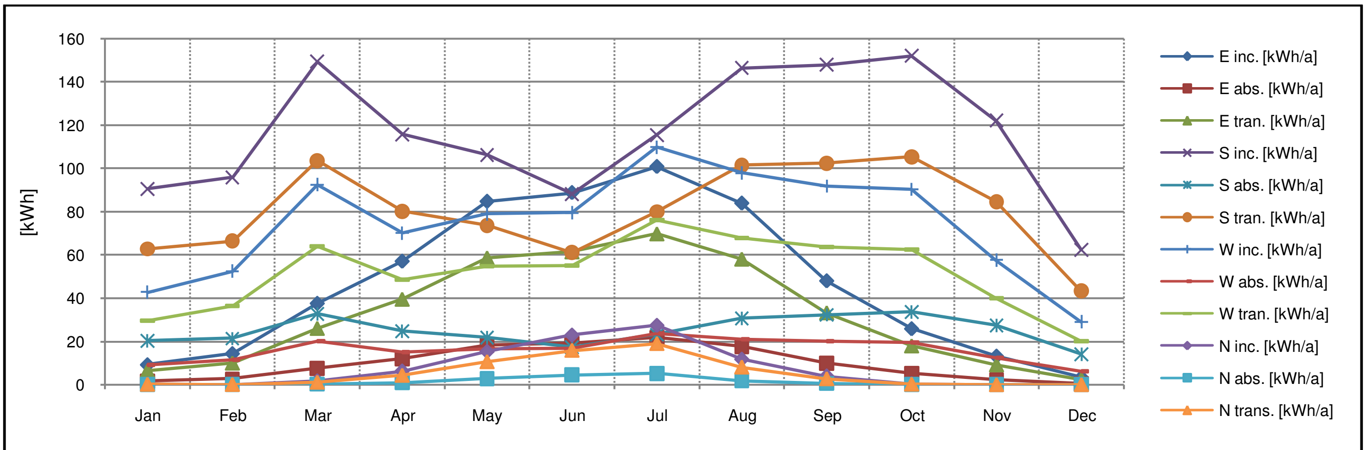


Tabela 5. Faktori osvetljenja za usvojene orijentacije

Istok (min 350 lx)			Zapad (min 350 lx)		
Kancelarije	Procenat nepotrebne električne rasvete (%)		Kancelarije	Procenat nepotrebne električne rasvete (%)	
30% 1.97 FO	69	Usvojena zastakljenost 30%	30% 1.78 FO	66	Usvojena zastakljenost 30%
Jug (min 350 lx)			**Sever (min 350 lx)**		
Kancelarije	Procenat nepotrebne električne rasvete (%)		Hodnik	Procenat nepotrebne električne rasvete (%)	
25% 2.05 FO	70	Usvojena zastakljenost 25%	20% 1.89 FO	67	Usvojena zastakljenost 20%

Godišnja izloženost solarnom zračenju je simulirana radi utvrđivanja ukupnog (eng. incident), propuštenog (eng. transmitted) i apsorbovanog (eng. absorbed) zračenja na fasadi za scenarije zastakljenja od 20%, 25%, 30% i 50%. Slika 8 prikazuje rezultate za 30% zastakljenosti fasade za sve orijentacije. Navedena simulacija je značajna zbog procene uticaja procenta zastakljenosti, osobina prozora i unutrašnjih energetskih dobitaka u daljim istraživanjima. Rezultati su detaljno predstavljeni u **trećem poglavlju** disertacije na engleskom jeziku i **Prilogu D.**



Slika 8. Ukupno, propušteno i apsorbovano sunčevo zračenja za sve orijentacije – zastakljenost 30%

Vrednovanje rezultata

Radi formulisanja najefikasnijeg rešenja za procenat zastakljenosti omotača i geometriju otvora rezultati su vrednovani sa stanovišta prethodno navedena četiri kriterijuma u funkciji vizuelnog komfora u radnom prostoru.

Prema analiziranim rezultatima disperzije svetlosti ustanovljeno je da vertikalni pravougaoni prozori prikazuju najprihvatljiviji kvalitet prirodnog osvetljenja u enterijeru. Visina prozora doprinela je dubljem upadu sunčeve svetlosti u enterijeru u poređenju sa ostalim geometrijama prozora. Tabela 6 predstavlja optimalno rešenje zastakljenja fasade prema navedenim kriterijumima.

Tabela 6. Optimalno rešenje zastakljivanja fasade

Orijentacija	Faktor osvetljenja u enterijeru [-]	Režim prigušivanja Procenat nepotrebne električne rasvete [%]	Usvojen procenat zastakljenosti za vertikalnu pravougaonu geometriju prozora
Istok	1.97	69	30% / 30˚ rotacija osnove (kancelarija)
Jug	2.05	70	25% / 30˚ rotacija osnove (kancelarija)
Zapad	1.78	66	30% / 30˚ rotacija osnove (kancelarija)
Sever	1.89	67	20% / 30˚ rotacija osnove (hodnik)

U nastavku istraživanja izloženost fasade solarnom zračenju biće jedan od veoma značajnih faktora u procesu izračunavanja energetskih zahteva za grejanje i hlađenje administrativnih zgrada. Analiza ukupnog, propuštenog i apsorbovanog zračenja je simulirana za iste osobine prozora za koju je sprovedena simulacija disperzije svetlosti. S obzirom da je simulacija izvršena prema konstantnom koeficijentu transmisije zraka koji definiše procenat propuštene svetlosti, neophodno je da navedeni parametar ostane približan odabranom u daljem istraživanju, dok ostali parametri (U-vrednost i KSTD-koeficijent solarnog toplotnog dobitka) mogu da budu varijabilni.

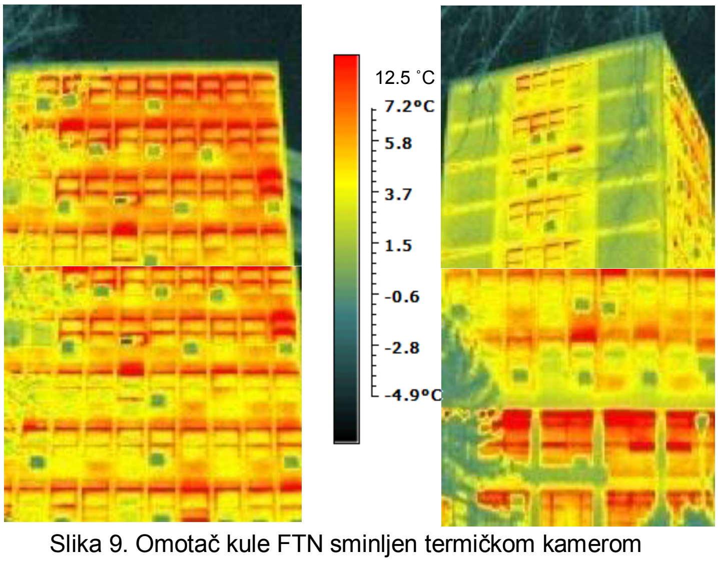
Poglavlje 4 **Performansa omotača zgrade**

Standardi i zahtevi omotača administrativnih zgrada

Države članice EU imaju različite zahteve za nove zgrade i zgrade koje podležu rehabilitaciji. U **četvrtom poglavlju** disertacije na engleskom jeziku navedene su vrednosti iz regulativa o termičkim karakteristikama poslovnih zgrada u pojedinim vodećim evropskim državama. Poboljšanje termičkog omotača i krovne konstrukcije kule Fakulteta tehničkih nauka sprovedena je uz uvažavanje Pravilnika o energetskoj efikasnosti zgrada Zakona o planiranju i izgradnji, Službeni glasnik RS:61/2011 u skladu sa analiziranim regulativama u Austriji, Nemačkoj, Italiji i Mađarskoj.

Analiza postojećeg omotača kule-FTN

Termička performansa postojećeg omotača zgrade snimljena je termičkom kamerom tokom grejne sezone u januaru 2015 godine. Termičko snimanje je izvršeno tokom radnog dana u vremenskom intervalu između 11h i 13h. Zabeležena spoljašnja temperatura vazduha iznosila je – 3˚C tokom snimanja. Na slici 9 prikazan je snimljen omotač zgrade na temperaturnoj skali od – 4.9˚C do + 12.5˚C. Sa temičkih slika zaključilo se da postojeći omotač ne ispunjava minimalne standarde termičkih svojstava. Energija od grejanja se prenosi u spoljnu atmosferu većinom preko neadekvatnog kvaliteta zastakljenja, slika 9 (levo). Takođe se pojavljuju i hladni mostovi (AB grede i stubovi) koji su istaknuti u termičkim slikama na slici 9 (desno).



Slika 9. Omotač kule FTN sminljen termičkom kamerom

Poboljšana termička osobina omotača sa opcionim zastakljenjem

Konstrukcija omotača zgrade koja je primenjena u simulaciji odabrana je u skladu sa termičkim zahtevima. U cilju pronalaženja efikasnog i ekonomski prihvatljivog rešenja za unapređenje termičke performanse fasadnih zidova sa minimalnim intervencijama. S obzirom da je zgrada sagrađena 1968. godine, termički zahtevi su u velikoj meri odstupali od današnjih. Detaljan opis konstrukcije nalazi se u **četvrtom poglavlju** disertacije na engleskom jeziku. Ponuđeno unapređenje termičkih karakteristika spoljašnjeg omotača je urađena u cilju višestrukog smanjenja U-vrednosti koja trenutno iznosi 2.32 W/(m^{2}K). Modifikovan fasadni zid u poređenju sa trenutnim stanjem uz dodatak izolacije snizio je koeficijent prolaza toplote približno deset puta.

Ponuđena intervencija rezultirala je u unapređenju termičkog omotača prema prethodno navedenom pravilniku Zakona o planiranju i izgradnji, Službeni glasnik RS:61/2011. Rehabilitovani opcionalni fasadni zidovi iznose 0.22 W/(m^{2}K) kao što je prikazano u tabeli 7. Nadalje ustanovljeno je da ukupna zastakljena površina omotača iznosi 37.5% (kabineti sa jednom orijentacijom iznose 50%, hodnik 80%) dok U-vrednost prozora iznosi približno 2.78 W/(m^{2}K).

U narednom poglavlju energetskih simulacija istražiće se uticaj različitih tipova prozora. Razlog odabira 10 tipova prozora sa različitim osobinama doprineće analizi i vrednovanju parametara koji imaju značajan uticaj na energetske zahteve zgrade. U tabeli 8 prikazana su moguća primenljiva rešenja koja ispunjavaju propisane termičke zahteve (U-vrednost) fasadnih prozora u Srbiji. Prozori sa različitim osobinama i parametrima prikupljeni su od proizvođača kao što su Pilkington, Guardian itd. uz razne tipične dvoslojne i troslojne prozore (Pilkington 2014) (Pilkington Planar 2014) (All Weather Windows Ltd. 2014) (Guardian Industries Corp. 2014).

Tabela 7. Konstrukcija fasadnog zida

Postojeća konstrukcija		Modifikovana (opcionalna)	
Fasadni zid	**Osobine materijala specifikacija**	**Fasadni zid**	**Osobine materijala specifikacija**
Cementni malter	d = 10 mm	Portland cementni malter	d = 20 mm λ = 0.6918 W/(mK) ρ = 1858 kg/m^3 Q = 837 J/kgK
Pečena opeka	d = 250 mm λ = 0.675 W/(mK) ρ = 1601.84 kg/m^3 Q = 790 J/kgK	Ekspandirani polistiren	d = 140 mm λ = 0.0352 W/(mK) ρ = 24 kg/m^3 Q = 1210 J/kgK
		Pečena opeka	d = 250 mm λ = 0.675 W/(mK) ρ = 1601.84 kg/m^3 Q = 790 J/kgK
Cementni malter	d = 5 mm	Portland cementni malter	d = 10 mm λ = 0.6918 W/(mK) ρ = 1858 kg/m^3 Q = 837 J/kgK
U = 2.32 W/(m^{2}K)		**U = 0.22 W/(m^{2}K)**	

Tabela 9. Konstrukcija ravnog krova

Modifikovana (opcionalna)	
Krovna terasa	**Osobine materijala specifikacija**
Ploče od lakog betona	d = 40 mm, λ = 0.530 W/(mK) ρ = 1280 kg/m^3, Q = 840 J/kgK
Vazdušni sloj	R = 0.15 m^{2}K/W
Stirodur C – BASF	d = 180 mm, λ = 0.040 W/(mK) ρ = 33 kg/m^3, Q = 1450 J/kgK
Vodonepropusna membrana (3 sloja)	d = 0.009mm, λ =0.160 W/(mK) ρ = 1121.29kg/m^3, Q=1460 J/kgK
Armirano betonska ploča	d = 200 mm, λ = 1.95 W/(mK) ρ = 2240 kg/m^3, Q = 900 J/kgK
Portland cementni malter	d = 10 mm, λ = 0.692 W/(mK) ρ = 1858 kg/m^3, Q = 837 J/kgK
Vazdušni sloj	R = 0.15 m^{2}K/W
Gipsana ploča	d = 19 mm, λ = 0.160 W/(mK) ρ = 800 kg/m^3,Q =1090 J/kgK
U = 0.18 W/(m^{2}K)	

Unapređena termička osobina krovne terase prikazana je u tabeli 9 sa predloženim rešenjem koji ispunjava termičke zahteve prema Pravilniku o energetskoj efikasnosti zgrada u Srbiji.

Zgrada kule FTN je ponovo izmodelovana u programu Sketchup Make 3D [7] pomoću OpenStudio programskog priključka u cilju formulisanja multi-zonskog termičkog modela. Nakon konstruisanja termičkog modela informacije o modelu se konvertuju u numeričke podatke sa IDF ekstenzijom i importuju se u program EnergyPlus koji će biti razrađen u narednom poglavlju.

[7] Program Sketchup Make 3D, 2013, http://www.sketchup.com/products/sketchup-make

Tabela 8. Tipovi prozora

Postojeći prozori		
Prozori	**Osobine materijala - specifikacija**	
2 x 3 mm Običan stakleni panel	U-vrednost / KSTD / Koef. transmisije	2.788 W/(m^{2}K) / 0.765 / 0.812

Simulirana konstrukcija (opcionalni prozori)			
Br.	**Prozori**	**Osobine materijala - specifikacija**	
W1	Dvoslojno staklo, Pilkington (Optifloat-clear)	U-vrednost / KSTD / Koef. transmisije	1.70 W/(m^{2}K) / 0.60 / 0.70
W2	Dvoslojno staklo, Pilkington (Optifloat-clear)	U-vrednost / KSTD / Koef. transmisije	1.30 W/(m^{2}K) / 0.50 / 0.73
W3	Troslojno staklo, Pilkington (Planar + Optifloat + K Glass)	U-vrednost / KSTD / Koef. transmisije	0.90 W/(m^{2}K) / 0.34 / 0.57
W4	Troslojno staklo,Pilkington (Planar + Optifloat + Optitherm)	U-vrednost / KSTD / Koef. transmisije	0.70 W/(m^{2}K) / 0.23 / 0.42
W5	Dvoslojno staklo, Pilkington, Energy Advantage, (Argon, Low-E 3 sloja)	U-vrednost / KSTD / Koef. transmisije	1.67 W/(m^{2}K) / 0.75 / 0.77
W6	Dvoslojno staklo, Guardian (Clima-Guard 80/70)	U-vrednost / KSTD / Koef. transmisije	1.53 W/(m^{2}K) / 0.69 / 0.81
W7	Troslojno staklo (jedan "Sun-Stop" filtrirajući sloj, Argon)	U-vrednost / KSTD / Koef. transmisije	1.05 W/(m^{2}K) / 0.34 / 0.63
W8	Troslojno staklo (dva "Sun-Stop" filtrirajuća sloja, Argon)	U-vrednost / KSTD / Koef. transmisije	0.70 W/(m^{2}K) / 0.31 / 0.54
W9	Troslojno staklo, Pilkington (Planar + Optifloat + K Glass)	U-vrednost / KSTD / Koef. transmisije	0.80 W/(m^{2}K) / 0.22 / 0.39
W10	Troslojno staklo,Pilkington (Planar + Optifloat + Optitherm)	U-vrednost / KSTD / Koef. transmisije	0.70 W/(m^{2}K) / 0.26 / 0.52

Poglavlje 5 **Simulacija energetske performanse**

Multi-zonski termički model

Zoniranje podrazumeva podelu sistema za grejanje i hlađenje zgrade u regije koje dopuštaju nezavisnu kontrolu temperature vazduha, relativne vlažnosti, brzine kretanja vazduha i kvaliteta vazduha. Većina zgrada je sačinjena od više termičkih zona, ali svaka pojedina zona može da ima različite energetske dobitke i gubitke. Energetski dobici se odnose na solarno zračenje i toplotne dobitke od strane korisnika i opreme. Kontrola energetskih performansi zavisi od definisanih karakteristika termičkih zona u dinamičkoj simulaciji, za koju su neophodne karakteristike i parametri građevinskih materijala, električnog osvetljenja, električnih uređaja i opreme, zatim broj korisnika, njihova aktivnost i zauzetost prostora, i osobine sistema za grejanje i hlađenje. U EnergyPlus-u moguće je primeniti režim za idealne termičke uslove. Primenom OpenStudio priključka za Sketchup kreirana su sledeća dva modela:

- 3D geometrijski model i
- Parametarski OpenStudio model koji sadrži informacije o termičkim zonama.

Nakon kreiranja geometrijskog modela pristupilo se unosu sledećih podataka: definisanje površina u modelu (spoljašnje i unutrašnje površine), definisanje konstrukcije i materijala, navođenje spratova, određivanje karakteristika prostorija i konačno definisanje termičkih zona u cilju detaljog unosa podataka unutrašnjeg energetskog opterećenja u narednoj fazi pripreme simulacije. Ukupan broj definisanih elemenata parametarskog modela u programu OpenStudio iznosio je 1536. Detaljno obrazloženje elemenata i termičkih zona nalazi se u **petom poglavlju** disertacije na engleskom jeziku.

Energetsko opterećenje termičkih zona

Unutrašnje energetsko opterećenje je najznačajnija komponenta u određivanju ukupnih energetskih zahteva za hlađenje u nestambenim zgradama. Izvori energetskih dobitaka u prostorijama su sledeći: sunčevo zračenje, toplotni dobitak kondukcijom, električno osvetljenje, električni uređaji i korisnici. Međutim energetski zahtevi za hlađenje u mnogim slučajevima nisu ujednačeni sa unurašnjim energetskim opterećenjem, jer zavise od efikasnosti instaliranih mehaničkih sistema za grejanje, klimatizaciju i ventilaciju (ASHRAE Standard 55 2013).

Unutrašnje toplotno opterećenje od strane korisnika zavisi od metaboličke stope koji razvija toplotne dobitke u administrativnim zgradama. Takođe toplotno opterećenje od strane osvetljenja i električnih uređana imaju značajna opterećenja i neophodno ih je implementirati u energetsku simulaciju. Unutrašnje toplotno opterećenje se određuje u funkciji vremenskih intervala pri dnevnim periodima zauzetosti objekta. Neophodno je implementirati klimatske podatke koji značajno utiču na dodatno energetsko opterećenje u zavisnosti od termičkih performansi spoljašnjeg omotača zgrade, infiltracije i ventilacije.

Istraživanje je sprovedeno primenom metode toplotne ravnoteže (eng. heat balance) sa implementiranim termodinamičkim modelima (eng. system thermodynamics). Detaljna razrada energetskih izvora i rasporeda prikazana je u **petom poglavlju** disertacije na engleskom jeziku.

Definisanje korisnika i električne opreme

Broj korisnika sa karakterističnim energetskim opterećenjima implementirani su u energetsku simulaciju prema sledećim koracima:

- Izračunat je predviđen broj korisnika;
- Određena je površina iskorišćenog prostora za rad;
- Određena je površina slobodnog i retko korišćenog prostora u zgradi.

Očekivan broj zaposlenih po spratovima prikazan je u tabeli 10. Površine kancelarija, komunikacija i dodatnih sadržaja prema etažama prikazane su u trećoj koloni.

Od 4. do 9. sprata radni prostor po zaposlenom iznosi 10.8 m^2, dok na 3. spratu iznosi 24.5m^2 a na 2. spratu 16.33 m^2. Konačno u prizemlju približna površina po zaposlenom iznosi 13.3m^2.

Tabela 10. Broj zaposlenih i površina radnog prostora

Broj korisnika	Etaže	Približna površina kancelarija [m^2]
(18 x 6) 108	4 – 9	(196 x 6) 1176
8	3	196
12	2	196
16	1	196
10	Prizemlje	133
Retka zauzetost	Podrum	0
Ukupan br. 154 Usvojen br. 160	Ukupan br. 11	Ukupna površina: 3430 m^2 Površina radnog prostora: 1897 m^2 Ulaz, hodnik, stepenište, liftovi, WC, podstanica, instalacije, arhiva, ostalo: 1533 m^2

Karakteristike električne opreme importovane su iz globalne elektronske datoteke programa OpenStudio prema ASHRAE standardima. Energetski zahtevi električnih kancelarijskih uređaja za rad u kancelarijama iznose 5.812514 W/m^2 prema podacima iz datoteke "ASHRAE_189.1-2009 Kompleksna administrativna zgrada, električni uređaji i oprema".

Karakteristike električnog osvetljenja takođe su unete iz globalne elektronske datoteke. Energetski zahtevi električnog osvetljenja u kancelarijama iznose 9.687519 W/m^2 prema podacima iz datoteke "ASHRAE_189.1-2009 Kompleksna administrativna zgrada, električno osvetljenje". U energetskoj simulaciji operacija i intenzitet električnih uređaja i osvetljenja prilagođeni su referentnom objektu prema formulisanim prioritetima koji su detaljno obrazloženi u **petom poglavlju** disertacije na engleskom jeziku.

Metodologija dinamičke energetske simulacije

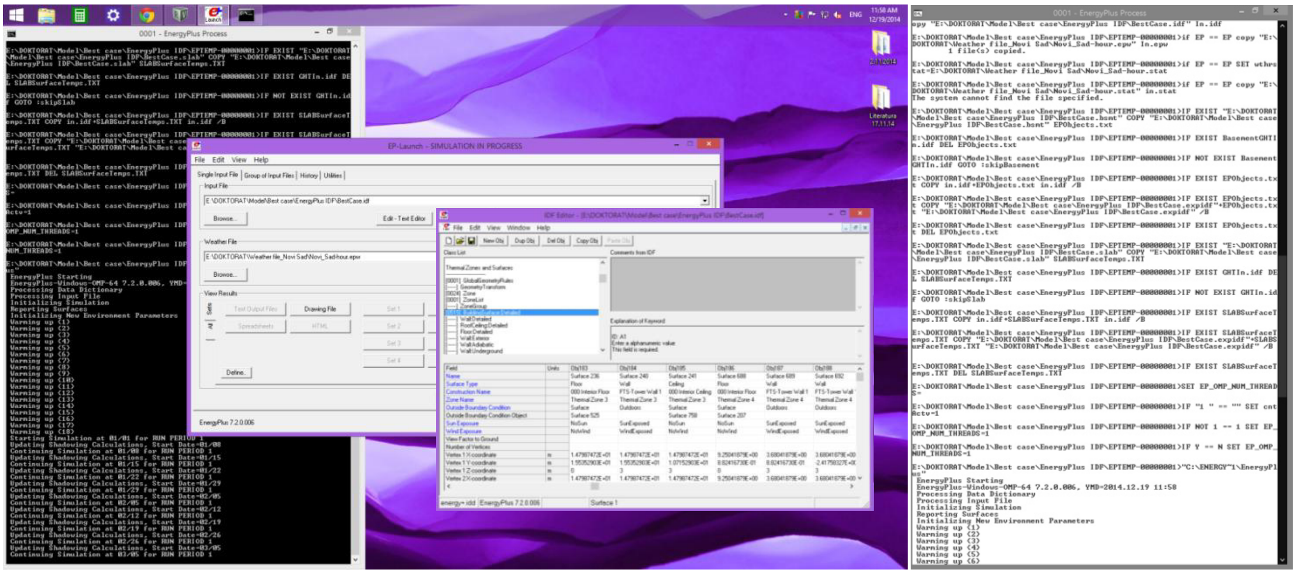
Pre energetske simulacije neophodno je savladati brojne korake radi formulisanja i kalibracije termičkog modela sa definisanim energetskim opterećenjima. U cilju utvrđivanja godišnje energetske performanse zgrade kalibracija simulacije obuhvata sledeće korake:

1. Formulisanje geometrijskog modela sa RVT extenzijom referentnog objekta primenom BIM tehnologije;
2. Modelovanje omotača zgrade sa poboljšanim procentom zastakljenja i geometrije otvora;
3. Konstrukcija osnovnog modela i definisanje termičkih zona, građevinske konstrukcije i materijala;
4. Eksportovanje termičkog modela sa OPS ekstenzijom u program OpenStudio radi dodeljivanja svojstava građevinske konstrukcije i materijala, zatim parametara omotača, unutrašnjih energetskih opterećenja, rasporeda operacije električnih uređaja i osvetljenja;
5. Konverzija modela u numeričke podatke sa IDF ekstenzijom u cilju importovanja u program EnergyPlus;
6. Unos klimatskih podataka i koordinata u EnergyPlus, implementacija simulacije okruženja, algoritama za proračun i vremenskih intervala simulacije;
7. Dinamička energetska simulacija, tumačenje i vrednovanje rezultata sa izborom najefikasnijeg scenarija;
8. Optimizacija energetskog opterećenja prema kriterijumima graničnih vrednosti parametara komfora i Fangerovog modela za određivanje PPG i PPN indeksa.

Dinamička energetska simulacija zahteva unos sledećih rubrika podataka:

- Klimatski podaci;
- Zauzetost objekta, rasporedi i operacija mehaničkih sistema;
- Građevinska konstrukcija i materijali;
- Unutrašnje energetsko opterećenje;
- Osobine termičkog modela sa zonama;
- Definisanje izlaznih podataka;
- Definisanje i podešavanje toka simulacije.

Mašinski elementi sistema za grejanje i hlađenje nisu modelovani jer je cilj iznalaženje godišnjih energetskih zahteva za grejanje i hlađenje u funkciji konstantnog održavanja propisanih granica oscilacija parametara komfora prema evropskim standardima EN 15251. U dinamičkoj simulaciji primenjen je ventilacioni sistem sa idealnim opterećenjem (eng. ideal load air system) formulisan prema termodinamičkim modelima (eng. system thermodynamics) u programu EnergyPlus. Navedeni koraci pripreme termičkog modela sa svim neophodnim podacima detaljno su razrađeni uz diskusiju u **petom poglavlju** disertacije na engleskom jeziku. Interfejs programa EnergyPlus sa EP Launch i IDF Editor prozorom prikazan je na slici 10 levo. Proces simulacije prikazan je na slici 10 desno, sa kojeg je moguće pratiti i tumačiti tok simulacije. Proces dinamičke simulacije, izlazni podaci; promenljive, izveštaj toka simulacije, podaci o simulaciji, izveštaj o unetim podacima, fizičko okruženje, opcije dimenzionisanja navedeni su u **Prilogu E.**



Slika 10. Interfejs programa EnergyPlus sa EP Launch i IDF Editor prozorom (levo), proces simulacije (desno)

Analiza i vrednovanje rezultata energetske simulacije

Dinamična energetska simulacija izvedena je za deset različitih scenarija sa sledećim konstantnim parametrima koji su obrazloženi u prethodnom poglavlju:

- Građevinska konstrukcija: fasadni zidovi, krovna konstrukcija, tavanica, podrum i unutrašnji pregradni zidovi;
- Unutrašnja energetska opterećenja od strane korisnika, električne opreme i osvetljenja;
- Zauzetost objekta, operacija opreme i termostata.

Promenljive u scenarijima bili su parametri fasadnih pozora iz razloga jer osobine zastakljenja najznačajnije utiču na povećanje ili smanjenje energetskih zahteva za grejanje i hlađenje pri konstantnoj zauzetosti koja je karakteristična u administrativnim zgradama. Istraživanje je sprovedeno u cilju određivanja performansi i uticaja svojstava/parametara prozora radi odabira efikasnog rešenja za klimatske uslove na teritoriji Novog Sada. U scenarijima od 1 do 10, primenjeno je deset proizvoda sa različitim parametrima koji su prikazani u prethodnom poglavlju u tabeli 8. Prozori se primenjuju za usvojenu zastakljenost iz trećeg poglavlja. Uzeti su u obzir sledeći parametri: koeficijent toplotne provodljivosti, koeficijent solarnog toplotnog dobitka (KSTD) i koeficijent transmisije.

Tabela 11. Energetski zahtevi električne opreme i osvetljenja

Mesec	Električno osvetljenje [kWh]	Električna oprema [kWh]
Jan	5617	7180
Feb	5067	6490
Mar	5548	7159
Apr	5537	7015
Maj	5392	7060
Jun	5537	7015
Jul	5773	7278
Avg	5392	7060
Sept	5537	7015
Okt	5617	7180
Nov	5313	6896
Dec	5773	7278
Ukupno	**66104 kWh/a 19 kWh/m^2/a**	**84626 kWh/a 25 kWh/m^2/a**

Energetski zahtevi električne opreme i osvetljenja su usagšeni sa intenzitetom i rasporedom zauzetosti zgrade. Energetska simulacija prikazala je približne zahteve između 5000 - 6000 kWh mesečno za električno osvetljenje i 6500 - 7300 kWh mesečno za električnu opremu. Mesečni , godišnji i maksimalni zahtevi prikazani su u tabeli 11. Ukupni godišnji zahtevi za električno osvetljenje iznose približno 19 kWh/m^2/a, a ukupna godišnja potrošnja električne opreme iznosi približno 25 kWh/m^2/a.

Zaključeno je da energetsko opterećenje za električnu opremu i osvetljenje u slučaju analiziranog modela kule FTN u kojem se procenjuje najintenzivnija zauzetost pri opterećenju u proseku od 9 sati radnim danima i 4 sata subotom, najviša racionalno raspoređena potražnja za električnom energijom po kvadratnom metru korisne površine iznosi približno 44 kWh/m^2/a.

Rezultati energetskih simulacija ukazale su na značajnost uticaja KSTD parametra na energetske zahteve za grejanje i hlađenje administratvne zgrade.

Izbor efikasnog zastakljivanja leži u pronalaženju korelacije između energetskih zahteva grejanja i klimatizacije administrativnih zgrada i klimatskih uslova. Kako bi se pronašlo efikasno rešenje za objekte u umerenim klimatskim uslovima, deset tipova prozora je aplicirano na fasadi sa različitim vrednostima parametara (U-vrednost, KSTD parametar i koeficijent transmisije) u cilju analize uticaja i određivanja razlike između energetskih zahteva grejanja i hlađenja zgrade.

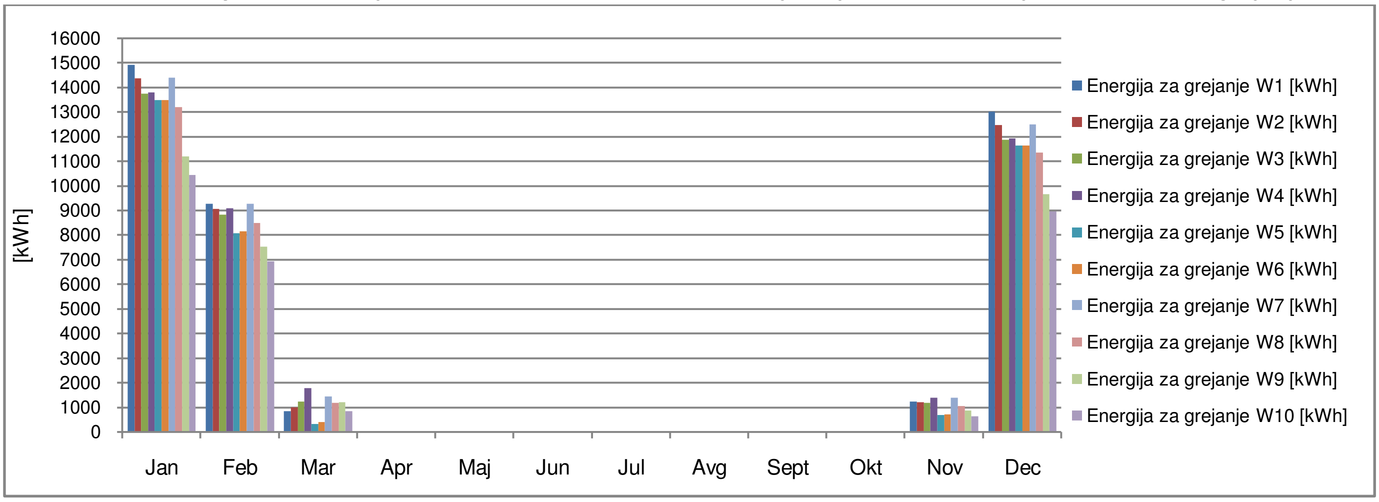
Rezultati energetskih performansi za sve scenarije predstavljeni su numerički u tabeli 12 i grafički na slikama 11 i 12. Najviši energetski zahtev za grejanje zabeležen je u scenariju W1, 39243 kWh/a, dok je scenario W10 predstavio najmanje zahteve grejanja 27773 kWh/a. Kada su upoređeni parametri KSTD navedena dva scenarija uočava se da relativno niska vrednost od 0.22 i 0.26 scenarija W9 i W10 rezultuje u značajno niskim energetskim zahtevima za grejanje zbog niskih toplotnih dobitaka od strane solarne energije, od kojih samo 22-26% se propušta kroz staklenu površinu, što je rezultiralo sa nižim energetskim potrebama za hlađenje u poređenju sa scenarijima sa visokim KSTD koeficijentima. Zahtev za grejanjem je niži zbog konstantnih unutrašnjih toplotnih dobitaka koji su specifični za kancelarijske prostore. Nizak KSTD koeficijent omogućava da toplotna energija ostane u radnom prostoru, te je moguće ponovo upotrebiti energiju uz pomoć toplotnog rekuperatora pri mehaničkoj ventilaciji.

Tabela 12. Energetski zahtevi za grejanje i hlađenje (scenariji od W1 do W10)

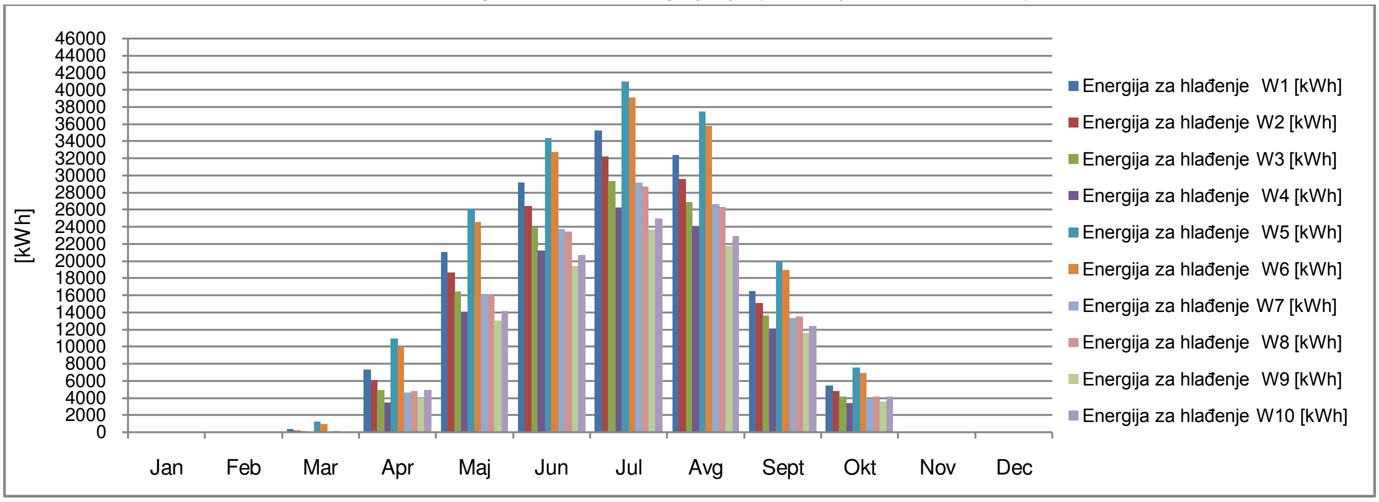
Mesec	Grejanje W1 [kWh]	Hlađenje W1 [kWh]	Grejanje W2 [kWh]	Hlađenje W2 [kWh]	Grejanje W3 [kWh]	Hlađenje W3 [kWh]	Grejanje W4 [kWh]	Hlađenje W4 [kWh]	Grejanje W5 [kWh]	Hlađenje W5 [kWh]
Jan	14905	0	14349	0	13737	0	13801	0	13482	0
Feb	9262	0	9052	0	8816	0	9088	0	8070	2
Mar	822	289	984	146	1218	59	1758	8	310	1195
Apr	0	7296	0	6073	0	4914	0	3498	0	10960
Maj	0	21028	0	18661	0	16440	0	13993	0	26150
Jun	0	29139	0	26459	0	24002	0	21191	0	34407
Jul	0	35289	0	32210	0	29355	0	26209	0	40964
Avg	0	32321	0	29602	0	26891	0	24031	0	37440
Sept	0	16460	0	15045	0	13662	0	12077	0	19945
Okt	2	5393	2	4782	3	4158	6	3364	0	7484
Nov	1233	0	1190	0	1170	0	1384	0	668	50
Dec	13019	0	12468	0	11873	0	11920	0	11621	0
Ukupno	39243	147213	38045	132978	36819	119481	37956	104372	34151	178597

Mesec	Grejanje W6 [kWh]	Hlađenje W6 [kWh]	Grejanje W7 [kWh]	Hlađenje W7 [kWh]	Grejanje W8 [kWh]	Hlađenje W8 [kWh]	Grejanje W9 [kWh]	Hlađenje W9 [kWh]	Grejanje W10 [kWh]	Hlađenje W10 [kWh]
Jan	13477	0	14387	0	13180	0	11188	0	10445	0
Feb	8143	1	9264	0	8485	0	7510	0	6924	0
Mar	384	922	1434	37	1167	58	1196	14	834	55
Apr	0	9970	0	4553	0	4820	0	3951	0	4881
Maj	0	24580	0	16083	0	16037	0	13033	0	14197
Jun	0	32703	0	23719	0	23439	0	19437	0	20685
Jul	0	39079	0	29105	0	28661	0	23645	0	24960
Avg	0	35761	0	26644	0	26279	0	21706	0	22917
Sept	0	18927	0	13371	0	13457	0	11542	0	12369
Okt	0	6938	5	3918	2	4145	2	3557	1	4127
Nov	715	30	1396	0	1038	0	867	0	631	0
Dec	11618	0	12478	0	11331	0	9657	0	8939	0
Ukupno	34337	168912	38963	117430	35204	116897	30420	96886	27773	104191

Kako bi se vrednovao i ustanovio uticaj i značaj KSTD parametara takođe su se analizirali i energetski zahtevi za hlađenje. Rezultati simulacije za zahteve hlađenja prikazali su značajne vrednosti u odnosu na zahteve grejanja zbog znatno visokih unutrašnjih energetskih dobitaka koji su karakteristični za administrativne zgrade. Ustanovilo se da su visoki interni energetski dobici, specifični za kancelarijske prostore tokom radnog vremena, jer električni uređaji i korisnici emituju značajnu toplotnu energiju. S obzirom da je emisija od strane uređaja konstantna tokom godine očekuju se znatno viši zahtevi za hlađenje objekta u poređenju sa zahtevima grejanja.



Slika 11. Energetski zahtevi za grejanje (scenariji od W1 do W10)



Slika 12. Energetski zahtevi za hlađenje (scenariji od W1 do W10)

Najviša energetska potreba za hlađenje zabeležena je u scenariju W5 koji iznosi 178597 kWh/a, dok je scenario W9 predstavio najniži zahtev za hlađenja, 96886 kWh/a. Akumulacija toplotne energije u prostorijama je pod uticajem KSTD parametra, jer visok KSTD parametar propušta veću količinu infracrvenih sunčevih zraka. Zahtevi scenarija W5 manifestuju visok pasivni solarni dobitak zbog visokog KSTD parametra, što je rezultiralo 90% višim zahtevima za hlađenje u odnosu na scenario W9 i 85% višim zahtevima za hlađenje u poređenju sa scenariom W10.

Pošto zahtevi za hlađenje u svim scenarijima predstavljali su najviše vrednosti, prvenstveni kriterijum odabira za dalju analizu bili su scenariji sa niskim energetskim zahtevima za hlađenje. Nakon poređenja scenarija sa sličnim godišnjim energetskim potrebama, kriterijumi za izbor su bili sledeći:

- Minimalna propisana ili niža U-vrednost prozora prema propisanim termičkim zahtevima Pravilnika o energetskoj efikasnosti u Srbiji;
- Vrednost KSTD parametra (≤ 0.3);
- Koeficijent transmisije (≥ 0.5).

Scenariji W4, W8, W9 i W10 rezultirali su manjim odstupanjima između zahteva grejanja i hlađenja u odnosu na scenarija W5 i W6. Scenariji W5 i W6 nisu prikazali prihvatljive rezultate za umerene klimatske uslove na teritoriji Novog Sada, jer je KSTD parametar bio najviši. Simulirani zahtevi grejanja su značajno niski, u proseku

34 MWh/a, dok su zahtevi za hlađenje prikazali značajno visoke vrednosti, između 168 MWh i 178 MWh. Visok KSTD parametar i visok koeficijent transmisije akumuliraju unutrašnje i pasivne energetske dobitke u prostorijama, što je nepovoljno za administrativne zgrade u umerenim klimatskim uslovima. Scenariji W5 i W6 bili bi efikasni za hladnijim klimatskim uslovima. Scenariji W1, W2, W3, W7 i W8 rezultirali su sličnim zahtevima grejanja između 35 MWh i 39 MWh, dok su zahtevi za hlađenje varirali između 117 MWh i 147 MWh.

Konačni scenario je usvojen između simuliranih modela W4, W9 i W10. Prema navedenim scenarijima ukupni simulirani energetski zahtevi bili su u granicama između 28 MWh/a i 38 MWh/a za grejanje i 97 MWh/a do 104 MWh/a za hlađenje. Koeficijent transmisije 0.52 scenarija W10 bio je odlučujući faktor usvajanja jer u prethodnim simulacijama disperzije svetlosti iz trećeg poglavlja koeficijent transmisije primenjenog zastakljivanja bio približan 0.5. Energetski zahtevi grejanja su različiti zbog izraženog uticaja KSTD parametra prozora. Zaključeno je da je KSTD parametar ima značajan uticaj kod pasivnih solarnih energetskih dobitaka i kod zadržavanja unutrašnjih energetskih dobitaka. Ukupni koeficijent prolaza toplote nije manifestovao značajan uticaju na zahteve grejanja i hlađenja. U-vrednosti u scenarijima W7 i W8 iznosili su 1.05 W/(m^{2}K) i 0.7 W/(m^{2}K), međutim rezultati ukupnih godišnjih energetskih zahteva bili su identični; ≈45 kWh/ m^2/a za scenario W7 i ≈45 kWh/ m^2/a za scenario W8. Oba KSTD parametra iznosila su približno 0.3 u oba scenarija.

Iz navedenog može se zaključiti da su energetski zahtevi u slučaju administrativnih zgrada sa konstantno visokim internim dobicima veoma značajni, te je neophodno ispitati uticaj KSTD parametra u selekciji adekvatnog i efikasnog zastakljenja.

Određivanje energetske performanse prema Evropskom Standardu EN 15251:2007

Prema Evropskom Standardu EN 15251 (Aneks B - Osnovi kriterijumi za kvalitet unutrašnjeg vazduha i ventilacionih stopa, B.1. Predložene ventilacione stope u ne-stambenim zgradama) proračunati su ukupni energetski zahtevi. Godišnji energetski zahtevi za ventilaciju u zavisnosti od potreba vazduha za korisnike prikazan je u tabeli 13. Energetski zahtev iznosi 25517 kWh/a u slučaju funkcionisanja mehaničke ventilacije 8 sati dnevno radnim danima. Značajan energetski zahtev preko 4 MWh zabeležen je za tri najhladnija meseca u godine; novembar, decembar i januar zbog najvećih energetskih zahteva tokom procesa pripreme vazduha pre puštanja u sistem.

Tabela 13. Energetski zahtevi za ventilaciju u zavisnosti od potreba vazduha za korisnike

Mesec	Br. korisnika	Parametri							Rezultati		
		A [m²]	V [m³/h]	ρ [kg/m³]	c [kJ/(kg°C)]	t_k [°C]	t_b [°C]	Δt [°C]	Q_f [kJ/h]	Q_f [kJ/s,kW]	Q [kWh] 8h dnevno
Jan	160	1200	4032	1.27	1.005	0.4	21	-20.6	106013	29.4	4712
Feb	160	1200	4032	1.26	1.005	2.3	21	-18.7	95477	26.5	4243
Mar	160	1200	4032	1.24	1.005	7.3	21	-13.7	68838	19.1	3059
Apr	160	1200	4032	1.21	1.005	12.7	21	-8.3	40696	11.3	1809
Maj	160	1200	4032	1.19	1.005	18.0	22	-4.0	19288	5.4	857
Jun	160	1200	4032	1.18	1.005	20.8	23	-2.2	10519	2.9	468
Jul	160	1200	4032	1.17	1.005	22.4	23	-0.6	2845	0.8	126
Avg	160	1200	4032	1.17	1.005	22.2	23	-0.8	3793	1.1	42
Sept	160	1200	4032	1.20	1.005	16.9	21	-4.1	19937	5.5	886
Okt	160	1200	4032	1.21	1.005	12.6	21	-8.4	41186	11.4	1830
Nov	160	1200	4032	1.24	1.005	7.1	21	-13.9	69843	19.4	3104
Dec	160	1200	4032	1.26	1.005	1.7	21	-19.3	98540	27.4	4380
										Ukupno [kWh/a]	**25517**

Sračunata površinsko zavisna količina ventilacije iznosi 19138 kWh/a. Značajan energetski zahtev zabeležen je iznad 3 MWh za tri najhladnija meseca u godini: novembar, decembar i januar. Rezultati su prikazani u tabeli 14.

Godišnji energetski zahtevi za ventilaciju sračunatih prema evropskom standardu EN 15251 iznose 44655 kWh/a gde izračunata energija po m^2 korisne površine iznosi 37 kWh/m^2/a. Konačni energetski zahtev za grejanje i hlađenje usvojenog scenarija W10 rezultirao je sa 176619 kWh/a, gde ukupna energija po m^2 korisne površine iznosi 51.5 kWh/m^2/a.

Tabela 14. Energetski zahtevi za površinsko zavisnu količinu ventilacije

Mesec	Br. korisnika	Parametri							Rezultati		
		A [m²]	V [m³/h]	ρ [kg/m³]	c [kJ/(kg˚C)]	t_k [˚C]	t_b [˚C]	Δt [˚C]	Q_f [kJ/h]	Q_f [kJ/s,kW]	Q [kWh] 8h dnevno
Jan	160	1200	3024	1.27	1.005	0.4	21	-20.6	79509	22.1	3534
Feb	160	1200	3024	1.26	1.005	2.3	21	-18.7	71608	19.9	3183
Mar	160	1200	3024	1.24	1.005	7.3	21	-13.7	51629	14.3	2295
Apr	160	1200	3024	1.21	1.005	12.7	21	-8.3	30522	8.5	1357
Maj	160	1200	3024	1.19	1.005	18.0	22	-4.0	14466	4.0	643
Jun	160	1200	3024	1.18	1.005	20.8	23	-2.2	7890	2.2	351
Jul	160	1200	3024	1.17	1.005	22.4	23	-0.6	2133	0.6	95
Avg	160	1200	3024	1.17	1.005	22.2	23	-0.8	2845	0.8	32
Sept	160	1200	3024	1.20	1.005	16.9	21	-4.1	14952	4.2	665
Okt	160	1200	3024	1.21	1.005	12.6	21	-8.4	30890	8.6	1373
Nov	160	1200	3024	1.24	1.005	7.1	21	-13.9	52382	14.6	2328
Dec	160	1200	3024	1.26	1.005	1.7	21	-19.3	73905	20.5	3285
										Ukupno [kWh/a]	**19138**

Komparativna analiza energetskih troškova i simuliranih rezultata

Komparacija godišnjih energetskih zahteva između troškova referentne zgrade i usvojenog scenarija prikazani su u tabeli 15. Godišnji energetski troškovi iz protekle tri godine podeljeni su na troškove daljinskog grejanja i zajedničku električnu energiju koja obuhvata veštačko osvetljenje, opremu i klimatizaciju zgrade. S obzirom da se ukupni troškovi električne energije isporučuju u zbiru nije postojala mogućnost utvrđivanja pojedinačne potrošnje.

Tabela 15. Komparacija energetskih performansi

<table>
<tr><th colspan="3">Referentna zgrada - kula FTN (troškovi iz 2011, 2012, 2013)</th><th colspan="3">Usvojen scenario</th></tr>
<tr><th>Mesec</th><th>Energija za grejanje [kWh]</th><th>Električna energija (veštačko osvetljenje, oprema i klimatizacija) [kWh]</th><th>Energija za grejanje [kWh]</th><th>Električna energija za klimatizaciju [kWh]</th><th>Električna energija za veštačko osvetljenje i opremu [kWh]</th></tr>
<tr><td rowspan="2">Ukupna godišnja energija [kWh/a]</td><td rowspan="2">442192 (2011)
338788 (2012)
378784 (2013)</td><td rowspan="2">217719 (2011)
219823 (2012)
203810 (2013)</td><td>27773</td><td>104191</td><td rowspan="2">Usvojeno veštačko osvetljenje - senzorski sistem
(32%) 21153
Električna oprema
(100%) 84626</td></tr>
<tr><td colspan="2">Prema EN 15251, Aneks B;
Energija za ventilaciju:
+ 37325 (grejanje vazduha)
+ 7330 (hlađenje vazduha)</td></tr>
<tr><td>Ukupna godišnja energija po m^2 [kWh/m^2/a]</td><td>129 (2011)
99 (2012)
110 (2013)</td><td>64 (2011)
64 (2012)
59 (2013)</td><td>19</td><td>32</td><td>31</td></tr>
</table>

Ukupna energetska potrošnja za grejanje u 2012. god. u slučaju referentne zgrade po m^2 podne površine iznosila je 99 kWh/a, za 2011. god. iznosila je 129 kWh/a i konačno u 2013. god. iznosila je 110 kWh/a. U poređenju sa usvojenim scenarijom energetski zahtevi za grejanje po m^2 podne površine sniženi su za **80%** (19 kWh/a) u odnosu na 2012. god., zatim za **83%** u odnosu na 2013. god. i konačno za **85%** u odnosu na 2011. god. Merenja parametara komfora u zgradi tokom zimskog i letnjeg perioda 2014. godine prikazali su intervale oscilacije temperature vazduha i relativne vlažnosti izvan predviđenih minimalnih zahteva mikroklimatskih uslova u radnom prostoru.

Rezultati usvojenog scenarija za ukupnu električnu energiju u koju spadaju veštačko osvetljenje, oprema i klimatizacija nisu prikazali značajna odstupanja od troškova referentne zgrade. Ali u suprotnom istraživanje je prikazalo rezultate za slučaj intenzivnih unutrašnjih energetskih opterećenja zgrade sa zadovoljenim mikroklimatskih uslova na godišnjem nivou.

Poglavlje 6 Optimizacija energetske performanse u funkciji parametara komfora

Mikroklimatski kvalitet i komfor u zgradama

Održavanje mikroklimatskih uslova ima veoma značajnu ulogu u vrednovanju energetske performanse zgrada. Direktiva o energetskim performansama zgrada (eng. Energy Performance Building Directive - EPBD) koja se odnosi na energetsku sertifikaciju, jasno naglašava značajnost predviđenih mikroklimatskih uslova usaglašenih sa energetskim performansama (Direktiva 2010/31/EU EPBD - recast) (EN 15217 2008) (EN 15603 2008).

Termički komfor korisnika je stanje svesti koje izražava fizičko zadovoljstvo u okruženju. Međutim uticaj psiholoških i fizioloških faktora korisnika usložnjava problem zadovoljenja termičkog komfora svih korisnika. Prema tome minimalan procenat termički nezadovoljnih korisnika uvek iznosi 5% prema Fangerovom modelu komfora. Mikroklimatski uslovi nisu podjednaki za sve korisnike prema ASHRAE Standardu 55 – Mikroklimatski uslovi okruženja ljudske zauzetosti (ASHRAE Standard 55 2013). Termički komfor predstavlja subjektivan način određivanja mikroklimatskih uslova, međutim komforno okruženje se može objediniti prema navedenim uslovima (EN ISO 7730 2005):

- Termički neutralan osećaj korisnika;
- Neizloženost korisnika lokalnom hlađenju ili grejanju na bilo kom delu tela.

Na stanje termičkog komfora utiču šest parametara: metabolička stopa, izolacija odeće, temperatura vazduha, temperatura zračenja površina, brzina kretanja vazduha i relativna vlažnost vazduha. Termičko nezadovoljstvo korisnika u okruženju utiče na zdravlje i sposobnost efikasnog obavljanja radnih aktivnosti. Metoda određivanja termičkog zadovoljstva korisnika biće zasnovana na pokazateljima PMV i PPD indeksa prema Fangerovim modelima termičkog komfora. Osnovni parametri, uslovi zadovoljenja termičkog komfora i način upravljanja mikroklimom detaljno su obrazloženi u **šestom poglavlju** disertacije na engleskom jeziku.

Teorija termičkog komfora i Fangerov model

U cilju određivanja kvaliteta termičkog komfora u radnom prostoru značajno je poznavanje intervala oscilacija parametara komfora radi postizanja prihvatljivih rezultata. ASHRAE Standard 55 i EN ISO 7730 primenjuju Fangerov model za određivanje PPG i PPN indeksa, koji je takođe primenjen u istraživanju za predviđanje kvaliteta termičkog komfora.

PPG (Predviđeni prosečan glas, eng. Predicted mean vote) izražava ljudsku percepciju termičke udobnosti. Indeks je definisan statističkim istraživanjem velike grupe korisnika. Korisnik procenjuje svoju percepciju termičke udobnosti za određenu unutrašnju klimu. Indeks obuhvata kombinaciju i međusobnu zavisnost sledećih faktora: metaboličku stopu, izolaciju odeće, temperaturu vazduha, prosečnu temepraturu zračenja površina, relativnu vlažnost vazduha i brzinu kretanja vazduha.

PPN (Predviđeni procenat nezadovoljnih, eng. Predicted percentage of dissatisfied) opisuje procenat korisnika koji su nezadovoljni datim termičkih uslovima. 5% je najniži procenat nezadovoljnih korisnika koji je moguće ostvariti, jer nije moguće obezbediti optimalno termičko okruženje za svaku osobu.

PPG (eng. PMV) indeks je opisan u navedenim izrazima 1, 2, i 3 (EN ISO 7730):

$$PMV = \left[0.303e^{(-0.036)} + 0.028\right] \cdot [(M-W) - 3.05 \cdot 10^{-3} \cdot (5733 - 6.99 \cdot (M-W) - p_a) - 0.42 \cdot [(M-W) - 58.15] - 1.7 \cdot 10^{-5} \cdot M \cdot (5867 - p_a) - 0.0014 \cdot M \cdot (34 - t_a) - 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl}+273)^4 - (t_r+273)^4] - f_{cl}h_c \cdot (t_{cl} - t_a)] \tag{1}$$

gde su:

$$t_{cl} = 35.7 - 0.028 \cdot (M-W) - I_{cl}\{3.96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl}+273)^4 - (t_r+273)^4] + f_{cl}h_c \cdot (t_{cl} - t_a)\} \tag{2}$$

$$t_{cl} = 2.38 \cdot (t_{cl} - t_a)^{0.25} \; for \; 2.38 \cdot (t_{cl} - t_a)^{0.25} > 12.1 \cdot \sqrt{v_{ar}}$$
$$t_{cl} = 12.1 \cdot \sqrt{v_{ar}} \; for \; 2.38 \cdot (t_{cl} - t_a)^{0.25} > 12.1 \cdot \sqrt{v_{ar}}$$
(3)
$$f_{cl} = 1.00 + 1.290 \cdot I_{cl} \; for \;\; I_{cl} < 0.078 m^2 °C/W$$
$$f_{cl} = 1.05 + 0.645 \cdot I_{cl} \; for \;\; I_{cl} < 0.078 m^2 °C/W$$

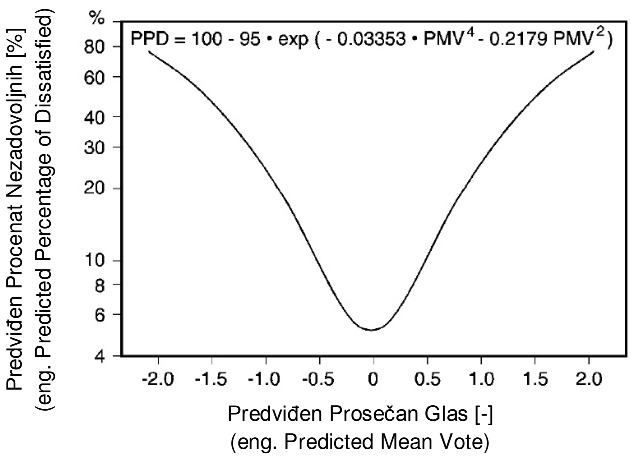
Gde su:

M	-	Metabolička stopa prema površini ljudskog tela	[W/m^2]
W	-	Efektivna mehanička snaga, jednaka nuli za većinu aktivnosti	[W/m^2]
I_{cl}	-	Termička otpornost odeće	[(m^2·°C)/W]
f_{cl}	-	Odnos površine odevenog i nagog ljudskog tela	[-]
t_a	-	Temperatura vazduha	[°C]
t_r	-	Prosečna temperature radijacije	[°C]
v_{ar}	-	Relativna brzina kretanja vazduha	[m/s]
p_a	-	Parcijalni pritisak vodene pare u vazduhu	[Pa]
h_c	-	Koeficijent konvektivnog prenosa toplote	[W/(m^2·°C)]
t_{cl}	-	Temperatura površine odeće	[°C]

Preporučena je primena PPG (eng. PMV) indeksa u slučaju kad su osnovni parametri unutar navedenih intervala: 46 W/m^2 (0.8 met) ≤ M ≤ 232 W/m^2 (4.0 met); 0 (0 clo) ≤ I_{cl} ≤ 0.310 (m^2·°C)/W (2 clo); 10°C ≤ t_a ≤ 30°C; 10°C ≤ t_r ≤ 40°C; 0 ≤ v_{ar} ≤ 10 m/s; 0 ≤ p_a ≤ 2700 Pa; 30% ≤ RV (Relativna vlažnost vazduha) ≤ 70%. Nakon određivanja PPG (eng. PMV) vrednosti PPN (eng. PPD) se određuje prema izrazu 4 (EN ISO 7730):

$$PPD = 100 - 95 \cdot e^{(-0.03353 \cdot PMV^4 - 0.2179 \cdot PMV^2)} \tag{4}$$

Simetrična PPG kriva prikazana je na slici 13 (ASHRAE Standard 55 2013) sa minimalnom vrednošću od 5% zbog subjektivnosti termičkog komfora.



Slika 13. PPN funkcija

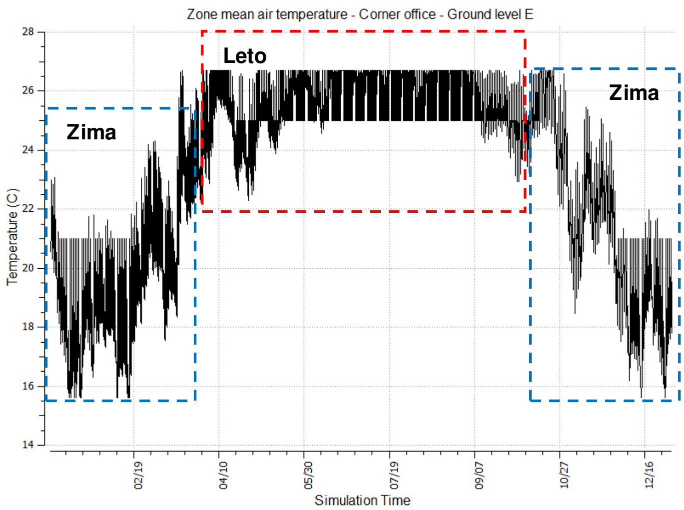
Simulacija i rezultati parametara komfora

U cilju određivanja PPG i PPN indeksa usredsredilo se na sledeće parameter; temperatura vazduha, temperatura zračenja površina, brzina kretanja vazduha, relativna vlažnost vazduha, metabolička stopa i izolacija odeće.

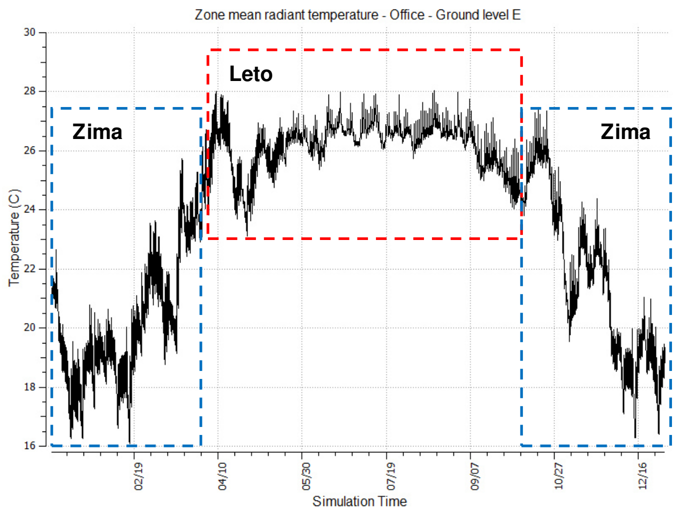
Simulirani su sledeći parametri u radnom prostoru; temperatura vazduha, temperatura zračenja površina, brzina kretanja vazduha, relativna vlažnost vazduha i operativna temperatura. Vrednosti parametara koji zavise od korisnika i mehaničkog sistema uzeti su konstantnim. Vrednost metaboličke stope za sedeću radnu aktivnost usvojena je 1.2 met dok je termička izolacija odeće korisnika bila prilagođena godišnjem dobu od 0.38 clo do 1.0 clo. Brzina kretanja vazduha iznosila je 0.10 m/s tokom radnog vremena.

Simulirani parametri komfora prikazani su za Istočnu orijentaciju prizemlja na slikama od 14 do 19. Ostali rezultati parametara komfora iz dinamičke simulacije detaljno su analizirani u **šestom poglavlju** disertacije na engleskom jeziku. Oscilacija temperature vazduha prikazana je na slici 14, sa koje se može odrediti se može efikasnost performanse omotača prema intervalima temperaturnih oscilacija vazduha. Analiza je podeljena na dve celine; zimsku i letnju sezonu koje su usaglašene sa vrednostima termostata. Rezultati prikazuju da tokom zimske sezone u periodu kada je grejanje isključeno u intervalu od 16 sati, temperatura vazduha u prostorijama ima maksimalan pad od 5°C. Oscilacija temperature vazduha u zimskom periodu je uvećana na slici 15 radi detaljnije analize parametra. Zagrade ukazuju na pad temperature u periodima kada je grejanje isključeno iz razloga nezauzetosti zgrade (procenjena zauzetost zgrade je 8 sati radnim danima). Razmatrajući letnji period na slici 16 situacija je drugačija. Zabeležen je porast temperatura vazduha zbog unutrašnjih toplotnih dobitaka od strane enektričnih uređaja i korisnika, specifičnih za administrativne zgrade.

Unutrašnje energetsko opterećenje a administrativnim zgradama je konstantno tokom godine i dovodi do značajnih odstupanja između zahteva za grejanje i hlađenje. Visoko termički izolovana administrativna zgrada će uvek zahtevati značajnu količinu energije za hlađenje dok se u suprotnom drastično smanjuju energetske potrebe za grejanje. Prema tome treba voditi računa o odabiru adekvatnog zastakljenja.

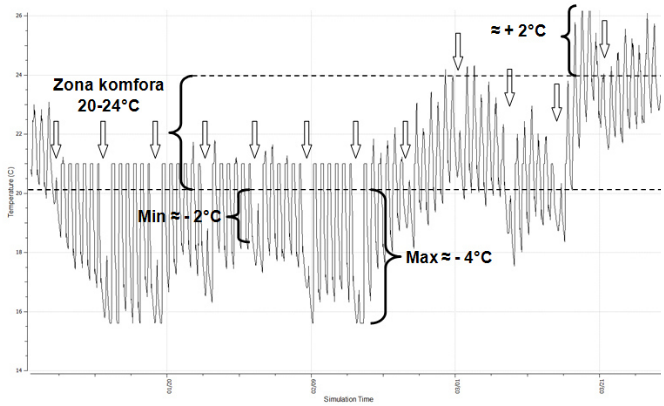


Slika 14. Godišnja oscilacija temerature vazduha u prizemlju

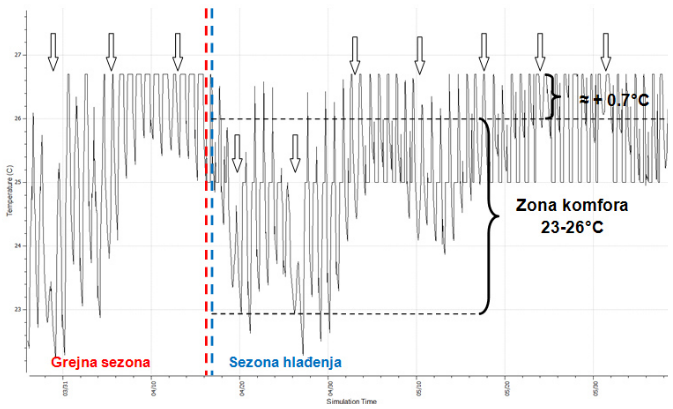


Slika 17. Godišnja oscilacija temerature zračenja u prizemlju

Prosečna temperatura zračenja površina u geometrijskom centru prostorije prikazano je na slici 17. Uočene su blage oscilacije tokom zimskog i letnjeg perioda koji pozitivno utiče na komfor korisnika. Maksimalna oscilacija temperature zračenja u zimskom periodu iznosila je 3°C koja je prihvatljiva za unutrašnje mikroklimatske uslove.



Slika 15. Oscilacija temerature vazduha u zimskom periodu

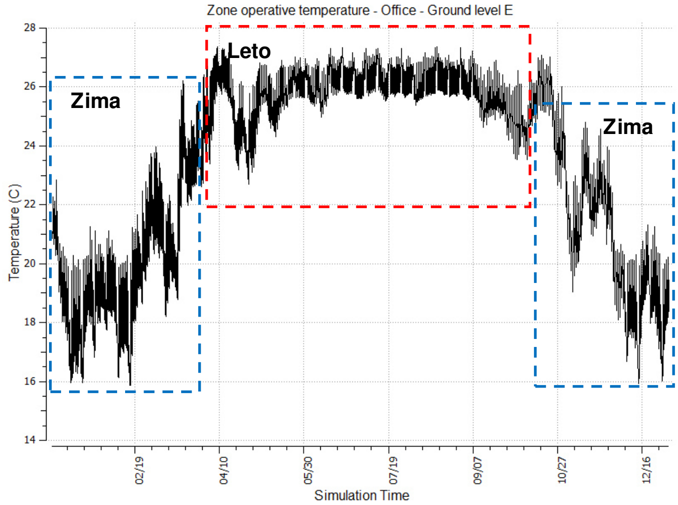


Slika 16. Oscilacija temerature vazduha u letnjem periodu

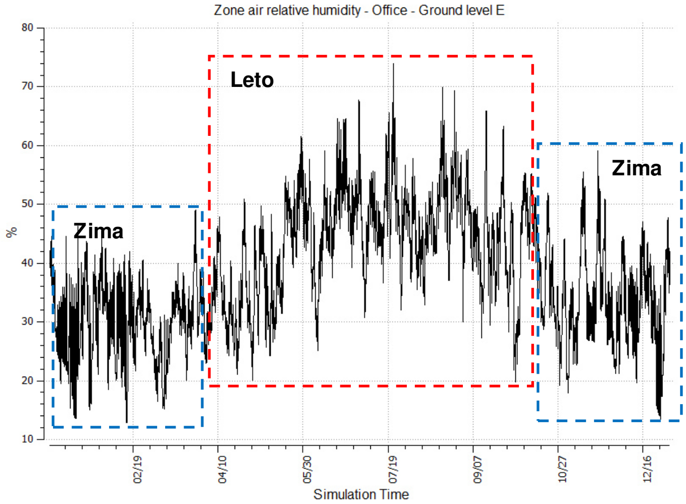
Operativna temperatura se određuje kao aritmetička sredina temperature zračenja i temperature vazduha u prostoriji, mereno prema odgovarajućem koeficijentu prenosa toplote (ASHRAE Standard 55 2013). Operativna temperatura je značajna u oblasti korisničkog komfora. Rezultati iz simulacije prikazani su na slici 18 gde oscilacija operativne temperature iznosi maksimalno 5°C zimi i 2.5°C u letnjoj sezoni.

Priprema ulaznog vazduha u zgradu je značajna jer tokom niskih temperatura zimi relativna vlažnost drastično opada pri zagrevanju ulaznog hladnog vazduha. Dodatno vlaženje vazduha u zatvorenom prostoru je relativno redak slučaj jer vlaga nema veliki uticaj na kvalitet vazduha u prostorijama sa sedentarnim radnim aktivnostima, međutim dugoročna visoka vlažnost u zatvorenom prostoru može da izazove porast štetnih mikroba, te je neophodno sušenje vazduha pri recirkulaciji u sistemu. Veoma niska vlažnost vazduha (<15-20%) izaziva iritaciju očiju. Uslovi za održavanje relativne vlažnosti vazduha pri vlaženju i sušenju takođe utiču na energetsku potrošnju (EN 15251 2007).

Preporučeni kriterijumi za dimenzionisanje ovlaživanja i sušenja vazduha prema EN 15251 prikazani su u tabeli 16 kao preporučene vrednosti u skladu sa uslovima projektovanja. Pored preporuka neophodno je da se ograniči apsolutna vlažnost vazduha na 12 g/kg (EN15251 2007).



Slika 18. Godišnja oscilacija operativne temerature u prizemlju



Slika 19. God. oscilacija relativne vlažnosti vazduha u prizemlju

Table 16. Preporučeni projektni kriterijumi za vlažnost vazduha u unutrašnjim zauzetim prostorijama ukoliko su instalirani sistemi za ovlaživanje i sušenje vazduha

Tip prostorije	Kategorija	Projektovana relativna vlažnost za sušenje vazduha [%]	Projektovana relativna vlažnost za ovlaživanje vazduha [%]
Prostorije u kojima se kriterijumi vlažnosti postavljaju prema korisničkoj zauzetosti	I	50	30
	II	60	25
	III	70	20
	IV	> 70	< 20

Analizirajući oscilaciju relativne vlažnosti vazduha u prizemlju sa slike 19. Može se zaključiti da se kancelarije u prizemlju nalaze u **II** kategoriji prema tabeli 16. jer su oscilacije u periodima zauzetosti kancelarija (od 8h do 16h) bile u intervalima od 25% do 60%. Dodatno sušenje vazduha nije bilo potrebno.

Detaljno obrazloženje oscilacija relativne vlažnosti za prizemlje, peti i deveti sprat prikazani su u **šestom poglavlju** disertacije na engleskom jeziku.

Rezultati modela komfora sa diskusijom

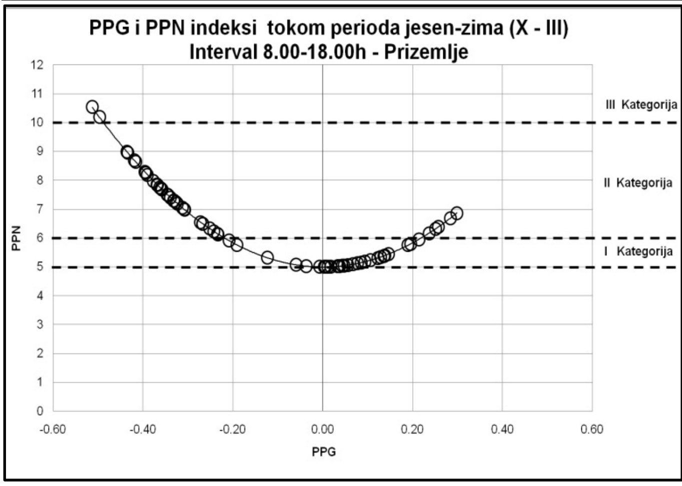
Rezultati PPG i PPN indeksa

PPG i PPN vrednosti su proračunate prema prethodno navedenom Fangerovom modelu komfora za usvojen scenario sa najboljom energetskom performansom. EnergyPlus simulacija za parametre komfora je sprovedena na godišnjem periodu sa intervalima od sat vremena. Simulirani su parametri temperature vazduha, prosečne temperature zračenja površina i relativne vlažnosti vazduha za prostorije prizemlja, petog i devetog sprata. Ukupan broj izlaznih podataka iz simulacije po parametru komfora za jednu prostoriju iznosio je 8760, ukupan broj bio je 78840. Mnogobrojni izlazni podaci prikazani su na PPN funkciji za intervale zauzetosti zgrade radnim danima u nedelji. Tabelarni podaci prikazani su u **Prilogu F** disertacije uključujući kategorije komfora prema Evropskom Standardu u jednočasovnim intervalima. Pod pretpostavkom različitih kriterijuma za PPG i PPN indeksa (EN ISO 7730 2005) ustanovljene su različite kategorije komfora za unutrašnje prostorije. Preporučeni PPN opsezi su prikazani u tabeli 17.

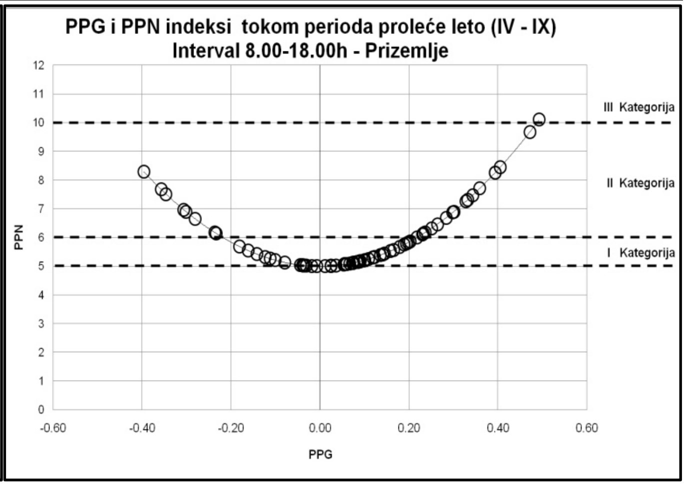
Tabela 17. Preporučenih PPG i PPN opsezi prema kategorijama komfora za projektovanje mehanički sistema za grejanje i hlađenje zgrada

Kategorija	PPN [%]	PPG
I	< 6	-0.2 < PPG < +0.2
II	< 10	-0.5 < PPG < +0.5
III	< 15	-0.7 < PPG < +0.7
IV	> 15	PPG < -0.7 ili +0.7 < PPG

Slike 20 i 21 prikazuju PPN funkciju tokom dva perioda (jesen-zima i proleće-leto) u intervalima zauzetosti zgrade od 8h do 18h. Sa PPG krive se može zaključiti da je u radnom prostoru zgrade ostvaren visok kvalitet komfora, jer je procenat nezadovoljnih korisnika od ukupnih 10950 PPN vrednosti u više od 95% slučajeva pokrivaju prve dve kategorije. Procenat nezadovoljnih korisnika spada većinom u prvoj a zatim drugoj kategoriju dok manje od 5% korisnika je približna donjoj granici treće kategorije.



Slika 20. PPN kategorije od X do III meseca



Slika 21. PPN kategorije od IV do IX meseca

Poglavlje 7 **Rešenje sistema za grejanje i hlađenje**

U cilju iznalaženje adekvatnog mehaničkog sistema za grejanje i hlađenje novih administrativnih zgrada na modelu fiktivnog objekta sa korisnom površinom od 300 m^2 i efikasnim termičkim omotačem (koji je detaljno opisan u **sedmom poglavlju** disertacije na engleskom jeziku) istražena je energetska performansa četiri različita sistema za grejanje i hlađenje zgrade primenom dinamičke simulacije u programu EnergyPlus. Modelovani, simulirani i vrednovani su sledeći mehanički sistemi; toplotna pumpa, sistem na gas, sistem na električnu energiju i fan-coil sistem sa čilerom i bojlerom. Šeme sistema za grejanje i hlađenje prikazane su u **Prilogu G**.

Energetske performanse navedena četiri sistema su konvertovane u primarnu energiju prema tehnologiji proizvodnje energenta iz kojeg se sistem snabdeva. Procenjen faktor konverzije za električnu energiju koja se dobija iz lignita u elektranama u Srbiji iznosi između 3.0 i 4.0, usvojila se vrednost f_{prim} = 3.5, dok faktor konverzije za gas je f_{prim} = 1.1 (Banjac 2014). Faktor konverzije se odnosi na tehnologiju proizvodnje i efikasnost transporta energije. Tabela 18 prikazuje ukupne godišnje primarne energetske zahteve po mehaničkom sistemu primenjenom na identičnim termičkim modelima.

Tabela 18. Godišnji zahtevi primarne energije

SISTEM 1 Toplotna pumpa	SISTEM 2 Gas i elek. energija	SISTEM 3 Električni sistem	SISTEM 4 Fan-coil
Primarna energija bez rekuperatora			
127 [kWh/m^2/a]	124 [kWh/m^2/a]	209 [kWh/m^2/a]	218 [kWh/m^2/a]
∑ 38255 [kWh/a]	∑ 37451 [kWh/a]	∑ 62965 [kWh/a]	∑ 65588 [kWh/a]
Primarna energija sa rekuperatorom			
87 [kWh/m^2/a]	84 [kWh/m^2/a]	135 [kWh/m^2/a]	151 [kWh/m^2/a]
∑ 26351 [kWh/a]	∑ 25332 [kWh/a]	∑ 40670 [kWh/a]	∑ 45585 [kWh/a]
Redukcija primarne energije sa rekuperatorom			
31.5%	32.3%	35.4%	30.7%

Proračuni takođe obuhvataju i energetske zahteve sistema za grejanje i hlađenje, prikazano u tabeli 19. Ova komparativna analiza ukazuje na značaj primene rekuperatora.

Tabela 19. Godišnji energetski zahtevi sistema za grejanje i hlađenje prema jedinici m^2 korisne površine

Sistem za grejanje i hlađenje	Energetski zahtevi bez rekuperatora [kWh/m^2/a]	Energetski zahtevi sa rekuperatorom [kWh/m^2/a]
Toplotna pumpa	21.15	15.56
Gas i elek. energija	6.65 Struja, 62.72 Gas, ∑ 69.37	6.21 Struja, 26.59 Gas, ∑ 32.8
Električni sistem	51.24	29.50
Fan-coil	23.56 Struja, 48.36 Gas, ∑ 71.92	29.16 Struja, 31.91 Gas, ∑ 61.07

Istraživanje obrazlaže da bi najefikasnije rešenje za nove administrativne zgrade bila primena sistema toplotne pumpe sa rekuperatorom iz razloga najnižih godišnjih energetskih zahteva za operaciju, 15.56 kWh/m^2/a. Moguće je primeniti istu metodologiju istraživanja i za druge klimatske uslove sa različitim unutrašnjim opterećenjima.

U slučaju postojećih administrativnih zgrada koje se snabdevaju iz centralnog sistema daljinskog grejanja, neophodno je ispitati padove pritisaka i protok tople vode u radijatorima u cilju izbegavanja hidrauličke neuravnoteženosti sistema za grejanje. Ako se objekat sastoji od više spratova kao što je primer referentne zgrade od devet spratova, neophodno je ispitati protoke na svakoj etaži i uskladiti ih da svaka etaža dobije istu količinu toplotne energije. S obzirom da su unutrašnja energetska opterećenja u administrativnim zgradama značajna od strane električne opreme i korisnika, najprihvatljivije rešenje bi bilo projektovanje centralnog sistema za hlađenje sa mogućnošću kontrole temperature vazduha u zavisnosti od zauzetosti prostorija. U cilju formulisanja efikasnog sistema za grejanje, hlađenje i ventilaciju, neophodno je ostvariti mehaničko vetrenje bez učešća korisnika u manualnom otvaranju prozora na fasadi. Fasadni prozori bi se otvarali mehanički ili manualno samo u posebnim potrebama.

Poglavlje 8 Sažetak i zaključak

Sažetak

Dinamička energetska simulacija je značajna sa aspekta procene i analize energetskih zahteva u zgradama, a takođe i u donošenju odluka u početnim fazama projektovanja kod rehabilitacije postojećih ili razvoja novih projekata. Prema tome, donošenje odluka je efikasnija u daljim fazama projektovanja i optimizacije. U disertaciji formulisan je model za unapređenje energetskih karakteristika tipičnih ne-efikasnih administrativnih zgrada na teritoriji Novog Sada u umerenim klimatskim uslovima. Kriterijumi optimizacije energetskih perfromansi bili su u funkciji parametara komfora, poštujući propise termičkih karakteristika omotača poslovnih zgrada prema evropskim standardima i srpskoj regulativi.

Optimalno zastakljenje omotača u cilju unapređenja energetskih performansi i korisničkog komfora referentne administrativne zgrade je formulisano prema; redukciji površine prozora na fasadnim zidovima, zatim određivanju geometrije prozora u funkciji vizuelnog komfora (kriterijumi su: disperzija svetlosti, minimalni faktor osvetljenja, učestalost električnog osvetljenja - senzorski sistem, analiza izloženosti solarnoj radijaciji) i prema godišnjim energetskim zahtevima za grejanje i hlađenje. Kriterijumi za selekciju efikasnih prozora u cilju redukcije energetskih zahteva zgrade definisani su u skladu sa unutrašnjim energetskih opterećenjima i klimatskim uslovima. Analizirao se uticaj parametara zastakljivanja (U-vrednost, KSTD parametar i koef. transmisije) na godišnjim energetskim zahtevima za grejanje i hlađenje. Zaključeno je da KSTD parametar ima najznačajniji uticaj na energetsku performansu zbog značajnih unutrašnjih energetskih dobitaka u administrativnim zgradama.

Godišnji energetski zahtevi za grejanje i hlađenje istraženi su u funkciji zahteva korisničkog komfora u cilju redukcije PPN-indeksa (procenta nezadovoljnih korisnika) prema Fangerovom modelu termičkog komfora. Predlog sistema za grejanje i hlađenje u novim i postojećim administrativnim zgradama u umerenim klimatskim uslovima je formulisana prema uporednoj analizi četiri različita sistema. Zaključeno je da sistem toplotne pumpe sa rekuperatorom ima najmanje godišnje energetske zahteve među analiziranim sistemima. U slučaju rehabilitacije sistema za grejanje u postojećim zgradama priključenim na daljinsko grejanje treba prvenstveno voditi računa o hidrauličkoj uravnoteženosti sistema, neophodno je učestalo regulisanje sistema grejanja. Dok je najefikasniji centralni sistem za hlađenje zbog mogućnosti kontrole temperature vazduha u zavisnosti od zauzetosti prostorija.

Zaključak

Energetska efikasnost, zdrava životna sredina i korisnički komfor danas spadaju među najznačajnije zahteve kod projektovanja visoko efikasnih pametnih zgrada. Iznalaženje optimalnog rešenja za unapređenje energetskih performansi administrativnih zgrada u funkciji korisničkog komfora je moguće. Formulisanje modela za unapređenje energetskih performansi postojećih i novih objekata obuhvata detaljnu analizu brojnih uticajnih parametara kao što su; klimatski i urbanistički podaci, omotač objekta, zauzetost objekta, unutrašnje energetsko opterećenje, i operacija i karakteristike sistema za grejanje, hlađenje i ventilaciju.

Disertacija predstavlja složenost numeričkog energetskog modela koji obuhvata međusobno usaglašavanje i povezivanje termičkih zona modela sa dodeljenim energetskim opterećenjima, karakteristikama konstrukcije i materijala, intervalima zauzetosti i operacijama mehaničkih sistema u jedinstvenu celinu.

Osnovna tema razmatranja je zdravlje i komfor korisnika u cilju formulisanja zdravih zgrada sa racionalnim korišćenjem energije. Kako bi se postigli i održali adekvatni mikroklimatski uslovi koji utiču na zdravlje, komfor i produktivnost zaposlenih neophodno je uzeti u obzir šest parametara; metabolička stopa, izolacija odeće, temperatura vazduha, temperatura zračenja, brzina kretanja vazduha i relativna vlažnost vazduha. Problem se usložnjava jer na navedene faktore utiču klimatski uslovi, konstrukcija, omotač zgrade, sistem za grejanje, hlađenje i ventilaciju, zauzetost objekta i unutrašnje energetsko opterećenje. Model za unapređenje energetskih performansi postojećih administrativnih zgrada je formulisan kao optimalno rešenje za klimatske uslove na teritoriji Novog Sada sa mogućnošću adaptibilnosti modela i za druge klimatske uslove.

Mogućnost primene rezultata

Mogućnost primene rezultata istraživanja bio bi sledeći:

- Poboljšanje energetskih performansi administrativnih zgrada sa istim ili sličnim karakteristikama kao kod referentnog višespratnog objekta kule Fakulteta tehničkih nauka;
- Postizanje zdravog i komfornog radnog okruženja za zaposlene;
- Racionalno i efikasno korišćenje energije u administrativnim zgradama prema kapacitetu i predikciji zauzetosti zgrade;
- Pružanje smernica u ranim fazama projektovanja novih administrativnih zgrada;
- Pružanje smernica u rehabilitaciji postojećih administrativnih zgrada;
- Fleksibilnost modela u cilju projektovanja efikasnog omotača za administrativne zgrade;
- Predlaganje efikasnog sistema za grejanje, hlađenje i ventilaciju u određenim klimatskim uslovima;
- Formulisan model je fleksibilan sa mogućnošću primene u različitim klimatskim uslovima.

Pravci daljih istraživanja

Pravci daljih istraživanja obuhvataju analizu primene obnovljivih izvora energije na formulisanom modelu za administrativne zgrade i određivanje negativnog uticaja proizvodnje energije na životnu sredinu. Osnovna tema budućih istraživanja obuhvatiće određivanje energetskih zahteva sistema za grejanje, hlađenje i ventilaciju, konverziju energetskih zahteva na nivou zgrade u primarnu energiju uz procenu stope zagađenja pri proizvodnji energije. Cilj daljih istraživanja je iznalaženje modela sa nultim energetskim zahtevima za umerene klimatske uslove.

Buduća istraživanja formulisaće različita rešenja za efikasnu konstrukciju omotača novoprojektovanih administrativnih zgrada u određenim klimatskim uslovima prema kriterijumima korisničkog komfora. Analiziraće se parametri komfora u funkciji različitih konstrukcija fasada sa različitim karakteristikama zastakljivanja i osobinama primenjenih materijala sa posebnim naglaskom na pasivnim i inteligentnim tehnologijama.

Investicioni aspekt je značajna tema razmatranja u cilju unapređenja energetskih performansi administrativnih zgrada. Dalja saradnja sa arhitektama, građevinskim, mašinskim inženjerima i programerima je neophodna zbog multidisciplinarnosti i kompleksnosti oblasti energetskih simulacija. U cilju formulisanja efikasnih, funkcionalnih i isplativih rešenja međusobna saradnja i razmena iskustava je veoma značajna u razvoju energetske optimizacije u visokogradnji.

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Doctoral Dissertation

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Abstract

Investigations in the doctoral dissertation are based on determination of a highly efficient solution for energy performance improvement of multi-level administrative buildings in temperate climate conditions. Special emphasis is on achieving and maintaining acceptable indoor environmental standards and thermal comfort of occupants. The research is based on complex multi-criteria optimization utilizing the most contemporary dynamic energy simulation technology.

The developed methodology for energy performance improvement in the function of occupant comfort will have the possibility of wide application on multi-level administrative buildings in order to offer adequate and efficient methods for energy performance improvement and satisfactory indoor environmental standard achievement. The formulated model also possesses flexibility and adaptability for further improvement and application in different climate conditions.

Key words: Energy performance, dynamic energy simulation, occupant comfort, Fanger model, EnergyPlus

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Terms and Definitions

Building energy simulation	The process of using a computer to build a virtual replica of a building in order to simulate it and quantitatively predict its future energy performance and potential, all in the function of climatic conditions of the region.
Clothing insulation	Clothing insulation is the resistance to sensible heat transfer provided by a clothing ensemble (expressed in units of clo, which is a unit to quantify the insulation provided by garments and clothing ensembles, 1 clo = 0.155 $m^2 \cdot °C/W$)
Comfort zone	Comfort zone refers to the combinations of air temperature, mean radiant temperature and relative humidity that are predicted to be an acceptable thermal environment at particular values of air velocity, metabolic rate, and clothing insulation.
Daylight factor	A daylight factor is the ratio of internal light level to external light level and is defined as follows: DF = (Ei / Eo) x 100% where, Ei = illuminance due to daylight at a point on the indoors working plane, Eo = simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky.
District heating	District heating is a system for distributing heat generated in a centralized location for residential and commercial heating requirements such as space heating and water heating.
Energy-modeling	Virtual or computerized simulation of a building or complex that focuses on energy consumption.
Internal heat gain	Internal heat gain in buildings is the major component of the total building cooling load which consists of transmitted solar radiation, conductive heat gain, electric lighting, equipment and occupants.
Mean radiant temperature	The mean radiant temperature is the average effect of radiation from surrounding surfaces. At the center of the room this temperature can be taken as being equal to the mean surface temperature.
Metabolic rate	Metabolic rate is the rate of transformation of chemical energy into heat and mechanical work by metabolic activities of an individual, per unit of skin surface are (expressed in units of met) equal to 58.2 W/m^2 which is the energy produced per unit skin surface are of an average person seated at rest.
Operative temperature	Defined as a uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment.
Peak load	The term peak demand refers to the highest amount of electricity being consumed at any one point in time across the entire network system.
Solar heat gain coefficient	SHGC refers to the solar energy transmittance of a window or door as a whole, factoring in the glass. SHGC may also refer to the solar energy transmittance of the glass alone (sometimes more specifically termed center-of-glass SHGC), in which case it is analogous to g-value.
Thermo active building system	Thermo active building system (cool and heat the building structure using tube heat exchanges integrated with building elements) activated by water or air 18-22 ^0C.

Thermal comfort	Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.
Thermal zone	A thermal zone is a space or collection of spaces within a building having sufficiently similar space conditioning requirements so that those conditions could be maintained with a single thermal control device.
Thermostat	A thermostat is a component of a control system which senses the temperature of a system so that the system's temperature is maintained near a desired set point.
Thermal transmittance	Thermal transmittance (U-value) is the rate of transfer of heat (in watts) through one square meter of a structure divided by the difference in temperature across the structure. It is expressed in $W/(m^2K)$.
Visible light transmittance	Expresses how much of the visible light is entering the building through the glass. 1.0 would mean all of the light was getting through and 0 would mean none of it was getting in.
Sensible heat gain	The heat added to space by conduction, convection and/or radiation.
Latent heat gain	The energy added to space when moisture is added to space by means of vapor emitted by occupants, generated by process or through air infiltration from outside or adjacent areas.

Abbreviations

ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
AT	Air Temperature
BIM	Building Information Modeling
BRE	Building Research Establishment
CAD	Computer Aided Design
CLTD	Cooling Load Temperature Difference
DF	Daylight Factor
DXF	Drawing Exchange Format
EPIA	European Photovoltaic Industry Association
EPW	EnergyPlus Weather File
GWEC	Global Wind Energy Council
HAMT model	Heat and moisture transfer model
HB model	Heat Balance model
HR unit	Heat Recovery unit
HVAC	Heating Ventilation And Air Conditioning
IDD	Input Data Dictionary
IDF	Input Data File
IEA	International Energy Agency
IRC	Internally Reflected Component
MRT	Mean Radiant Temperature
OPT	Operative Temperature
PMV	Predicted Mean Vote
PPD	Predicted Percentage Of Dissatisfied
RH	Relative Humidity
RTS	Radiant Time Series
RVT file	Autodesk Revit Architecture project file
SHGC	Solar Heat Gain Coefficient
TABS	Thermo Active Building System
TETD	Total Equivalent Temperature Difference
TFM	Transfer Function Method
VT	Visible Transmittance
WG	Window Geometry
WWR	Window to Wall Ratio

Nomenclature

G-Gh	Mean irradiance of global radiation horizontal	[W/m^2]
G-Dh	Mean irradiance of diffuse radiation horizontal	[W/m^2]
P	Air pressure	[hPa]
RH	Relative humidity	[%]
N	Cloud cover fraction	[-]
SD	Sunshine duration	[h/day]
RR	Precipitation	[mm]
RD	Days with precipitation	[-]
FF	Wind speed	[m/s]
Snd	Snow depth	[mm]
PAR	Photosynthetically active radiation	[W/m^2]
WWR	Window to wall ratio	[%]
SHGC	Solar heat gain coefficient	[-]
VT	Visible transmittance	[-]
U	Thermal transmittance	[$W/(m^2K)$]
Q_f	Power	[kW]
Q	Energy	[kWh]
ρ	Density	[kg/m^3]
c	Specific heat	[kJ/(kg˚C)]
V	Air flow	[m^3/h]
M	Metabolic rate, of body surface area	[W/m^2]
W	External work, equal to zero for most activities	[W/m^2]
I_{cl}	Thermal resistance of clothing	[(m^2 * °C)/W]
f_{cl}	Ratio of man's surface area while clothed, to man's surface are while nude	[-]

t_a	Air temperature	[°C]
t_r	Mean radiant temperature	[°C]
t_k	Outside temperature	[°C]
t_b	Indoor temperature	[°C]
Δt	Temperature difference	[°C]
v_{ar}	Relative air velocity (relative to human body)	[m/s]
p_a	Partial water vapor pressure	[Pa]
h_c	Convective heat transfer coefficient	[W/ (m^2 * °C)]
t_{cl}	Surface temperature of clothing	[°C]
Q_{tot}	Total ventilation rate of the room	[m^3/h]
n	Design value for the number of the persons in the room	[-]
q_p	Ventilation rate for occupancy per person	[m^3/h/pers.]
A	Room floor area	[m^2]
q_B	Ventilation rate for emissions from building	[m^3/h/m^2]

“We can create a more sustainable, cleaner and safer world by making wiser energy choices.”

(Robert Alan Silverstein)

“Energy conservation is the foundation of energy independence.”

(Thomas H. Allen)

“The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased, and not impaired in value.”

(Theodore Roosevelt)

Chapter 1

Introduction

1.1. Research subject and significance

1.1.1. Research subject

The research subject is to analyze the possibilities of improving the energy performance of general multi-level administrative buildings in the function of occupant comfort parameters. For this purpose, a state-assessment method is developed in order to evaluate the energetic condition of buildings and perform required interventions for improving the energy performance of inefficient office buildings on the territory of Novi Sad. The purpose of the research is to minimize the total annual energy demand of administrative buildings in order to achieve and maintain a healthy and comfortable work environment. The methodology will be tested and demonstrated on a reference office-tower building which is an integral part of the Faculty of Technical Sciences complex within the University campus of Novi Sad.

Standard EN 15251:2007 “Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustic” was developed for the same purpose of building energy performance improvement, with the aim of specifying environmental parameters and criteria in order to reach the objectives of energy performance standards, as indicated in Energy Performance Building Directive (EN 15251 2007) (EN ISO 7730 2005). The main topics related to indoor environmental quality in these rating systems are:

- Thermal comfort;
- Indoor air quality;
- Acoustic comfort;
- Visual comfort.

The requirements of user comfort are:

- Visual comfort and lighting quality;
- Thermal comfort;
- Air quality;
- Sound quality, noise and acoustics.

Investigation of air quality and acoustics is not part of the dissertation topic. The reason is that qualitative indoor air majorly depends from outdoor air quality, outdoor air temperature, air treatment procedure, regular air filters change and filter type, and maintenance of the ventilation ducts. In addition, the study of acoustics in buildings depends on the design and volume of the rooms and the composition of materials used in the construction to prevent transmission of sound.

The research subject and research problem of the dissertation is based on:

1. **Primarily a detailed energy performance assessment will be conducted on a general inefficient administrative building constructed on the territory of Novi Sad**. The selected typical reference building on the territory of Vojvodina is a multi-level office tower which is part of the Faculty of Technical Sciences complex in Novi Sad. The office tower is characterized by its typical building envelope construction with high exterior glazing area and inadequate thermal performance of exterior walls according to recent standards. The developed methodology for energy performance determination and evaluation will have the possibility of wide application on multi-level office buildings in order to offer efficient methods for energy performance improvement, occupant comfort maintenance and envelope performance rehabilitation;
2. **Assessment of quantitative and qualitative impact of parameters affecting occupant comfort sensation**. Within the developed methodology the aim is to define and calculate total annual energy demands in the function of occupant comfort achievement and maintenance for medium and large administrative buildings. The goal is to reduce the energy demands, while achieving a thermally comfortable and healthy work environment;
3. **Determination of optimal measures for construction rehabilitation and improvement of building energy performance** in the function of occupant comfort and healthy work environment by formulating preferable solutions of high quality defined as Best Case Scenario.

1.1.2. Research significance

Global

According to the International Energy Agency (IEA), buildings exceed 40% of world energy demand and emit close to 1/3 of CO_2 worldwide (International Energy Agency 2012). In addition, buildings have the greatest potential for reducing energy consumption with cost-effective investments. The energy consumption for heating and cooling of buildings takes the largest part of the total energy requirement in the world. Increase of energy demand, public pressure due to global warming, environmental protection and increasing energy costs raise critical questions.

Hence, energy performance optimization became a prerequisite for improvement and modernization of the building and construction sector. Concerns in the energy sector on global level are expressed by the following:

- The exploitation of non-renewable energy sources (oil, coal and gas) are limited
- Lack of application and cost-effectiveness of renewable energy utilization and clean technology application for energy production;
- Progressive increment of environmental pollution which is linked to global warming;
- Influential economic crises caused by the instability of global market price of non-renewable energy sources.

The global energy potential of fossil fuels and renewable energy sources is presented as estimated in Figure I - 1.

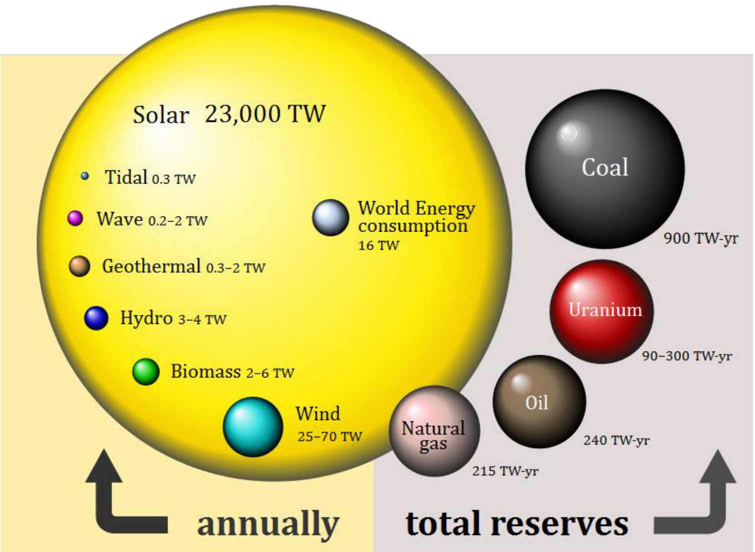


Figure I - 1 Global energy potential (Perez and Perez 2009)

"The International Energy Agency, through its programs such as solar heating and cooling, is actively working to advance the new energy technologies and strategies needed to meet future demand while reducing dependence on the liquid fossil fuels that currently drive the planet's economies" (Perez and Perez 2009). Renewable sources are cost-effective which is emphasized by the National Renewable Energy Laboratory. An example projects that the levelized cost of wind power will decline 25% from 2012 to 2030 as shown in Figure I - 2 (Lantz, Hand and Wiser 2012).

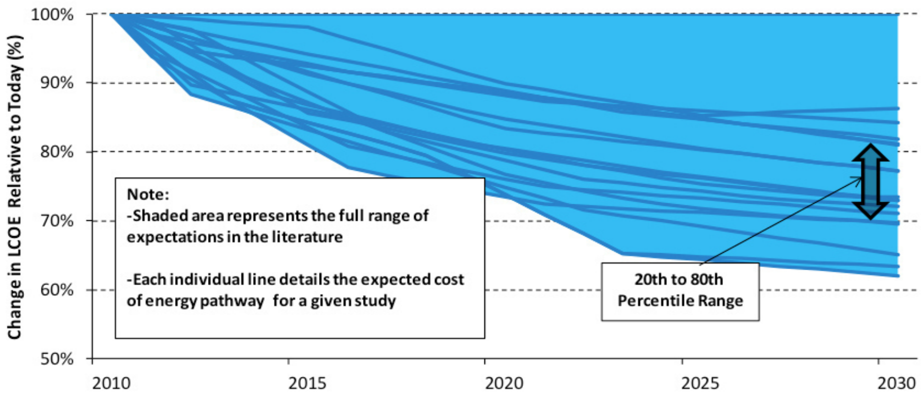


Figure I - 2 Levelized cost of wind power until 2030 (Lantz, Hand and Wiser 2012)

The Global Wind Energy Council presents an intensive application of wind power as seen in Figure I - 3, which resulted in cumulative capacity of 365.4 GW in the last year (Global Wind Energy Council 2014).

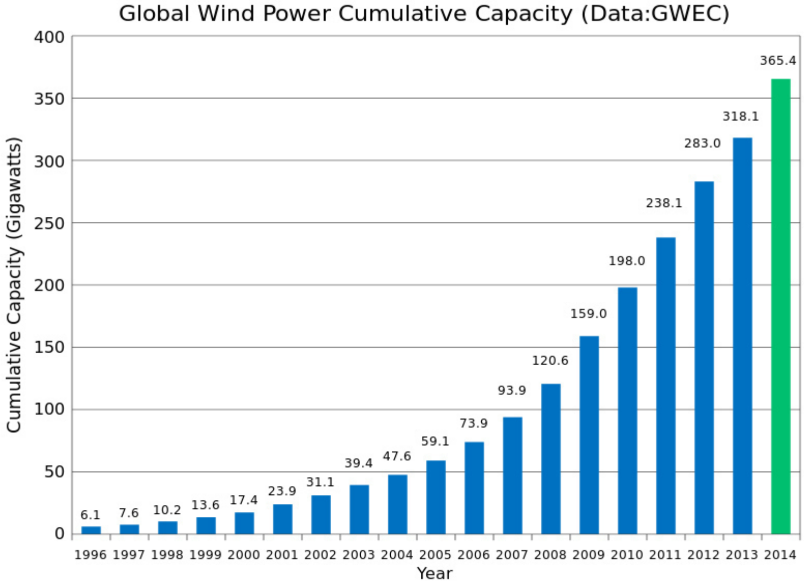


Figure I - 3 Global wind power cumulative capacity (Global Wind Energy Council 2014)

Solar photovoltaic was recognized as a promising renewable source of energy two decades ago. Today Europe takes the lead in the installed solar PV's energy production. Germany is the leading country with the most installed PV's as seen in Figure I - 4. (European Photovoltaic Industry Association 2014)

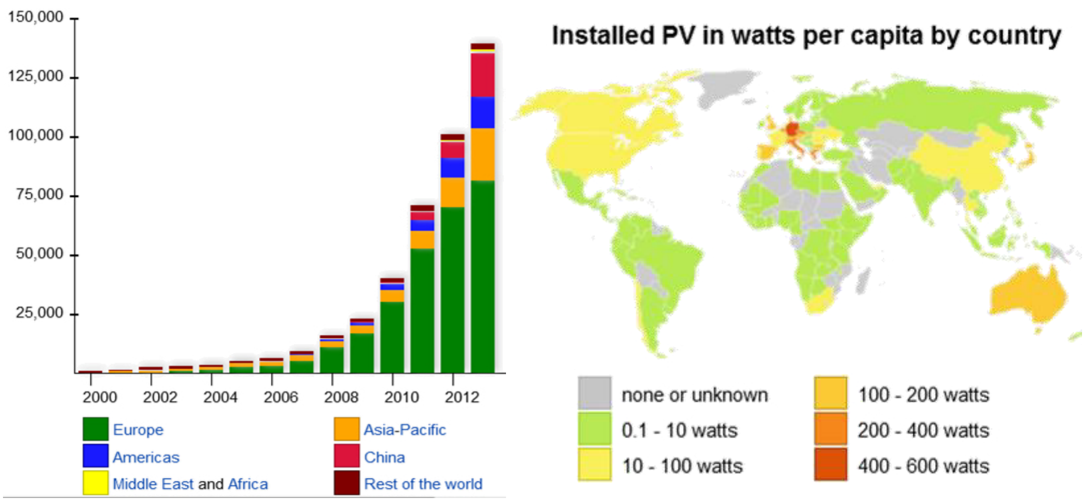


Figure I - 4 Cumulative capacity in megawatts [MW_p] grouped by region (European Photovoltaic Industry Association 2014)

Serbia

The Republic of Serbia has to pay great attention to its significant problems in the energy sector which are mandatory in order to improve the energy production and activate the production of clean energy which notably affects the economy. Reasons for promotion are the following:

- Serbian imports over 40% of energy, which makes it a highly energy dependent country;

- Energy consumption in buildings is among the highest in Europe, which significantly affects the state of the economy and life standard;
- Electric power system survives on the verge of endurance, since there are lack of funds for new and maintenance of existing facilities, which results in frequent breakdowns and losses in energy transmission;
- Air and water pollution are evident in large cities.

The scope and structure of energy reserves and resources of Serbia are unfavorable. Qualitative fossil reserves such as oil and gas account only 1% of total while remaining 99% of energy reserves are various types of low-quality coal. Lignite is estimated with 90% of the total balance reserves. Energy consumption in the building sector in Serbia is approximately 40% from estimated total energy consumption. Administrative buildings with poor energy performance are the most significant consumers. Hence the reorganization in the administrative sector related to energy consumption has to insist on efficient energy use according to the climatic conditions on the territory of Vojvodina.

1.2. Current state in the field

The World's energy demand is increasing progressively with the request to meet the growing energy needs. Enormous energy consumption is even more serious due to lack of natural resources and the presence of expressive ecological disbalance. The Republic of Serbia is one of those countries which are characterized by enormous inefficient energy consumption in the building sector. The major problem is the unadapted building sector to energy efficient requirements and the high percentage of energy derivation from non-renewable sources.

The increase of energy demand involves the increment of energy costs, public pressure enhances due to global warming, and therewith environmental protection raises key issues to solve the problems. Optimization of energy performance can become a target for improvement and modernization of the building sector.

According to the World Energy Council's report on "Climate Change: Implications for the Energy Sector", by director Tim Nuthall the key findings are the following (Nuthall 2014):

1. Energy demand is increasing globally, causing greenhouse gas (GHG) emissions from the energy sector also to increase. The trend is set to continue, driven primarily by economic growth and the rising population. In recent years the long-term trend of gradual decarbonisation of energy has reversed due to an increase in coal burning;
2. Climate change presents increasing challenges for energy production and transmission. A progressive temperature increase, an increasing number and severity of extreme weather events and changing precipitation patterns will affect energy production and delivery. The supply of fossil fuels, and thermal and hydropower generation and transmission, will also be affected. However, adaptation options exist;

3. Significant cuts in GHG emissions from energy can be achieved through a variety of measures. These include cutting emissions from fossil fuel extraction and conversion, switching to lower-carbon fuels (for example from coal to gas), improving energy efficiency in transmission and distribution, increasing use of renewable and nuclear generation, introduction of carbon capture and storage (CCS), and reducing final energy demand;
4. Strong global political action on climate change would have major implications for the energy sector. Stabilization of emissions at levels compatible with the internationally agreed 2°C temperature target will mean a fundamental transformation of the energy industry worldwide in the next few decades, on a pathway to complete decarburization;
5. Incentivizing investment in low-carbon technologies will be a key challenge for governments and regulators to achieve carbon reduction targets. Reducing GHG emissions also brings important co-benefits such as improved health and employment, but supply-side mitigation measures also carry risks.

Key findings for the building sectors are described by the author Patrick Chalmers in “Climate Change: Implications for Buildings” (Designing Buildings Ltd. 2014):

1. In 2010, the world’s buildings accounted for 32% of global final energy use and 19% of all greenhouse gas (GHG) emissions. Under business-as-usual projections, use of energy in buildings globally could double or even triple by 2050. Drivers include billions of people acquiring adequate housing and access to electricity;
2. Widespread implementation of best practices and technologies could see energy use in buildings stabilize or even fall by 2050. Many mitigation options promise multiple co-benefits;
3. Many barriers exist to greater uptake of energy-saving opportunities, including poor market transparency, limited access to capital and risk aversion. But know-how exists on retrofitting and how to build very low- and zero-energy buildings, often at little marginal investment cost; and there is a broad portfolio of effective policy instruments available to remove barriers to uptake;
4. The very long life-cycles of buildings create risks of energy use ‘lock-in’ with the effects of low ambition today playing out for decades. Using state-of-the-art standards immediately, for both new and retrofit buildings, would alleviate this hazard;
5. Buildings face major risks of damage from the projected impacts of climate change, having already experienced a big increase in extreme weather damage in recent decades. There is likely to be significant regional variation in the intensity and nature of such impacts.

In energy efficient technology there are many mitigation options specifically applicable to buildings (Designing Buildings Ltd. 2014):

- High-performance building envelopes. Typically, these have high-performance insulation and windows, avoiding thermal bridges and maintaining air tightness while using mechanical ventilation with or without heat recovery to maintain high indoor air quality;

- Energy-efficient appliances, efficient lighting, and Heating, Ventilation and Air-Conditioning (HVAC);
- Evaporative cooling and solar-powered desiccant dehumidification, as locally appropriate;
- Improved building automation and control systems that respond to changing conditions;
- 'Daylighting' – designing buildings for controlled admission of natural light, adjustable through the day using solar shading;
- Using smart meters and grids to modulate supply in real time.

Contemporary views for improving the energy performance of buildings classify the criteria for satisfying occupant comfort among the most important. ISO 7730 standard defines thermal comfort as being the condition of mind which expresses satisfaction with the thermal environment. Thermal comfort is very difficult to define because it has to take into account a range of environmental and personal factors when deciding what will make people feel comfortable. These factors make up what is known as the "human thermal environment" (Health and Safety Executive 2014).

The significance of achieving and maintaining indoor comfort in administrative buildings manifests itself in achieving a healthy and pleasant working environment, which also improves occupants' productivity. However, the perception of comfort is subjective, and it is almost impossible to meet the needs of each individual. Therefore, the goal of the designer is to satisfy the needs and requirements of most users.

1.3. Research objectives

1.3.1. Hypotheses and goals

The primary hypothesis is that it is possible to find an optimal solution for energy performance improvement of administrative buildings in the function of occupant comfort parameters and healthy work environment for the climatic conditions on the territory of Novi Sad.

The second hypothesis is that it is possible to develop a model for energy performance improvement of administrative buildings. Furthermore it is possible to formulate a simplified application of the model in order to achieve both energy reduction and comfortable/healthy work environment.

The goal is to find optimal intervention measures for energy performance improvement of administrative buildings respecting the requirements of occupants in order to achieve a thermally comfortable, healthy and productive work environment with the aim to formulate high quality solutions.

The dissertation investigates the possibility of effective energy performance improvement of administrative buildings via multi-criteria optimization and comparative analysis with the application of the following:

- BIM (Building Information Modeling) technology;
- Highly detailed parametric modeling;
- Dynamic energy simulation.

The aim of the research is to determine an optimal solution for energy performance improvement of typical inefficient multi-level office buildings, in temperate climate conditions, with special emphasis on achieving and maintaining satisfactory indoor environmental standards and thermal comfort of occupants. The formulated methodology for energy performance determination and evaluation will be simplified in order to be implementable and applicable on multi-level office buildings with same or similar characteristics in order to offer efficient methods for energy performance improvement, occupant comfort maintenance and envelope performance rehabilitation.

1.4. Literature review

Buildings energy performance assessment requires the input of numerous parameters e.g. construction, materials, occupancy, equipment operation. A dynamic energy simulation requires that all phases of the project are formulated precisely and in detail, because it is necessary to create a virtual environment approximated to natural laws described as a mathematical model.

The new generation building energy simulation program - EnergyPlus[1] (which is applied in the dissertation) was created by engineers and professors from the US Department of Energy, Research and Development Center Engineers of the US Army, University of Berkeley, the University of Illinois, the University of Oklahoma and GARD Analytics (Strand 2000). EnergyPlus provides highly detailed energy simulation, because it operates with mathematical and thermodynamic models that describe the physical properties of building materials, air movement and energy transfer by conduction, convection and radiation. EnergyPlus – building energy simulation engine allows programming of multi-zone buildings and mechanical systems in such detail that after the implementation of model properties it is possible to observe its behavior in certain time interval. This technology allows formulation performative project solutions from the aspect of energy performance. Useful information considering building automation is elaborated by author Wang in the book Intelligent Buildings and Building Automation and author Gevorkian in Sustainable Energy Systems in Architectural Design (Wang 2010) (Gevorkian 2006). Occupant comfort theory in buildings is discussed in The Whole Building Handbook - How to Design Healthy, Efficient and Sustainable Buildings by authors Bakalders and Block (Bokalders and Block 2010).

Smart buildings are a significant topic in the last decade in order to develop energy efficient yet user friendly solutions. The topic is well developed and the complexity lies in the integration of computational models with building operation in order to

[1] EnergyPlus Version 7.2.0. Build no. 006., 2013, Copyright © 1996-2012 The Board of Trustees of the University of Illinois and The Regents of the University of California through Ernest Orlando Lawrence Berkeley National Laboratory. All rights reserved

improve its efficiency and functionality. Author Sinopli describes smart buildings and operations in his book Smart Building Systems for Architects, Owners and Builders. (Sinopoli 2010). Significant source was the book of author Clarke titled Energy Simulation in Building Design which elaborates the problems of mathematical models in the field of energy simulation and reliability of the output generated through simulation (Clarke 2001). Considering green strategies and sustainability numerous sources were used informatively (Jayamaha 2007) (Sassi 2006) (Scott 1998). Doctoral dissertation with the title Climatic Influences on the Energy Demand of European Office Buildings by Schlenger from the Technical University of Dortmund, develops and analyzes the impacts of climate conditions on the energy performance of office buildings in central and northern Europe (Schlenger 2009). Numerous dissertations were analyzed prior to the investigation in order to analyze the methodology used in the field of building energy performance assessment (Petersen 2011) (Chan 2011) (Flodberg 2012) (Khazaii 2012) (Birchall 2011) (Janson 2010) (Artmann 2008) (Joelsson 2008) (Hansen 2006) (Wetter 2004).

The need to optimize building energy performance was elaborated in numerous researches using various analysis methods, energy simulations and techniques in order to design sustainable, energy efficient and cost-effective buildings (Blizzard and Klotz 2012) (Vuuren, et al. 2012) (Dylewski and Adamczyk 2012) (Gong, Akashi and Sumiyoshi 2012) (Yu, et al. 2012) (Lou, et al. 2012) (Roetzel, Tsangrassoulis and Dietrich 2014) (Bambrook, Sproul and Jacob 2011) (Milan, Bojesen and Nielsen 2012) (Sartori and Hestnes 2007) (Wang, Gwilliam and Jones 2009) (Pérez-Lombard, et al. 2011) (Pisello, Bobker and Cotana 2012) (Schein 2007) (Attia, Hamdy, et al. 2013) (Fumo, Mago and Luck 2010) (Gonzalez, et al. 2011) (Rabah, Emmanuel and Rafik 2015) (Rahman 2014) (Eui-Jong, et al. 2014)

Published investigations covering the dissertation topic of building energy performance simulation, occupant comfort analysis and HVAC system performance investigation were presented in the following papers (Harmati and Folić 2014) (Harmati, Folić and Magyar (no. 1) 2014) (Harmati, Folić and Magyar (no. 2) 2015) (Harmati and Jakšić 2014) (Harmati, Jakšić and Vatin. 2015) (Harmati and Magyar (no. 1) 2014) (Harmati and Magyar (no. 2) 2014) (Harmati and Magyar (no. 3) 2014) (Harmati and Magyar (no. 4) 2014) (Harmati and Magyar (no. 5) 2014).

Zero-energy buildings are today an important topic of consideration and are developed in numerous studies (Thalfeldt, et al. 2013) (Kolokotsa, et al. 2011) (Attia, et al. 2012) (Schimschar, et al. 2011) (Robert and Kummert 2012) (Marszal and Heiselberg 2011) (Lund, Marszal and Heiselberg 2011) (Kapsalaki, Leal and Santamouris 2012) (Adhikari, et al. 2012).

Optimal models for administrative buildings are elaborated in individual developed countries. Serbia still does not possess optimal administrative building models for temperate climate conditions on the territory of Novi Sad in Vojvodina. Energy performance improvement of office buildings today should be inseparable from indoor occupant comfort and healthy work environment. This direction of improvement could significantly reduce energy consumption and open the way to rational use of energy, reducing harmful emissions and environmental preservation.

1.5. Brief summary of the chapters

The dissertation consists of eight chapters.

Chapter 1 elaborates the research subject and research problem of the dissertation with concise description of topic significance in global and in Serbia. Current state in the field and research objectives (hypotheses) are outlined, followed by pertinent literature review.

Chapter 2 shows the applied research methodology and collected materials in the dissertation. On-site monitored data, technical information and program input data are analyzed and evaluated.

Chapter 3 presents the building envelope optimization in the function of illumination dispersion and daylight quality analysis in Radiance[2] engine. The geometric CAD building model constructed by using BIM technology is elaborated with detailed analysis and evaluation of the obtained results concerning exterior glazing properties.

Chapter 4 presents performative solutions for building envelope's thermal improvement according to the European Standards and Serbian directives. Existing building envelope is presented and evaluated, respectively.

Chapter 5 presents the complexity of designing a multi-zone thermal model and provides the definitions of all necessary input parameters in order to perform a dynamic simulation in EnergyPlus engine. Precise description of input data and calculation methodology are described followed by evaluation and comparative analysis of the results. The energy demand for air ventilation according to Annex B of EN 15251 was determined respectively. Findings define the Best Case Scenario from the energy performance aspect for temperate climate conditions.

Chapter 6 elaborates the optimal building model in the function of comfort parameters. The comfort model is applied for the Best Case energy performance Scenario in order to obtain and analyze the PVM (predicted mean vote) and PPD (predicted percentage of dissatisfied) values from the comfort equations. The investigation includes dynamic comfort parameter simulations in EnergyPlus and presents detailed analysis of parameter oscillations in hourly intervals. In conclusion the Best Case Scenario from the comfort aspect is determined.

Chapter 7 presents an overview of the Best Case Scenario's properties from the previously elaborated researches in Chapters 3, 4, 5 and 6. HVAC system efficiency is explored in newly designed buildings and proposals are given respectively for HVAC system improvement in existing office buildings.

Chapter 8 concludes the considerations, indicates the application of findings and proposes directions for further research.

[2] Desktop Radiance, Radiance CP Version 2.01, 2013, Lawrence Berkely National Laboratories, USA

Chapter 2

Methodology and materials

2.1. Applied scientific methods

Scientific methods:

- Method of analysis and synthesis, and comparative analysis;
  - Energy consumption monitoring will be performed and analyzed on the office tower building of the Faculty of Technical Sciences (B + GF + 9). The building was selected for analysis since it is a typical unreconstructed significant energy consumer on the territory Novi Sad,
  - Influences on the energy performance will be synthesized.
- Induction and deduction method;
- Method of parametric modeling;
- Method of dynamic simulation;
- Multi-criteria optimization;
  - Criteria optimization is to seek the best solutions from a range of possible solutions in terms of the adopted criteria,
  - The values of criterion analysis will demonstrate the formulated models level of quality for given alternatives. Optimization will determine the best solution according to the defined criteria that satisfies all given constraints.

Data collection techniques:

- Monitoring;
  - Indoor air temperature, indoor relative humidity and daylight oscillations were monitored with data loggers;
  - Daily energy consumption was recorded in the office buildings sub-station;
- Monthly energy consumption expenses are collected from “JKP Novosadska Toplana” heating plant and electricity distribution company “Elektrovojvodina doo” in Novi Sad;

- Technical documentation and project plans of the reference office tower building are gathered from the technical archive of the Faculty of Technical Sciences in Novi Sad.

2.2. Programs

2.2.1. BIM technology

The US National Building Information Model Standard Project Committee has the following definition for BIM (National BIM standard 2014);

“Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.”

The Department for Business Innovation and Skills in their report to the Government Construction Clients Board on Building Information Modelling and Management states;

"Building Information Modelling and Management BIM is a managed approach to the collection and exploitation of information across a project. At its heart is a computer-generated model containing all graphical and tabular information about the design, construction and operation of the asset." (CGD Ltd 2014)

The beneficiaries of BIM include owners, planners, realtors, appraisers, mortgage bankers, designers, engineers, estimators, specifies, safety, occupational health, environmentalists, contractors, lawyers, contract officers, sub-contractors, fabricators, code officials, operators, risk managers, renovators, first responders and demolition contractors (National BIM standard 2014). The benefits of the BIM technology is the information sharing between engineers as shown in, Figure II - 1 (CGD Ltd 2014). The BIM model gathers the following properties, presented in Figure II - 2 (Hanlon Engineering and Architecure 2014).

BIM software also defines objects parametrically; that is, the objects are defined as parameters and relations to other objects, so that if a related object is amended, dependent ones will automatically also change (ENGworks 2014). The importance of BIM technology lies in the following; 3D objects are machine readable, spatial conflicts in a building model can be checked automatically. Because of this capability, at both the design and shop drawing levels, errors and change orders due to internal errors are greatly reduced. Pieces can carry attributes for selecting and ordering them automatically, providing cost estimates and well as material tracking and ordering. Thus as a building representation, BIM technology is far superior to drawings (ENGworks 2014).

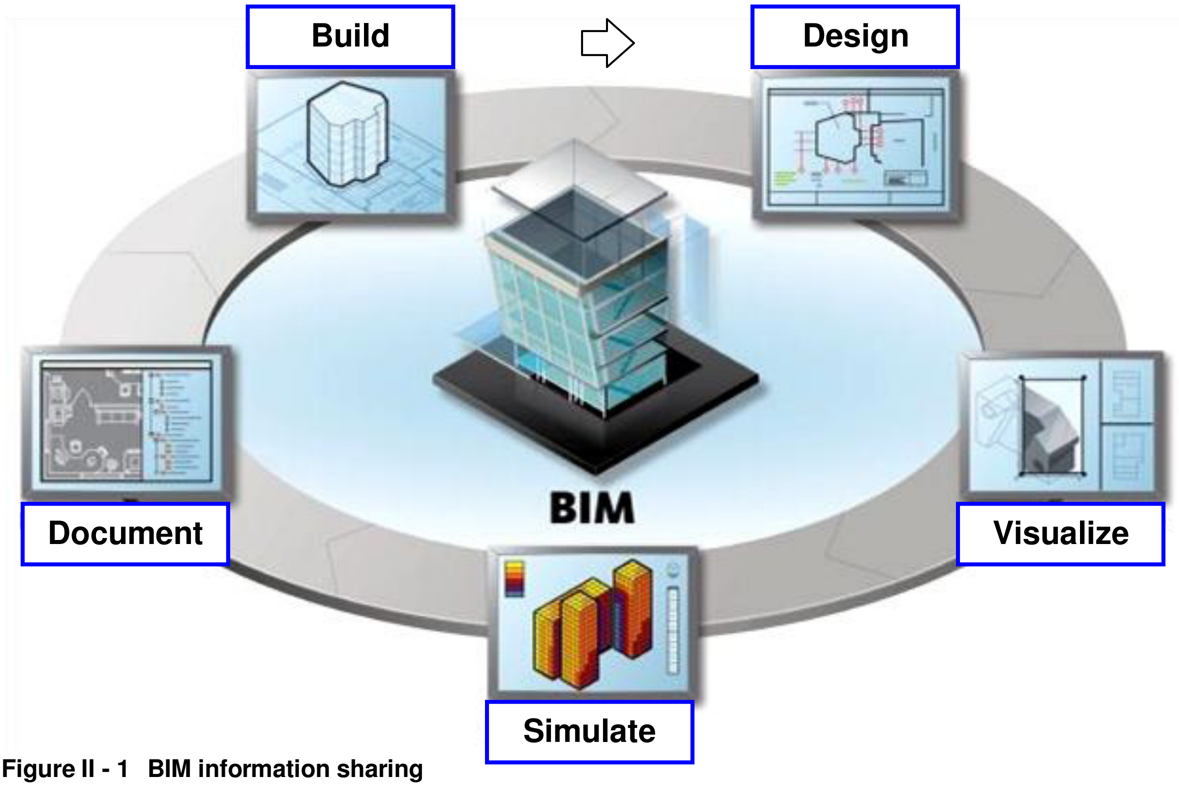


Figure II - 1 BIM information sharing

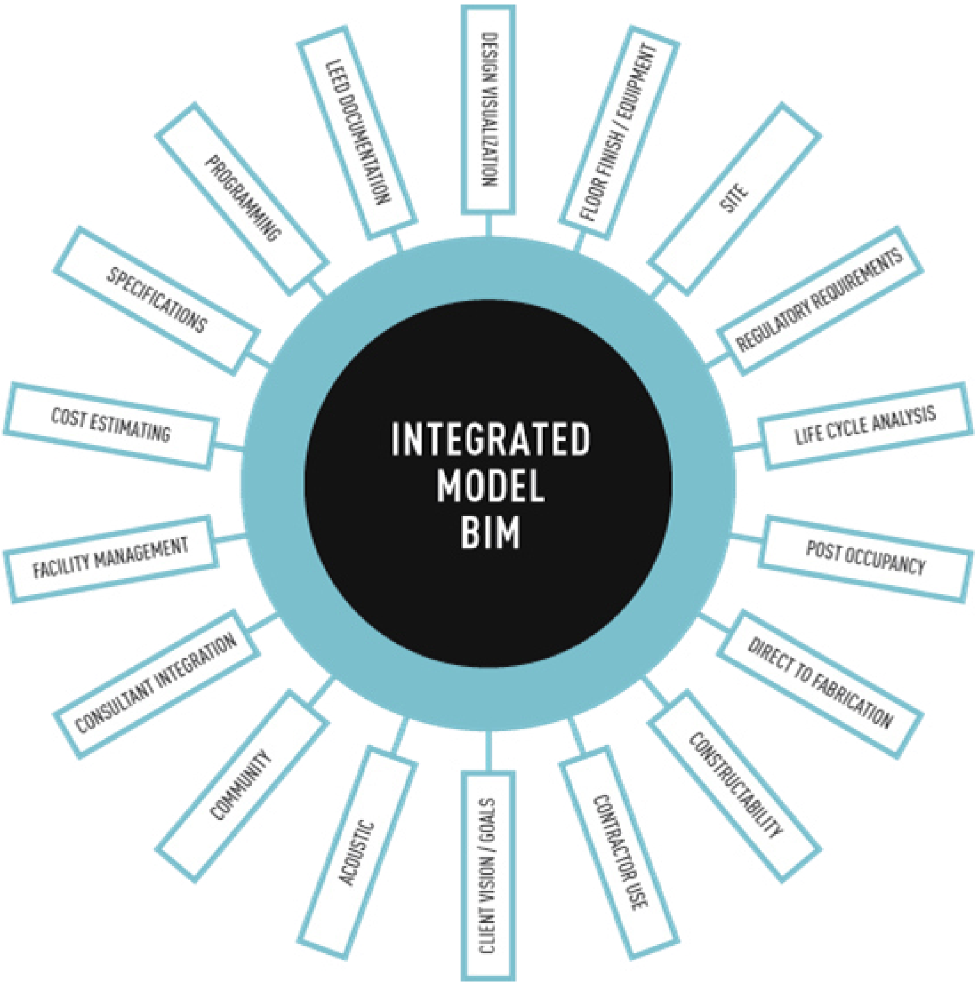


Figure II - 2 Integrated BIM model

2.2.2. Energy simulation engines

Numerous energy simulation engines are present depending on the method and accuracy of their calculations. The following emphasized programs are widespread for energy performance calculation: EnergyPlus, TRNSYS, TAS, IDA ICE, PHPP, Autodesk Ecotect[3], eQUEST, ESP-r, EnerWin, BSim, BLAST, Express, TRACE etc.

2.2.2.1. Calculation methods

Commercial load calculation methods

In the calculation of commercial building heating and cooling loads, many methods have been developed over the years (Smith 2011). ASHRAE has:

- TETD (Total Equivalent Temperature Difference),
- CLTD (Cooling Load Temperature Difference, 7 wall type and 13 roof type categories are provided),
- TFM (Transfer Function Method),
- HB (Heat Balance, allow smooth and infinite variations of wall types with different thermal mass)
- RTS (Radiant Time Series, hour by hour calc.)

The most current and sophisticated energy analysis program was developed by the U.S. government, and is called EnergyPlus. It uses the Heat Balance (HB) method primarily for building energy analysis. The designer must be prepared to enter more data and more details for all the load components. This is time consuming, and requires more thought and engineering judgment (Smith 2011).

2.2.2.2. EnergyPlus engine, new-generation building energy simulation program

EnergyPlus is a new-generation energy analysis and load calculation engine for buildings. The construction, calculation method and all features of EnergyPlus are cited from the authors Strand, Crawley, Pedersen, Liesen, Lawrie, Winkelmann, Buhl, Huang and Fisher (Strand 2000).

EnergyPlus is a new building performance simulation program that combines the best capabilities and features from BLAST and DOE–2 along with new capabilities. Developed using the heat balance based load calculation algorithm found in IBLAST (a research version of the BLAST program), it consists of new Fortran 90 code that was either created specifically for EnergyPlus or that was reengineered from one of the legacy programs. The use of Fortran 90 as the programming language for EnergyPlus also allows for the creation of a well-organized, modular program structure that facilitates adding new features and links to other programs (Strand 2000).

[3] Autodesk Ecotect Analysis 2011, License: Type; Standalone-Locked, ID; ECOA_F_S, Expiration; 10.06.2016.,

In addition, EnergyPlus is primarily a simulation engine. One of the reasons for this is the broad range of potential users the program might end up having. For example, an architect might be interested in monitoring energy consumption during the entire design phase of a program, a mechanical engineer may be interested in investigating various mixed air strategies on a particular air handling system, a homeowner could be interested in the yearly energy savings that might be realized from installing double pane windows with a low-emissivity coating instead of standard double pane windows, etc. While each type of user requires the same calculation to be performed, each will have different knowledge levels, skills, and goals. Thus, the simulation engine can be the same for all users but the interface to the simulation program will likely be very different. Private industry has shown itself to be much more capable of creatively responding directly to the demands of the highly diversified consumer market in this area. The EnergyPlus project will allow interface developers to tailor their products to their respective industries without having to produce the complex energy analysis program while also allowing all of the interfaces to be based on the same calculation engine (Strand 2000).

Work on EnergyPlus began by modularizing (restructuring) code from the heat balance engine in IBLAST, a research version of BLAST with integrated loads and HVAC calculation. Normally such restructuring would result in major rewrites involving a long development period and very extensive testing to ensure the new code performs as intended. One of the most encouraging results of the modularization process was the new clarity it brought to the program code's main simulation loops. At the outermost program level, the Simulation Manager controls the interactions between all simulation loops from a sub-hour level up through the user selected time step and simulation period; day, month, season, year, or several years. Actions of individual simulation modules are directed by the simulation manager, instructing simulation modules to take actions such as initialize, simulate, keep records, or report (Strand 2000).

Structure

The simulation manager was created to specifically address the legacy issues of spaghetti code and lack of structure in DOE-2 and BLAST (Strand 2000). The simulation manager provides several critical benefits:

- major simulation loops are contained in a single subroutine
- modules are self-contained and more object-based
- data access is controlled
- new modules are easily added

An integrated simulation became the underlying concept for EnergyPlus - loads calculated (by a heat balance engine) at a user-specified time step (15-minute default) are passed to the building systems simulation module at the same time step. The building systems simulation module, with a variable time step (down to one minute), calculates heating and cooling system and plant and electrical system response. Accurate prediction of space temperatures is crucial to energy efficient system engineering - system size, plant size, occupant comfort and occupant health all depend on space temperatures. Integrated simulation also allows users to evaluate a number of processes which include:

- Realistic system controls
- Moisture adsorption and desorption in building elements
- Radiant heating and cooling systems
- Interzone air flow

As shown in Figure II - 3, there are three basic components to EnergyPlus (Strand 2000):

- Simulation manager
- Heat and mass balance simulation module, and a
- Building systems simulation module

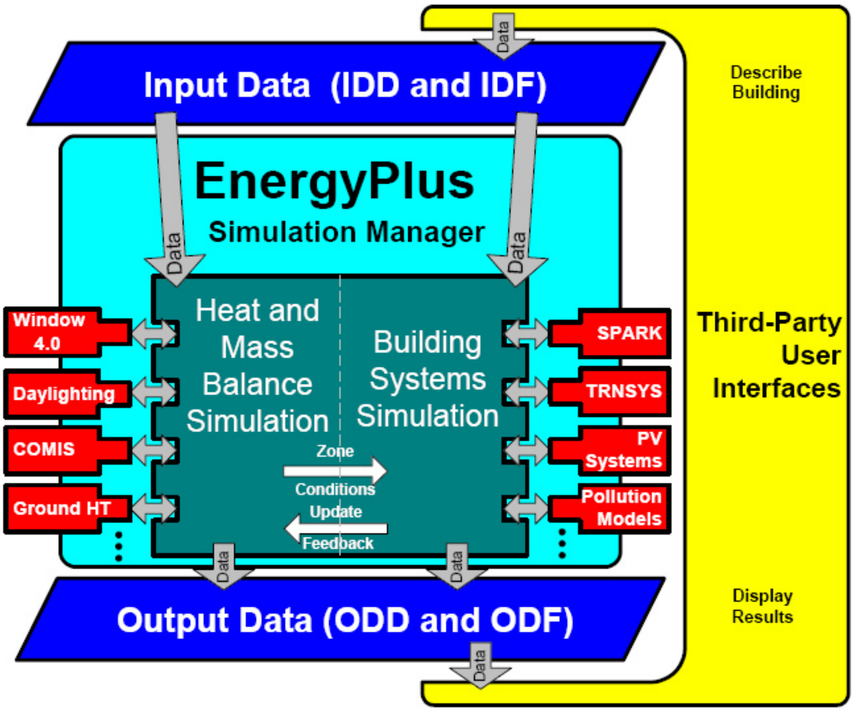


Figure II - 3 Basic components of EnergyPlus

The Simulation Manager controls the entire simulation process. The Building Systems Simulation Manager handles communication between the heat balance engine and the HVAC water and air loops and their attached components (coils, boilers, chillers, pumps, fans, etc.). User-configurable heating and cooling equipment components give users much more flexibility in matching their simulation to the actual system configurations. The Building Systems Simulation Manager also manages data communication between the HVAC modules, input data, and output data structures (Strand 2000).

Heat and mass balance calculation

The underlying building thermal zone calculation method in EnergyPlus is a heat balance model in which room air is modeled as well stirred with uniform temperature throughout. The modular structure of EnergyPlus allows more detailed room air convection calculations – such as CFD or zonal methods. It is also assumed that room surfaces (walls, windows, ceilings, and floors) have:

- Uniform surface temperatures,
- Uniform long and short wave irradiation,
- Diffuse radiating surfaces, and
- Internal heat conduction.

Figure II - 4 shows the structure of the EnergyPlus integrated solution manager that manages the surface and air heat balance modules and acts as an interface between the heat balance and the building systems simulation manager. The Surface Heat Balance Module simulates inside and outside surface heat balance, interconnections between heat balances and boundary conditions, conduction, convection, radiation, and mass transfer (water vapor) effects. The Air Mass Balance Module deals with various mass streams such as ventilation air, exhaust air, and infiltration. It accounts for thermal mass of zone air and evaluates direct convective heat gains (Strand 2000).

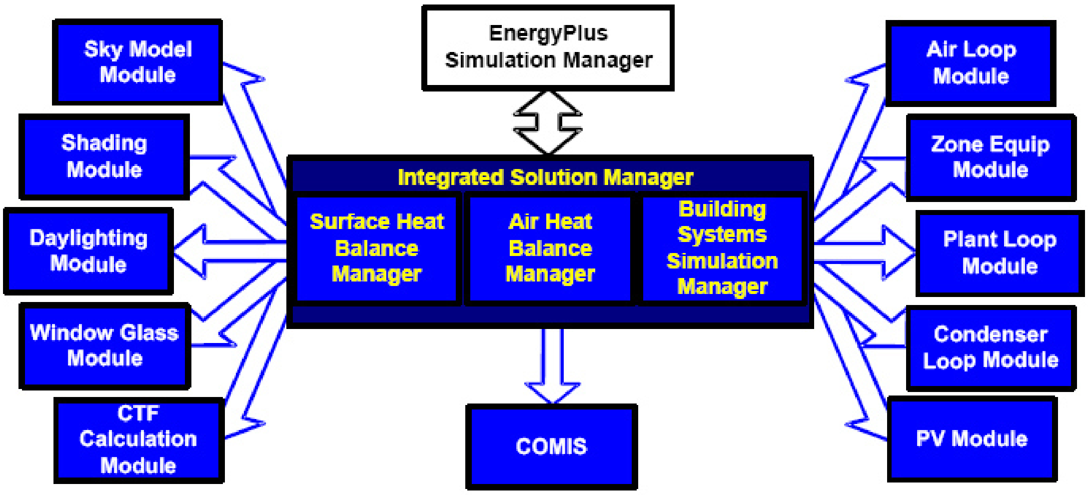


Figure II - 4 Structure of the EnergyPlus integrated solution manager

Building systems simulation manager

After the Heat Balance Manager completes its simulation for a time step, it calls the Building Systems Simulation Manager, which controls the simulation of HVAC and electrical systems, equipment and components and updates the zone-air conditions. EnergyPlus does not use a sequential simulation method (first building loads, then distribution system, and then plant) as found in DOE–2 and BLAST since this imposes rigid boundaries on program structures and limits input flexibility. Instead, the Building Systems Simulation Manager has been designed with several objectives; fully integrated simulation of loads, systems and plant, modular and extensible (Strand 2000).

Integrated simulation allows capacity limits to be modeled more realistically and provides tighter coupling between the air- and water-side of the system and plant.

Modularity is maintained at both the component and system level. This eases adding new components and flexibly modeling system configurations and, at the system level, equipment and systems are clearly connected to zone models in the heat balance manager. To implement these concepts, loops are used throughout the Building Systems Simulation Manager—primarily HVAC air and water loops. Loops mimic the network of pipes and ducts found in real buildings; later, EnergyPlus will simulate heat and thermal losses that occur as fluid moves in each loop (Strand 2000).

The air loop simulates air transport, conditioning, and mixing and includes supply and return fans, central heating and cooling coils, heat recovery, and controls for supply air temperature and outside air economizer. The air loop connects to the zone through the zone equipment (Strand 2000). There are two water loops for HVAC plant equipment—a primary loop (for supply equipment such as boilers, chillers, thermal storage, and heat pumps) and a secondary loop (for heat rejection equipment such as cooling towers and condensers). Equipment is specified by type (gas-fired boiler, open drive centrifugal chiller) and its operating characteristics (Strand 2000).

Input, output, and weather data

The other major data input is weather. Rather than a binary file created by a separate weather processor, again a simple text-based format was chosen, similar to the input data and output data files. The weather data format includes basic location information in the first eight lines: location (name, state/province/region, country), data source, latitude, longitude, time zone, elevation, peak heating and cooling design conditions, holidays, daylight savings period, typical and extreme periods, two lines for comments, and period covered by the data (Strand 2000).

2.2. Urban plan and climatic data

2.2.1. Urban site plan

The selected reference office tower building is part of the Faculty of Technical Sciences complex. This specific office-tower building was selected for monitoring and analysis since it is unreconstructed and also is a significant energy consumer on the territory of Novi Sad. The second reason for selection was the accessibility for monitoring and the availability of technical data (Archive 1968).

The Faculty of Technical Sciences is located in the University of Novi Sad campus, Liman 1 settlement situated on the coast of the river Danube. An urban site plan of the city is presented in Figures II - 5, II – 6 and II - 7, where the UNS campus is highlighted and the reference building marked. Aerial photo and the reference office tower building is presented in Figure II - 8.

Orientation

The office tower building's orientation is 30° counterclockwise from North axes. The orientation with the annual sun path is shown in Figure II - 9.

Figure II - 5 Urban site plan of Novi Sad, location of UNS campus

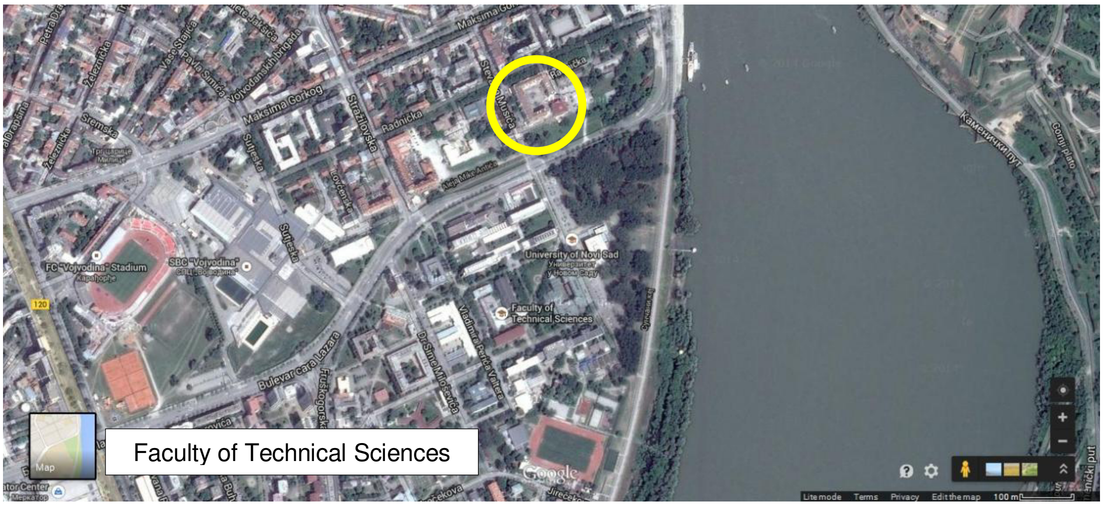


Figure II - 6 Location of the Faculty of Technical Sciences

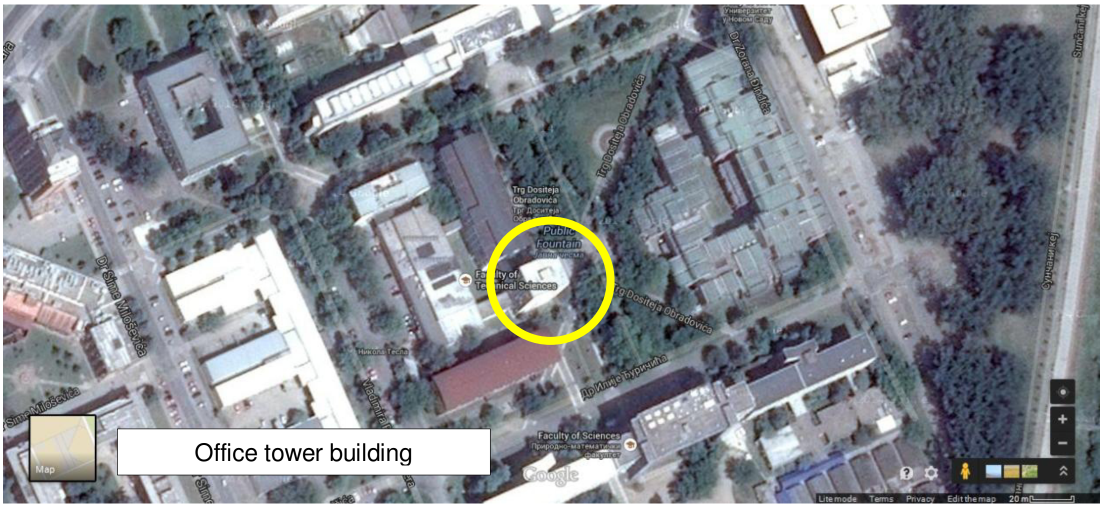


Figure II - 7 Office tower building location in the Faculty of Technical Sciences complex

The 10 level office tower building is located in the right side of the photos

Figure II - 8 Photo of the Faculty of Technical Sciences complex

2.2.2. Climatic data

2.2.2.1. General definitions

"Weather" is defined as the atmospheric conditions at a certain location and a certain point of time. Contrary to this, "climate" is defined as the average weather conditions occurring at a certain location over a longer period of time. Usually a climate consists of more or less constant annual recurrences of certain weather conditions (Schlenger, 2009).

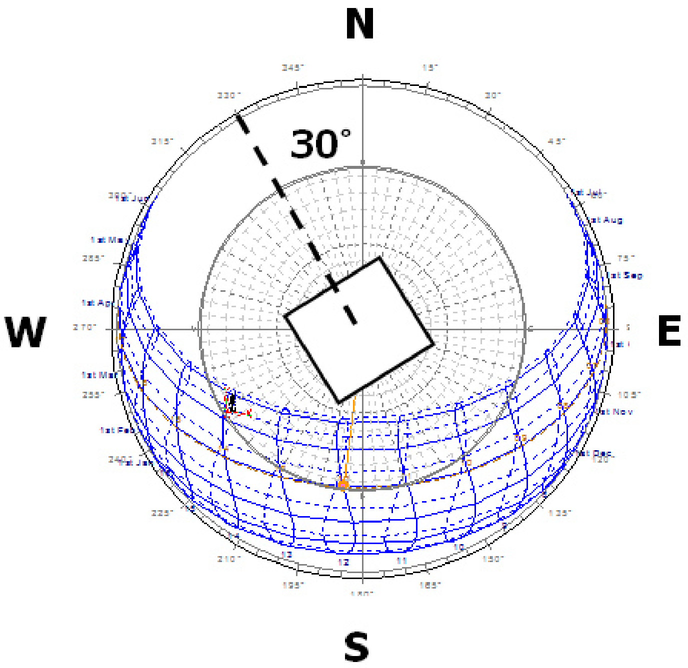


Figure II - 9 Building orientation and annual sun path for Novi Sad

A climate can be described with the help of different climate elements influencing the climatic conditions. Theses climate elements can be air temperature, air pressure, solar radiation, cloud cover, direction and intensity of winds etc. Very often average, minimum and maximum values of a selection of these elements are used to describe a climate (Schlenger, 2009).

In order to perform dynamic simulations a climatic data set was required for the analysis of the location's long-term climate. Since the dynamic simulation requires a certain level of detail, the climate information has to be converted into a readable EnergyPlus weather file format with EPW extension. Depending on the accuracy of the simulation the required time steps can be defined in the conversion preparation. The climatic data set for the location of Novi Sad was used from a global meteorological database Meteonorm [4]. Meteonorm is a comprehensive meteorological reference. It gives access to a catalogue of meteorological data for solar applications and system design at any desired location in the world. It is based on more than 25 years of experience in the development of meteorological databases for energy applications (Meteotest 2014). The periods 1961–1990 and 2000–2009 are available for temperature, humidity, wind speed and precipitation; the periods 1981–1990 and 1991–2010 for solar radiation. Monthly climatological means are available for the following eight parameters (Meteotest 2014):

- Global radiation
- Ambient air temperature
- Humidity
- Precipitation
- Days with precipitation

[4] Meteonorm Version 7.0.22.8, 2014, License: registered for N. Harmati, tutorial licence, Copyright © 2012 Meteotest Genossenschaft, Bern, Switzerland

- Wind speed
- Wind direction
- Sunshine duration

2.2.2.2. Data export in Meteonorm 7

36 different predefined export formats are available. They cover most of the established simulation software in solar energy applications and building design, including TMY2 and TMY3, EPW, TRNSYS as well as output formats for TRY (German test reference years), POLYSUN, TSOL/PVSOL, PVSyst and PHPP. All export formats are available for hourly as well as monthly values. Data is written to ASCII files (Meteotest 2014).

The exported climate data from Meteonorm 7 used in the simulations gathers the following information for Novi Sad, as shown below and in Table II - 1:
Name of site = Novi Sad
Latitude = 45.333°, Longitude = 19.850°, Altitude = 84 m
Climatic zone = III, 3
Radiation model = Default (hour)
Temperature model = Default (hour)
Tilt radiation model = Default (hour) (Perez model)
Radiation: New period = 1986-2005
Temperature: New period = 2000-2009

Legend:

Ta:	Air temperature
Ta min:	10 y minimum (approx.)
Ta max:	10 y maximum (approx.)
Ta dmin:	Mean daily minimum Ta
Ta dmax:	Mean daily maximum Ta
SD:	Sunshine duration
RR:	Precipitation
RD:	Days with precipitation
SD astr.:	Sunshine duration, astronomic
FF:	Wind speed
RH:	Relative humidity
DD:	Wind direction
Snd:	Snow depth
G_Gh:	Mean irradiance of global radiation horizontal
PAR:	Photosynthetically active radiation
G_Dh:	Mean irradiance of diffuse radiation horizontal

Temperature in [°C]
Wind speed in [m/s]
Sunshine duration in [h/day]
Radiation in [W/m²]
Snow depth in [mm]
SD: Only 4 station(s) for interpolation
RD: Only 4 station(s) for interpolation

Measured parameters (WMO nr: 131680) = Ta, FF, DD, RR, Td
Uncertainty of yearly values: Gh = 3%, Bn = 5 %, Ta = 0.3 °C
Trend of Gh / decade = - %
Variability of Gh / year = 2.5%

Climatic data charts from Meteonorm 7 are presented in Figures from II - 10 to II - 14. Figure II – 10 presents annual global and diffuse radiation for Novi Sad, the highest global radiation was recorded in July, 200 kWh/m^2, the lowest in December 30 kWh/m^2. Figure II – 11 shows annual daily global radiation oscillation.

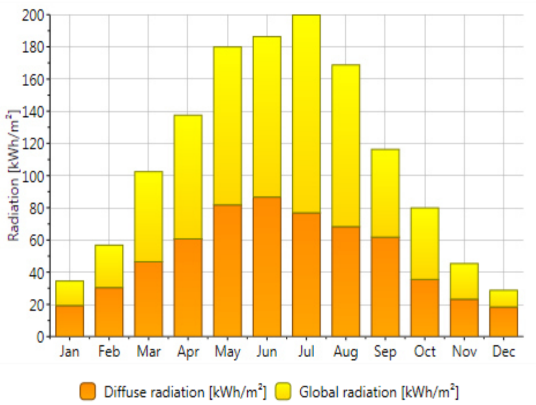


Figure II - 10 Radiation

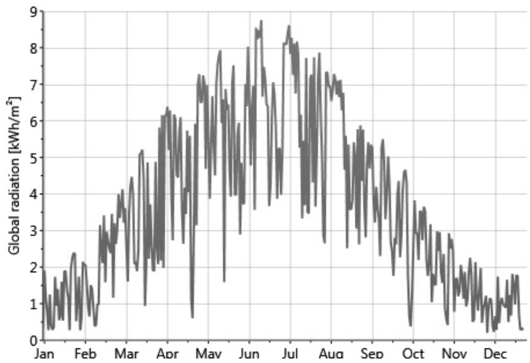


Figure II - 11 Daily global radiation

The annual outdoor air temperature oscillation is shown in Figure II – 12. Intervals for maximum, minimum and average air temperature values can be seen for each month. It can be concluded that august has the least oscillation interval, from 11°C to 33°C. The highest air temperature oscillation interval was from -6°C to 24°C.

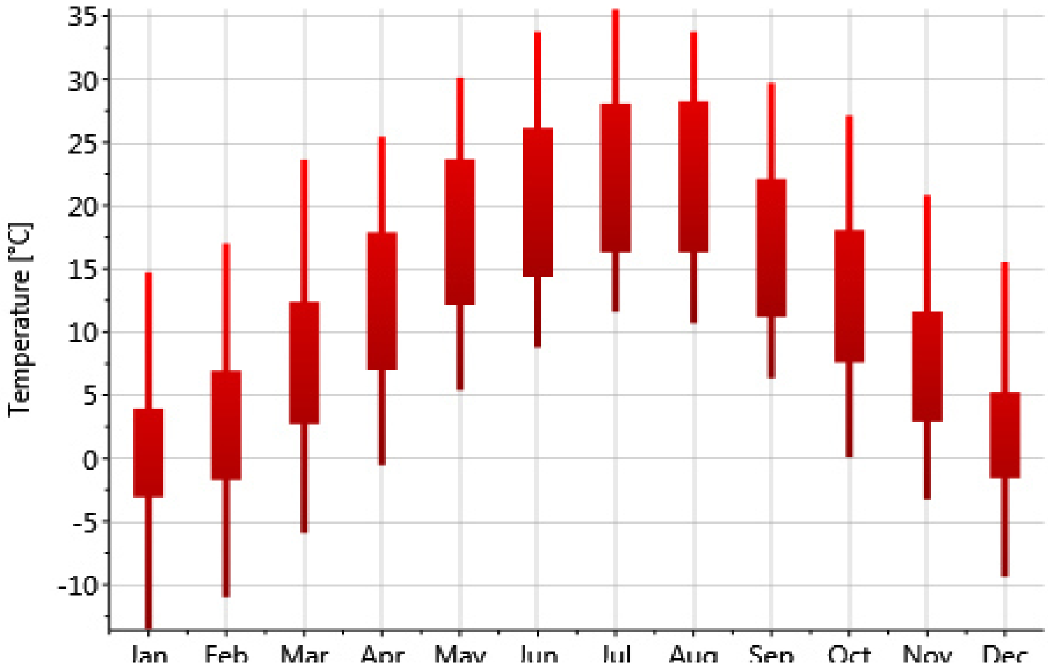


Figure II - 12 Outdoor air temperature

Daily air temperature oscillations throughout the year are presented in Figure II – 13 below. Maximum daily air temperature values are shown with dark gray color, while minimum daily values are light gray.

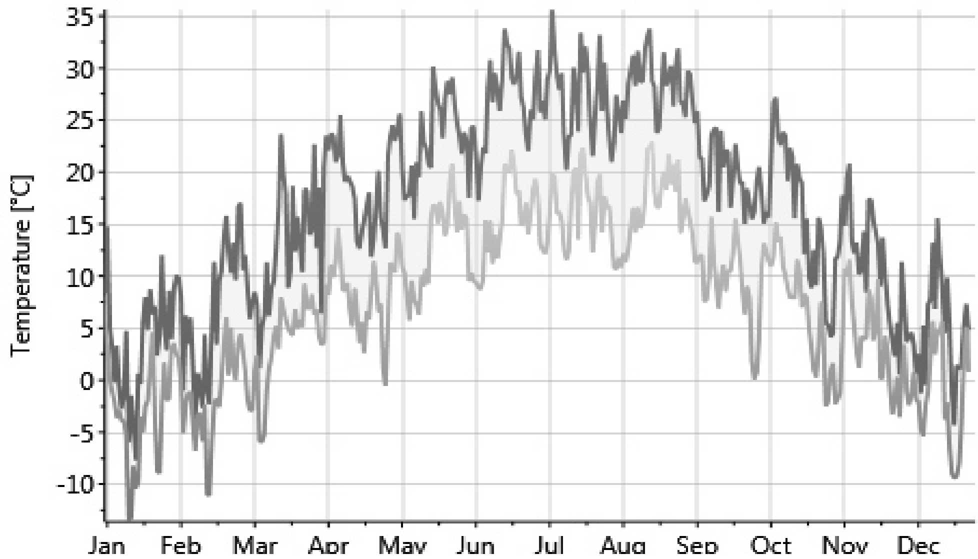


Figure II - 13 Daily air temperature

Annual monthly precipitation for the location of Novi Sad can be seen in Figure II – 14, where the left vertical axes presents monthly precipitation in mm and the right vertical axes shows the number of days per month with precipitation. It can be seen that significant precipitation is during May a June while the values from August to November are similar, and finally the least precipitation is shown for January. Considering the number of rainy days, May and June presents the most number of days with rainfall. August, September and October show least rain.

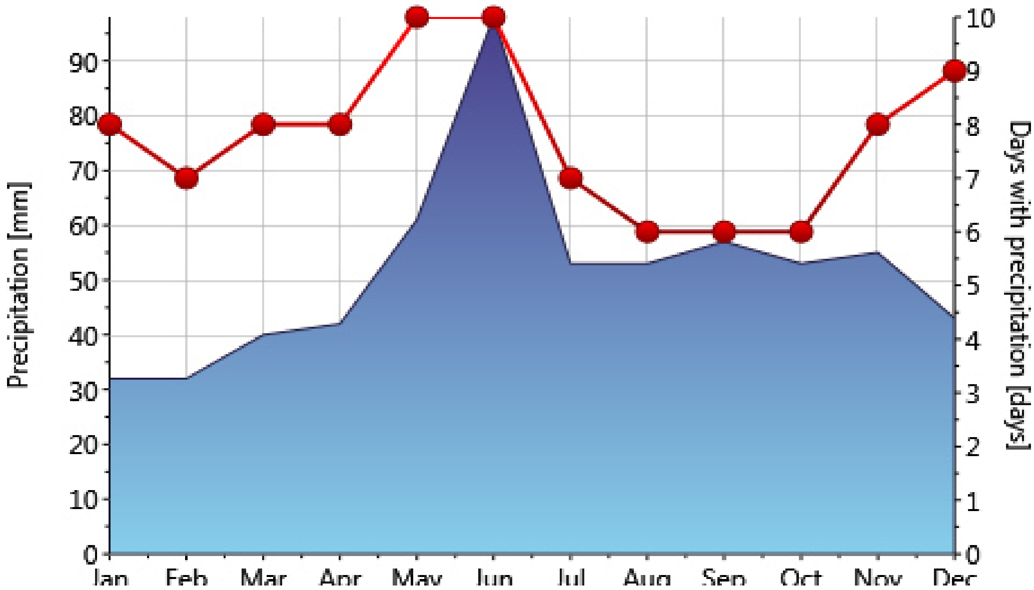


Figure II - 14 Precipitation

Table II - 1 Climate data from Meteonorm 7 – monthly average values for Novi Sad

Month	Ta	G_Gh	Td	RH	G_Dh	FF	DD	IRD
Jan	0.4	46.3	-2.3	81.9	26	2.6	270	271
Feb	2.3	84.5	-1.3	76.8	41.1	2.8	113	274
Mar	7.3	137.7	1.2	65	60.5	3.1	113	291
Apr	12.7	191	5.8	62.7	93.5	2.9	113	313
May	18	241.8	10.9	63.3	105.5	2.4	113	343
Jun	20.8	258.8	14.2	65.9	118.4	2.1	270	356
Jul	22.4	268.5	15.3	64.2	100.2	2.1	293	366
Aug	22.2	226.8	14.9	63.3	98.3	1.9	113	364
Sep	16.9	161.5	11.1	68.6	77.1	2	113	344
Oct	12.6	107.5	8	73.6	58.8	2.3	113	326
Nov	7.1	63	3.7	78.7	35	2.6	113	299
Dec	1.7	38.7	-0.7	83.8	23.2	2.6	270	282
Year	12	152.2	6.7	70.7	69.9	2.5	127	319

Month	PP	Sd	N	TL	Bn	Ghmax	G_Gex	PAR	Snd
Jan	1003	70	6	2.6	65.3	94	139	20.1	5.2
Feb	1003	89	5	2.8	110	139	202	36.2	0.8
Mar	1003	145	5	2.9	149.8	214	292	58.7	2.7
Apr	1003	180	5	3.1	171.4	288	384	82.3	0
May	1003	230	4	3.3	214	341	453	104.7	0
Jun	1004	251	4	3.4	216.4	358	482	112.9	0
Jul	1004	289	4	3.4	259	349	467	117	0
Aug	1004	269	4	3.3	208.7	302	411	99.6	0
Sep	1003	207	5	3.2	155	242	328	71.5	0
Oct	1003	170	5	3	111.9	166	235	47.9	0
Nov	1003	87	5	2.8	86.5	107	158	28.2	0.4
Dec	1003	60	7	2.7	50.5	79	122	17.3	15.2
Year	1003	2047	5	3	150.1	223	306	66.4	2

2.3. Monitoring and energy expenses

2.3.1. Monitoring

Monitoring was performed in order to evaluate the office buildings heating energy consumption during the winter and summer period of 2014. District heating energy was recorded in the reference building's sub-station. Recorded winter values present the heating intensity and heating system operation period. The period of the monitoring was performed during winter and summer in order to assess the heating and cooling system's efficiency, heating and cooling operation schedule and building envelope performance. The energy consumption monitoring in the winter period was performed from the 20th of January until the 17th of March 2014. The office building is equipped with district heating system by receiving hot water from the power plant. The heat is rejected through radiators beneath the windows in each office.

Heating energy consumption and heating intensity were recorded in the reference building's sub-station in intervals of 24 hours as shown in Tables II - 2 and II - 3. It was distinguished that the heating system was always turned on throughout the week. Despite the temperate winter of 2014 it was observed that the heating consumption was significantly high in the period from 26th of January until the 5th of February, due to outdoor mean air temperature which was approximately - 5°C during daytime and - 10°C during night with intensive wind. The heating consumption in this period was significantly high; the building required between 3.65 MWh and maximum 5.36 MWh, as shown in Figure II - 16. It was recorded that the incoming district heating water temperature varies between 70°C and 90°C for this specific period. The incoming, outgoing and temperature difference are presented in Figure II - 17. The daily flow quantity and flow rate were recorded from the digital-meter respectively, as shown in Figures II - 18 and II - 19. As observed, the heating was turned off on the 25th of January due to repairs.

The energy consumption for cooling could not be monitored since it is manually operated. Most of the offices have separate electric air conditioning units. The operation of the air conditioning units is not scheduled since it depends on the individual's physical state of thermal comfort and building occupancy intervals. The inability of monitoring the air conditioning units' energy supply was that the office building's total electricity expenses (lights, equipment, elevators and air conditioning) are assembled and delivered on a single account.

During the heating season parameters which affect indoor occupant comfort were monitored respectively with digital KIMO instruments (KIMO 2014). Three KIMO data loggers were lent for use by Aleksandar Inženjering co. in Novi Sad (Aleksandar Inzenjering 2014). The accuracy of the data loggers (KIMO KH 200 and KT 200) for temperature recording is ±3°C (from -25°C to +70°C), for the light sensor ±10% (from 0 lx to 10000 lx, KIMO KH 200). Relative humidity recording accuracy is ± 2.58% for values displayed between 18°C and 28°C and ±0.5°C beyond. The monitoring was performed for indoor comfort parameters, in order to assess and evaluate the environmental quality in offices. Digital KIMO instruments were setup on three floors of the reference office building, as shown in Figure II - 15. On the ground floor level, East oriented office, the KIMO KTH 300 monitored air temperature and relative humidity oscillations. KIMO KT 100 was set up in a South oriented office on the 5th floor monitoring air temperature oscillations. Finally KIMO KH 200 was monitoring the oscillations of three parameters; air temperature, relative humidity and daylight intensity in an office on the 9th floor with West orientation.

Winter monitoring includes three periods where each consists of two weeks. Mean air temperature, relative humidity and illumination oscillations were recorded in intervals of 15 minutes, 24 hours a day. The monitoring periods are the following:

- Period I 20.01. – 03.02.2014.
- Period II 03.02. – 15.02.2014.
- Period III 03.03. – 17.03.2014.

The results from Period I are presented in Figures II - 20, II - 21, and II - 22 from Period II are show in Figures II - 23, II - 24 and II - 25 and finally from Period III in Figures II - 26, II - 27 and II - 28. Numerical monitored data are presented in **Appendix A**.

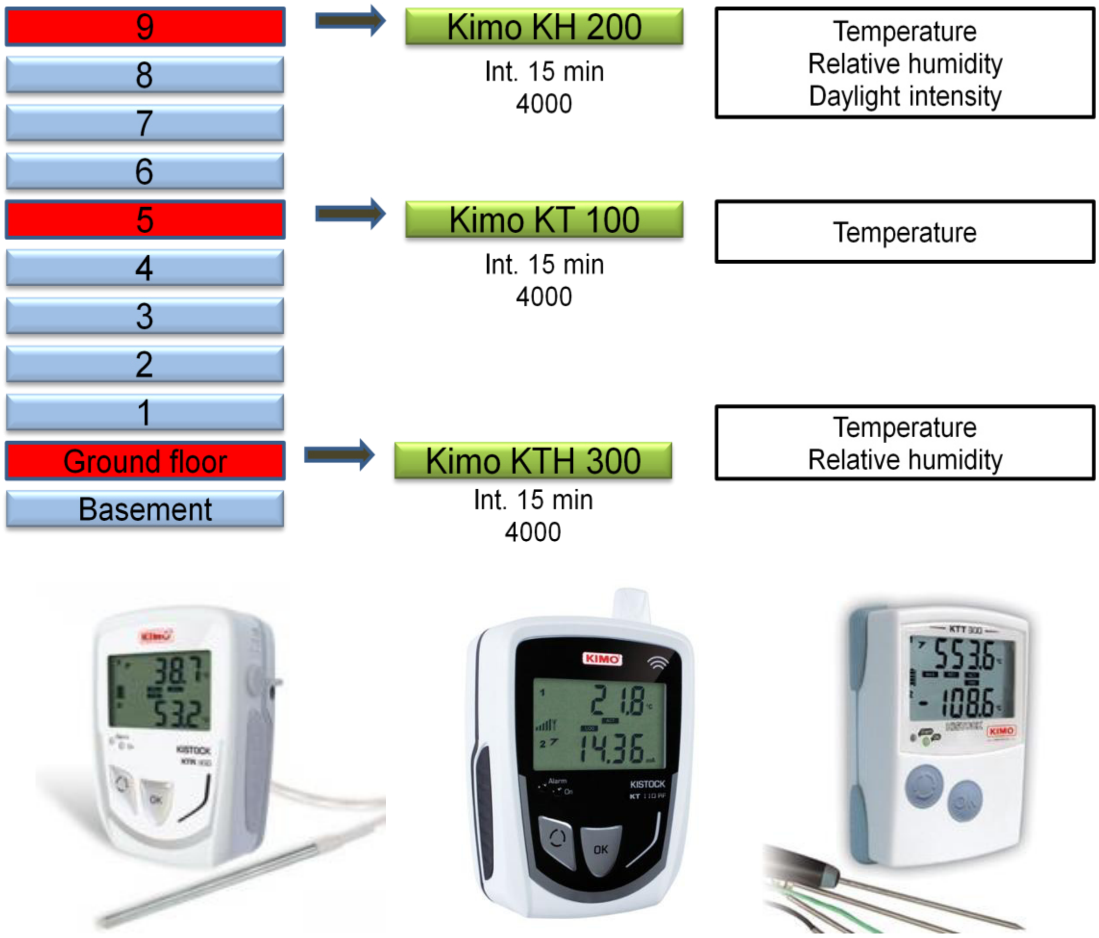


Figure II - 15 KIMO instruments setup

Summer monitoring includes a single monitoring period which consists of six weeks from the middle of July until the end of August 2014. The monitored parameters for the summer period are shown in Figures II - 29, II - 30 and II - 31.

As analyzed from Table II – 2 the heating was turned off on the 25th of January 2014 due to repairs on the district heating system. The air temperature in all offices significantly dropped due to envelope inefficiency. Air temperature dropped 10°C during 12 hours in the ground floor office, and both 5°C in offices on the 5th and 9th floor. Significant energy amount was recorded for heating from 26.01. to 05.02.2014. above 3 MWh, as framed in Table II – 2. In Figures II – 15 and II – 16 it can also be seen that this specific period when outdoor air temperature was average -5°C during daytime and average -10°C during night the incoming district heating water temperature was between 70°C and 90°C.

Analyzing the oscillation of comfort parameters from the monitored data and presented graphs it can be concluded that due to significantly high energy consumption which was recorded in the sub-station the indoor environmental standards were not satisfied in the reference building. Air temperature, relative humidity and daylight oscillations were in major intervals above or below the specified comfort parameter limits. The comfort boundaries for mean air temperature are 21-25°C, for relative humidity 25-60% (II comfort category PMV/PPD) and the minimal requirements for daylight level are 350-500 lx.

Table II - 2   Office tower building's energy consumption monitoring

Energy consumption monitoring - heating intensity Office tower building, Faculty of Technical Sciences										
Sub-station measurements (Digital-meter reading)										
No.	Date	Time [h]	Energy [MWh]	24h energy [MWh]	Water [m³]	24h flow quantity [m³]	Incoming water temp. [°C]	Outgoing water temp. [°C]	Temperature Difference [°C]	Flow rate [l/h]
1	20.01.2014.	12.00	1825	1.72	81753	115	41	32	9	4705
2	21.01.2014.	12.00	1827	1.60	81867	114	40	32	8	4712
3	22.01.2014.	12.00	1829	2.26	81982	114	61	39	22	4777
4	23.01.2014.	11.15	1832	2.56	82092	110	63	40	23	4820
5	24.01.2014.	12.00	1835	2.94	82211	119	64	39	24	4842
6	SAT 25.01.2014.	9.30	1835	0.12	82216	4	60	0	0	0
7	SUN 26.01.2014.	12.00	1840	**4.67**	82335	119	**82**	40	42	4851
8	27.01.2014.	13.00	1845	**5.36**	82457	121	**89**	47	41	4878
9	28.01.2014.	12.00	1849	**4.36**	82570	113	**83**	46	37	4935
10	29.01.2014.	12.00	1853	**4.08**	82687	116	**81**	44	36	4993
11	30.01.2014.	14.30	1858	**4.28**	82815	128	**70**	41	29	4998
12	31.01.2014.	12.00	1862	**4.28**	82927	112	**73**	41	32	4845
13	SAT 1.02.2014.	12.00	1866	**4.15**	83041	113	**75**	43	32	4856
14	SUN 2.02.2014.	12.00	1870	**3.65**	83155	114	**75**	42	33	4832
15	3.02.2014.	12.00	1874	**3.96**	83271	115	**80**	43	36	4946
16	4.02.2014.	12.00	1878	**3.97**	83387	115	**79**	43	35	4986
17	5.02.2014.	12.00	1882	**3.87**	83503	116	**71**	42	28	4957
18	6.02.2014.	13.30	1885	3.36	83629	125	56	38	18	4820
19	7.02.2014.	12.00	1887	2.51	83745	115	55	37	18	4749
20	SAT 8.02.2014.	12.00	1890	2.32	83859	114	45	32	12	4704
21	SUN 9.02.2014.	13.00	1892	1.75	83970	110	40	30	9	4698
22	10.02.2014.	12.00	1894	2.01	84076	105	50	36	14	4727

Outdoor air temperature (approx. -10°C at night, -5°C at day)
Building envelope inefficiency
Daily energy demand is above 3MWh, approx 1.25 kWh/m²/day

High incoming water temperature (between 70°C and 90°C)
Outdoor air temperature (approx. -10°C at night, -5°C at day)

Table II - 3 Office tower building's energy consumption monitoring

Energy consumption monitoring - heating intensity Office tower building, Faculty of Technical Sciences										
Sub-station measurements (Digital-meter reading)										
No.	Date	Time [h]	Energy [MWh]	24h energy [MWh]	Water [m³]	24h flow quantity [m³]	Incoming water temp. [°C]	Outgoing water temp. [°C]	Temperature Difference [°C]	Flow rate [l/h]
23	11.02.2014.	12.00	1895	1.89	84196	119	40	30	9	4756
24	12.02.2014.	14.00	1897	1.86	84315	118	40	31	9	4720
25	13.02.2014.	13.00	1900	2.32	84424	109	46	34	12	4605
26	14.02.2014.	13.00	1902	2.31	84538	114	45	34	11	4634
27	SAT 15.02.2014.	14.00	1904	2.33	84657	119	46	34	12	4655
28	03.03.2014.	12.00	1937	2.53	86462	115	55	36	19	4763
29	04.03.2014.	14.00	1939	2.59	86589	113	49	35	13	4712
30	05.03.2014.	12.00	1942	2.48	86706	117	52	32	20	4745
31	06.03.2014.	12.00	1944	2.61	86822	116	51	33	18	4810
32	07.03.2014.	13.00	1946	2.12	86937	114	48	31	17	4790
33	SAT 08.03.2014.	12.00	1948	1.80	87052	115	47	35	12	4757
34	SUN 09.03.2014.	12.00	1950	1.57	87164	112	49	35	14	4732
35	10.03.2014.	14.00	1952	2.04	87275	112	51	36	15	4749
36	11.03.2014.	13.30	1954	2.19	87386	111	46	34	11	4727
37	12.03.2014.	14.00	1956	1.97	87501	115	41	32	8	4720
38	13.03.2014.	12.00	1958	1.80	87608	106	42	34	8	4626
39	14.03.2014.	14.00	1959	1.69	87729	120	39	31	7	4720
40	SAT 15.03.2014.	12.00	1961	1.90	87847	118	40	32	7	4789
41	SUN 16.03.2014.	12.00	1963	1.75	87964	117	41	32	9	4885
42	17.03.2014.	12.00	1965	1.86	88082	117	42	32	9	4532

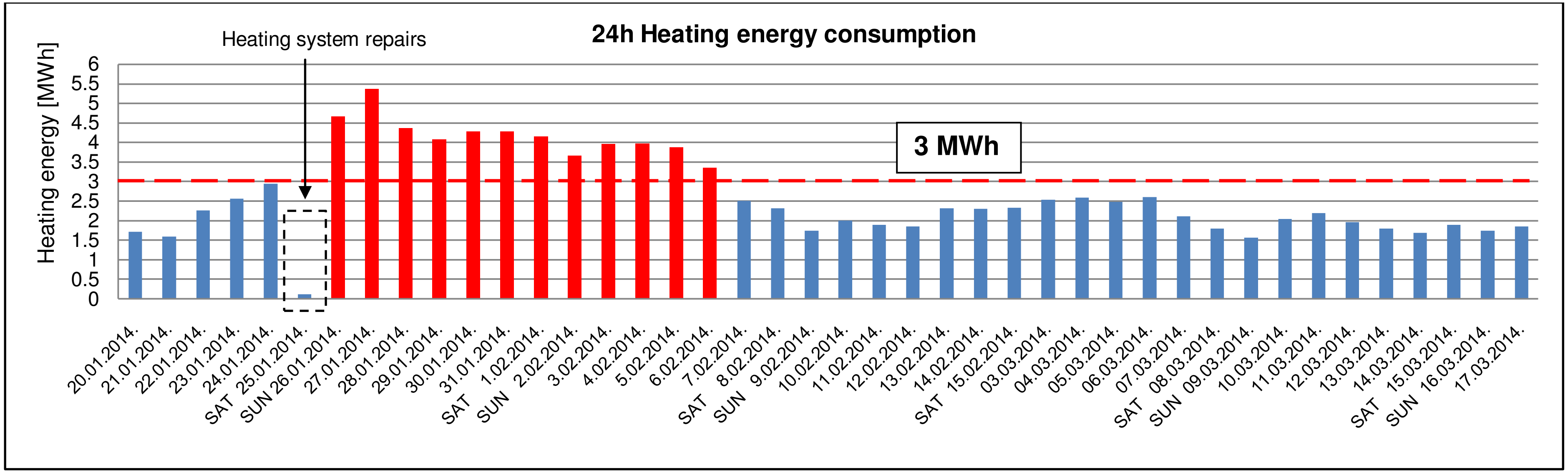


Figure II - 16 24h Heating energy consumption

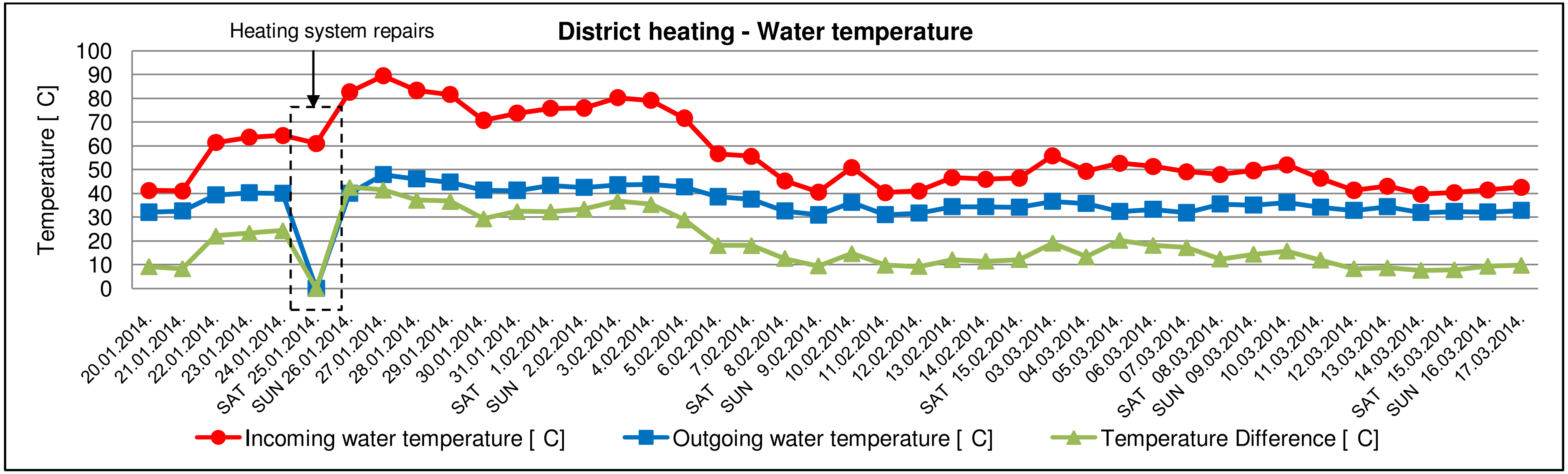


Figure II - 17 Heating - Water temperature

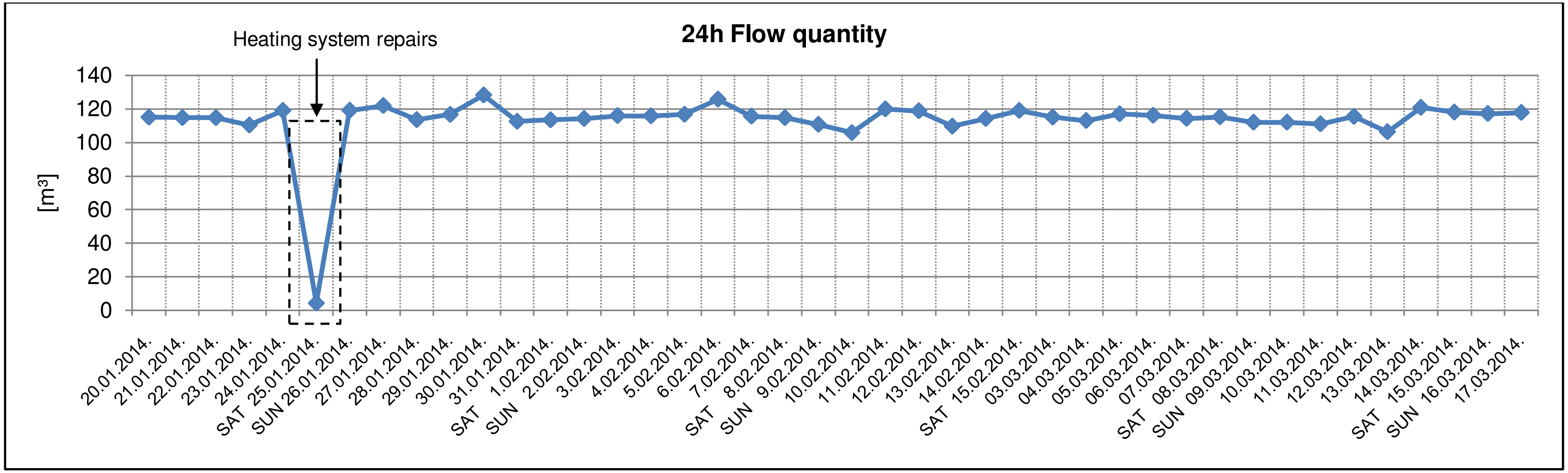


Figure II - 18 24h Flow quantity

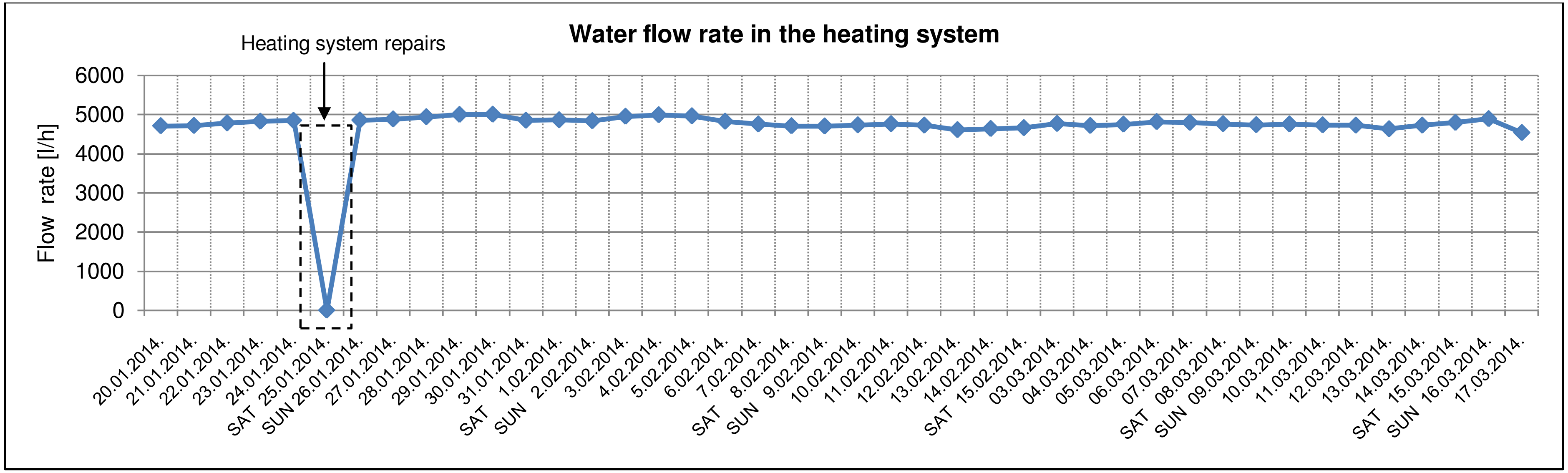


Figure II - 19 Water flow rate in the heating system

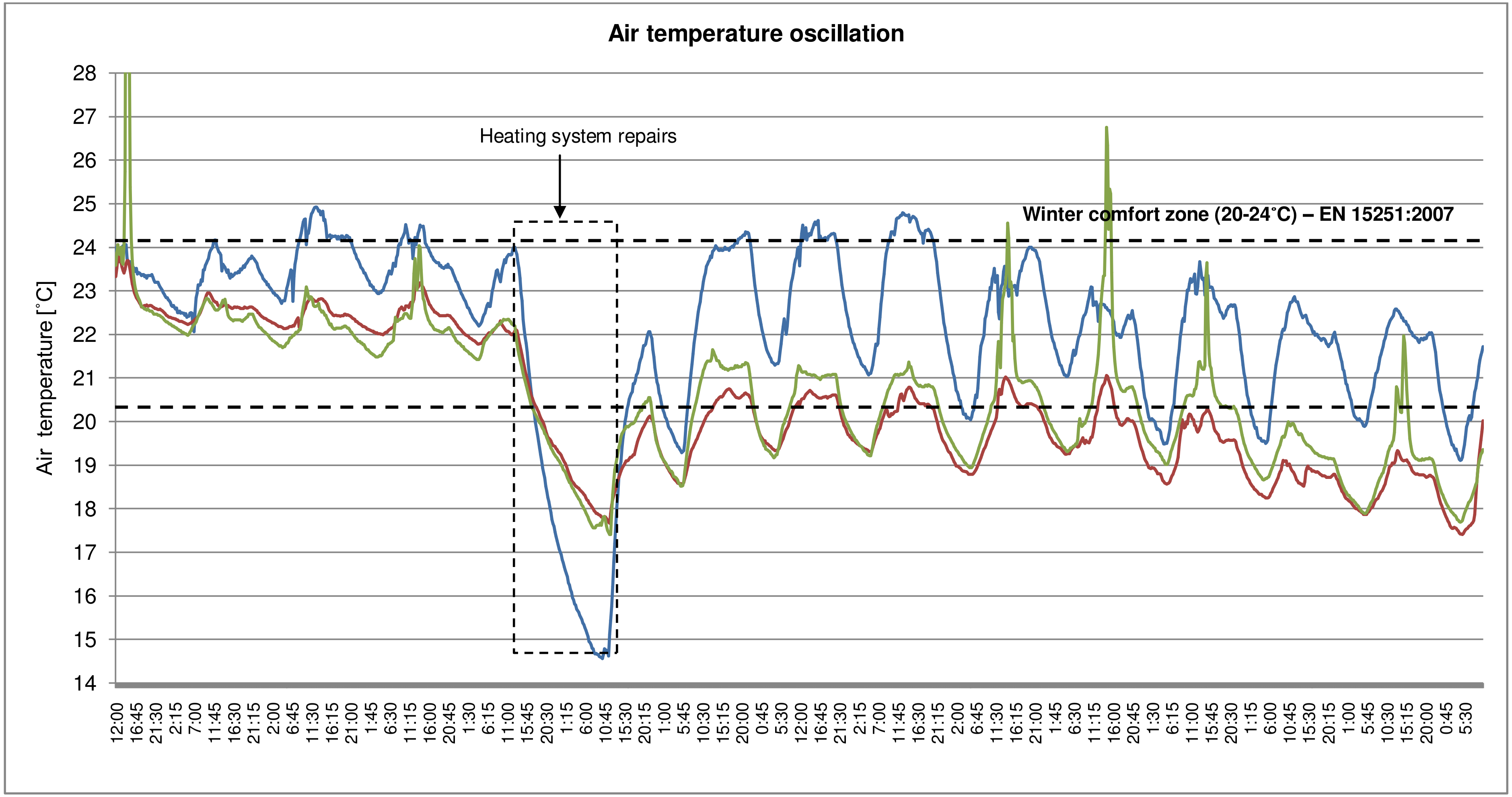


Figure II - 20 Air temperature oscillation for Period I

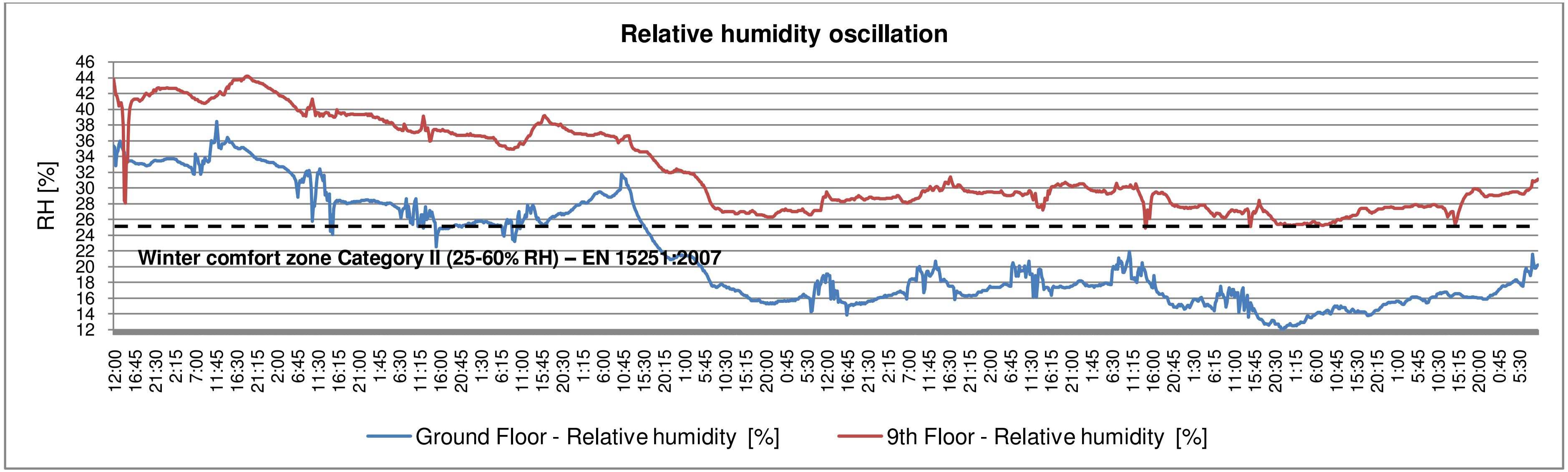


Figure II - 21 Relative humidity oscillation for Period I

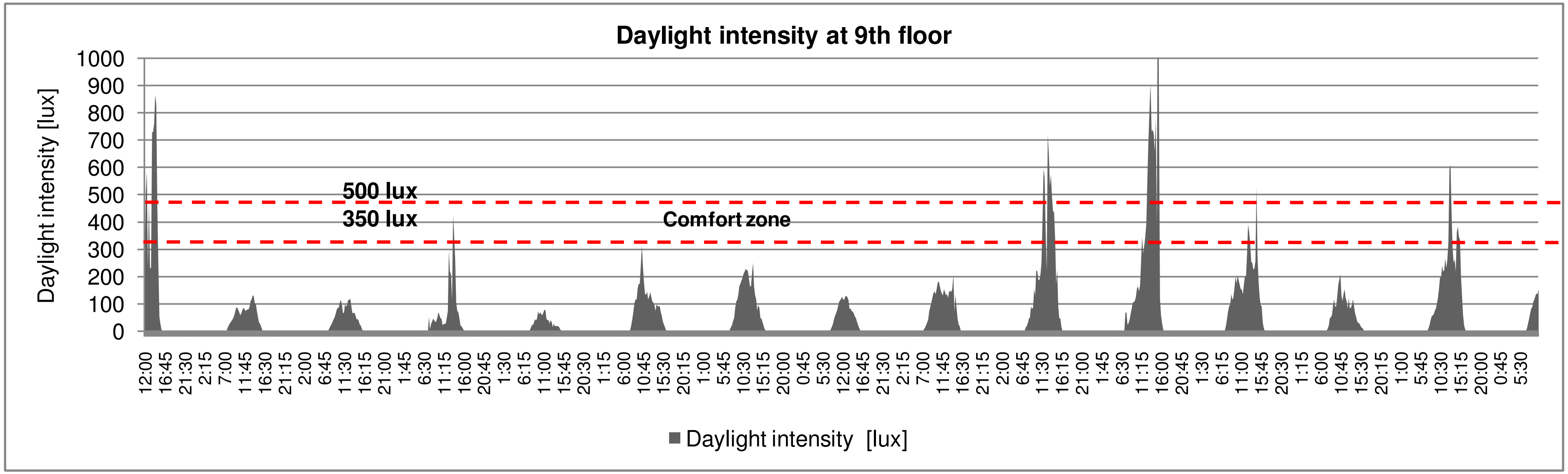


Figure II - 22 Daylight intensity at 9th floor, West orientation, for Period I

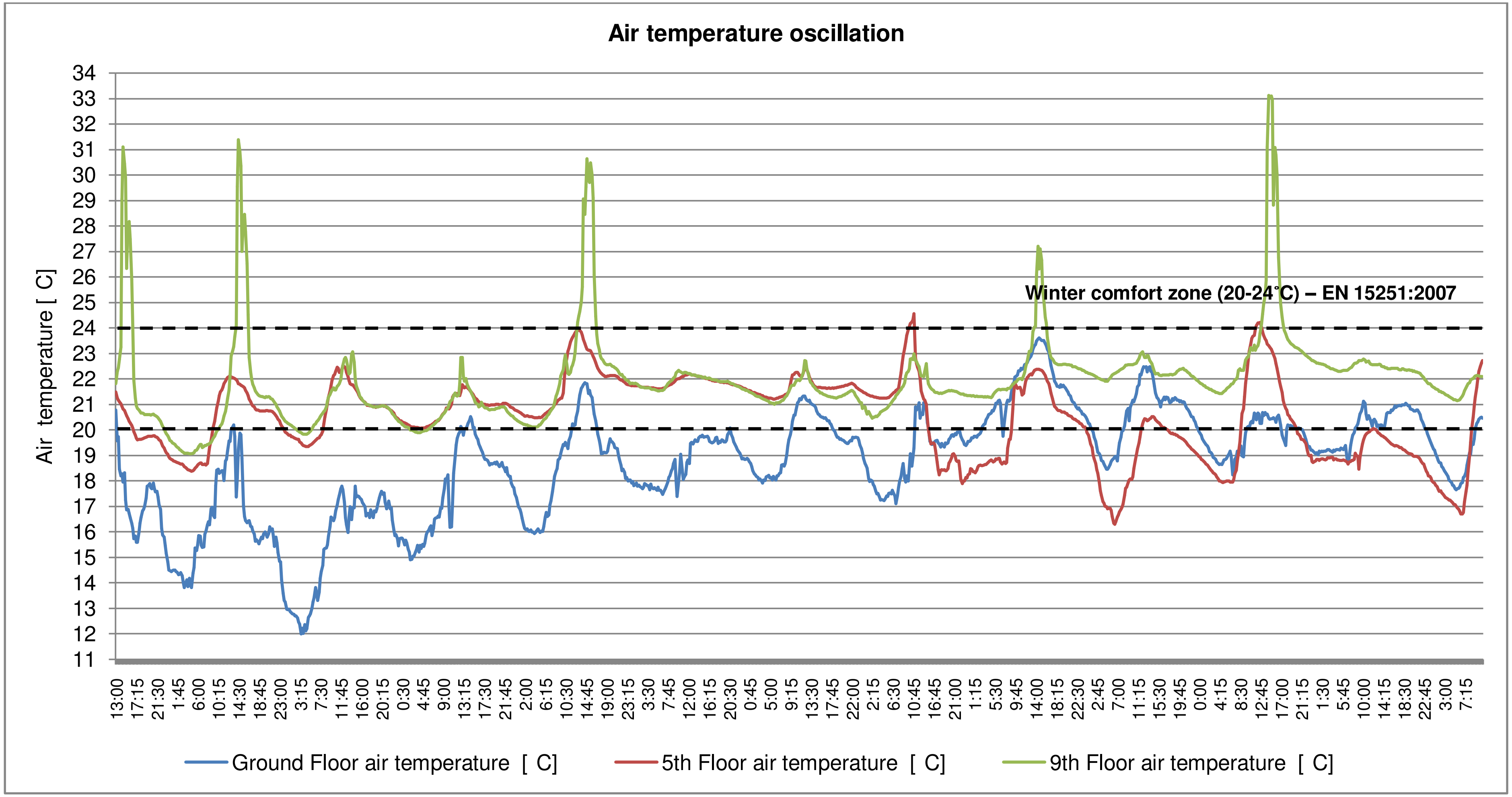


Figure II - 23 Air temperature oscillation for Period II

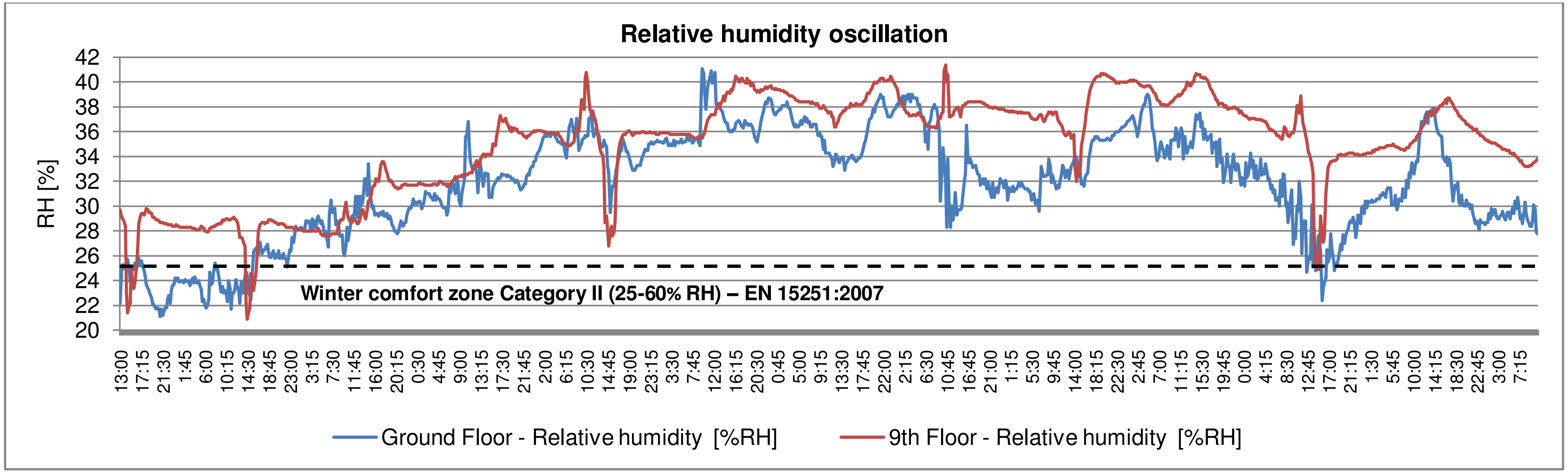


Figure II - 24 Relative humidity oscillation for Period II

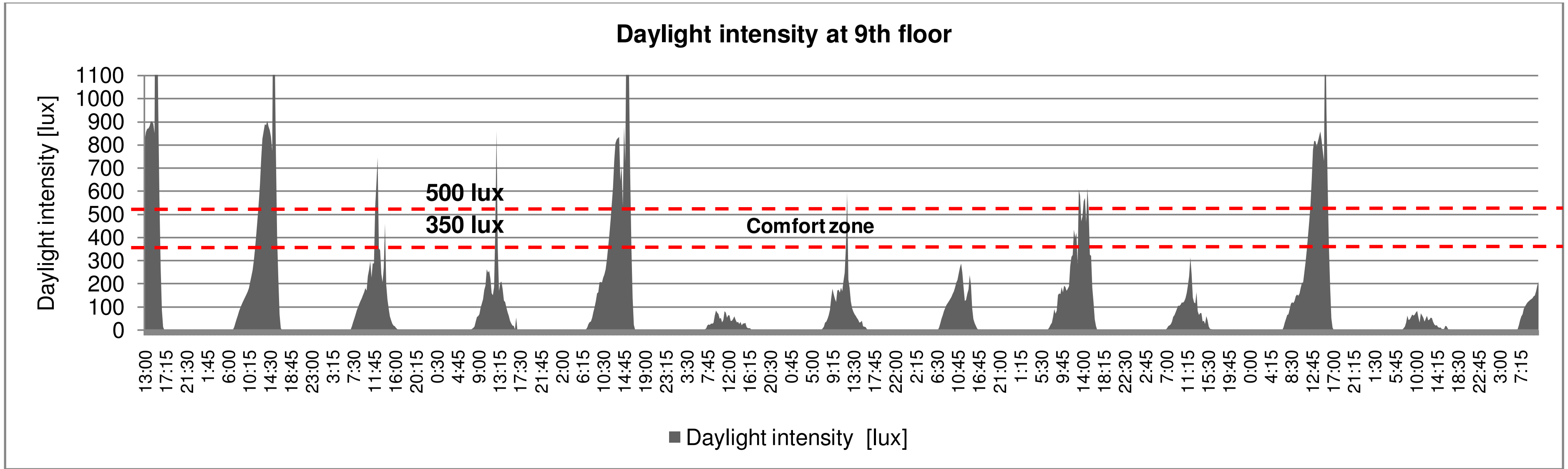


Figure II - 25 Daylight intensity at 9th floor, West orientation, for Period II

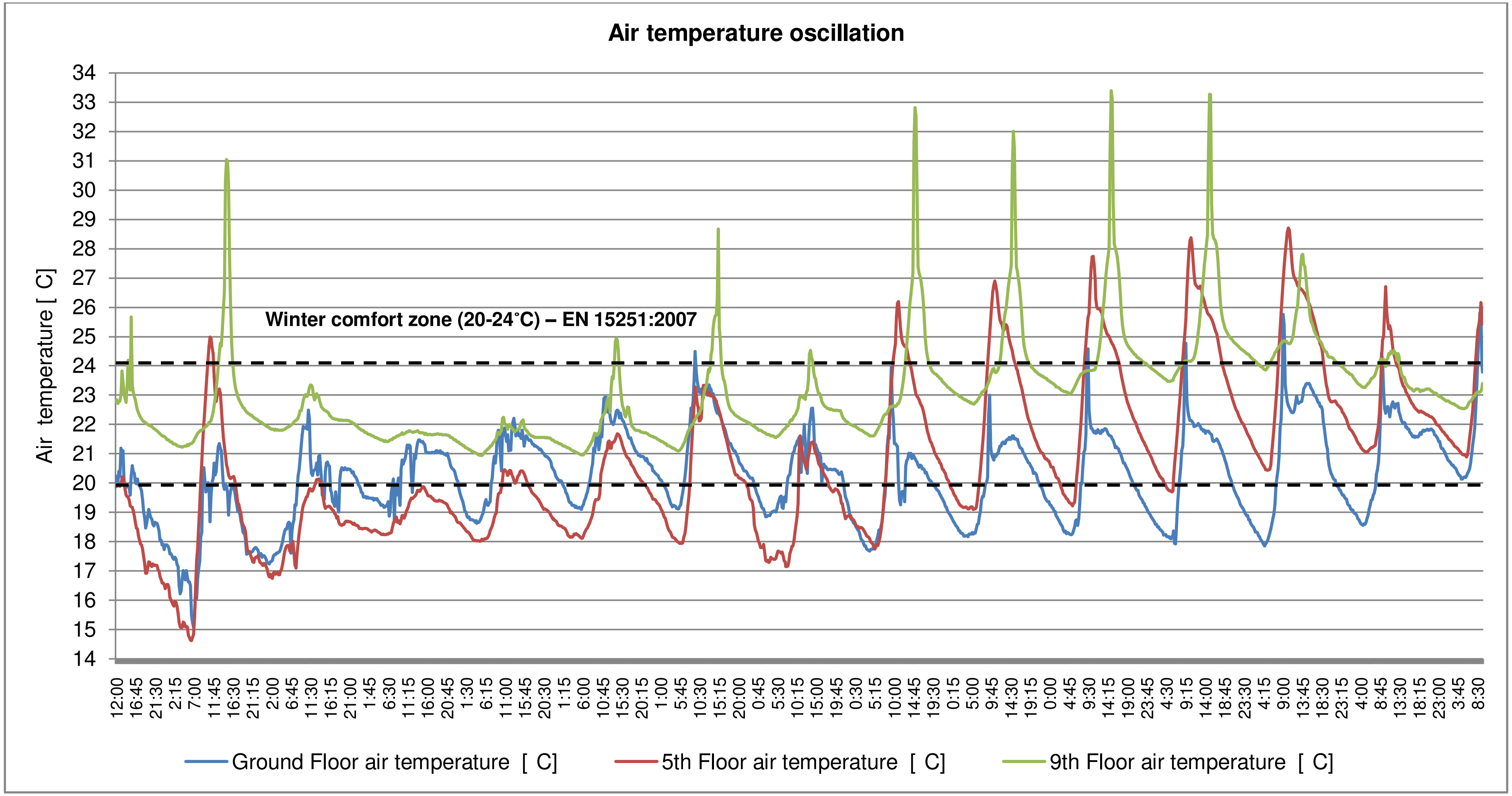


Figure II - 26 Air temperature oscillation for Period III

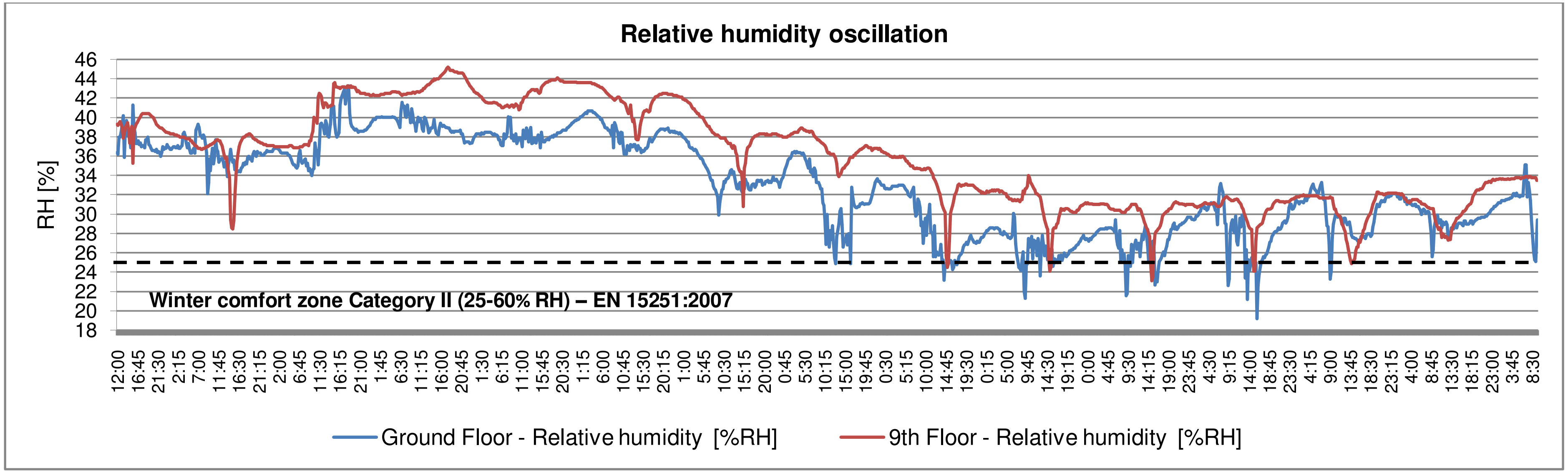


Figure II - 27 Relative humidity oscillation for Period III

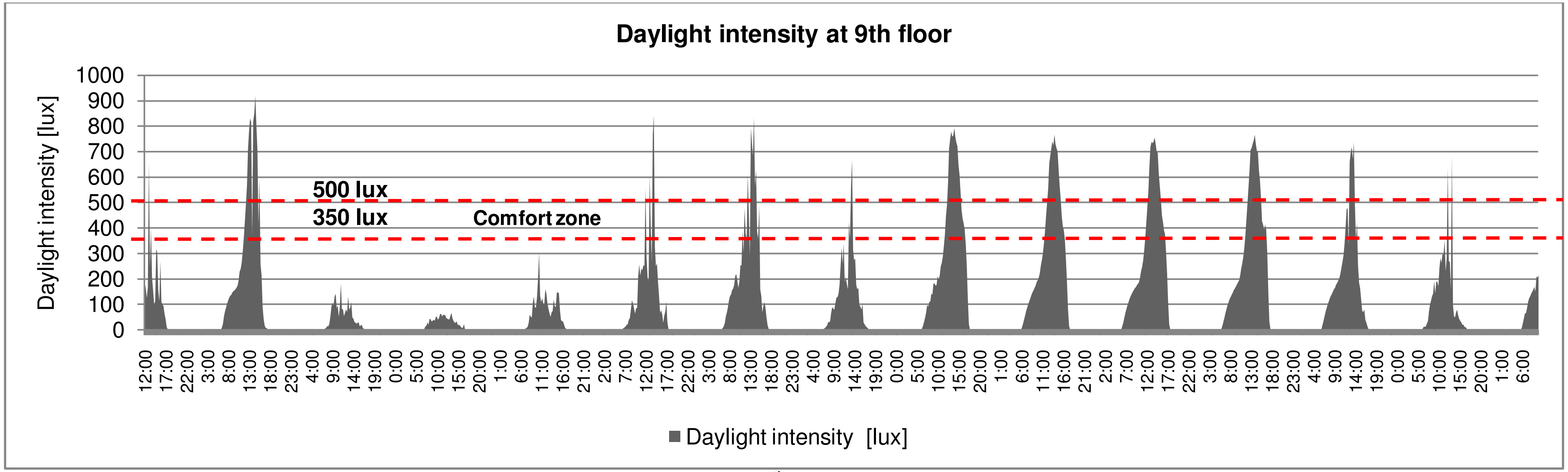


Figure II - 28 Daylight intensity at 9th floor, West orientation, for Period III

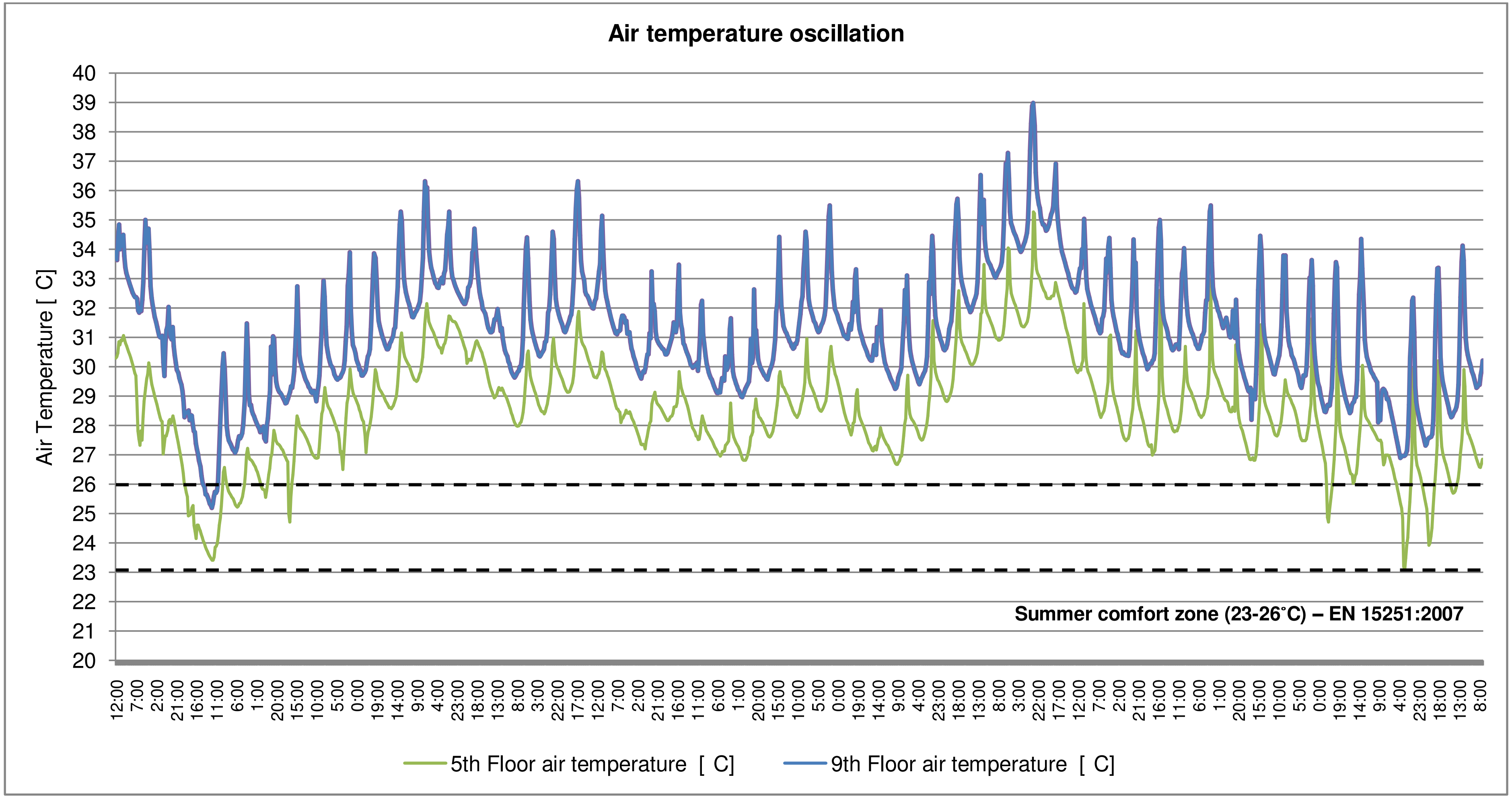


Figure II - 29 Air temperature oscillation for Summer period

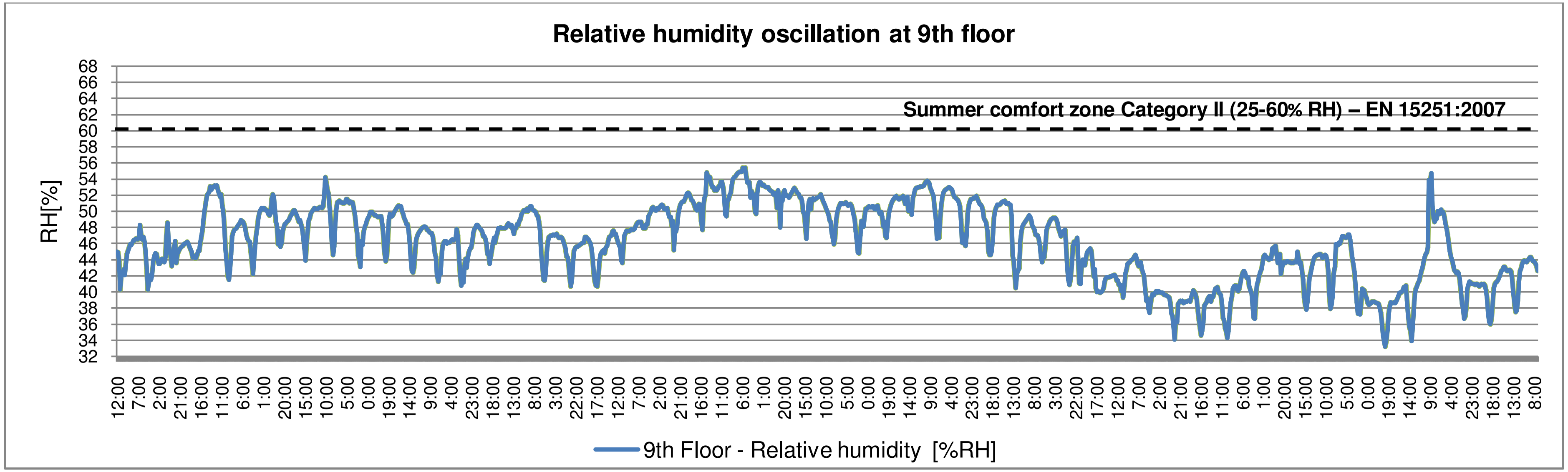


Figure II - 30 Relative humidity oscillation for Summer period

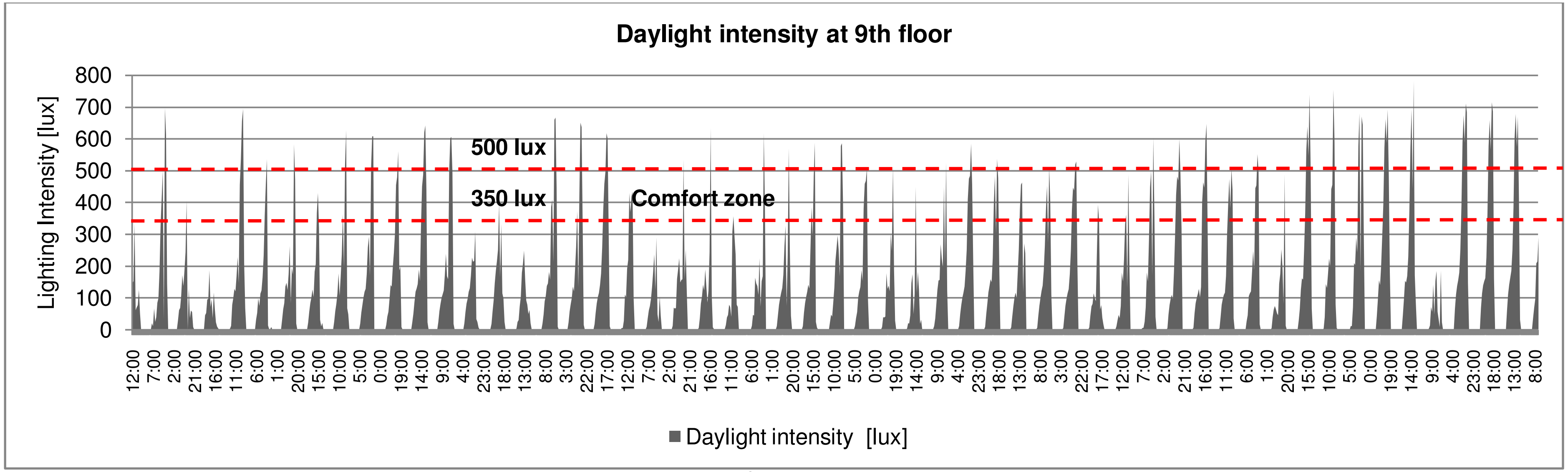


Figure II - 31 Daylight intensity at 9th floor, West orientation, for Summer period

From the winter indoor air temperature monitoring it can be concluded that during the first monitoring period, Figure II – 20, occupant comfort was mostly satisfied during occupied periods. In case of ground floor office the air temperature during work hours was in most cases close to the upper comfort limit of 24°C or slightly above. In offices on the 5th and 9th floor air temperature during working hours was in most cases close to the lower comfort limit of 20°C or slightly below. Further monitoring in winter periods II and III, Figures II – 23 and II – 26, presented continual rising of indoor air temperature oscillations. At the beginning of period II daily indoor temperature was 4°C below the lower comfort limit while with continuous rising until the end of period III indoor air temperature reached the height of 29°C, which is 5°C above upper limit. Summer monitoring presented unsatisfactory indoor environmental standards, since indoor air temperature was above the upper comfort limit of 26°C during whole monitoring period. Due to poor thermal properties of exterior walls and glazing inefficiency, air temperature in offices was in intervals from 31°C to 39°C during daytime.

From the monitoring of relative humidity it was concluded that the oscillations were mostly in intervals of the II comfort category according to EN 15251 (25-60% RH), Figures II – 21, II – 24, II – 27 and II – 30 except in the first winter monitoring period when relative humidity values were below 25%. It was also observed that relative humidity in the working environment is dependable only from outdoor conditions and occupants since the ventilation is manually controlled through opening of windows. A mechanical system for humidification and dehumidification does not exist in the reference building.

Daylight intensity monitoring presented unsatisfactory values during occupied intervals. Illumination was below and above the prescribed visual comfort limits as seen in Figures II – 22, II – 25, II – 28 and II – 31.

2.3.2. Annual energy expenses

Building energy expenses have been collected from the previous three years of 2013, 2012 and 2011. The reason of gathering annual heating energy expenses was in order to compare the recorded values with the simulated in the evaluation process. Table II - 4 shows numerical data, while Figures II - 32, II - 33 and II - 34 present annual heating energy and electricity intensities in the last three years.

The monthly energy expenses for electricity are the sum of electric lighting, equipment and electricity demand of the air conditioning units, therefore the account is issued together. From the expenses it can be concluded that the electricity demand for the reference building was equable in the last 3 years. 217 MWh (63 kWh/m^2) in 2011, 219 MWh (64 kWh/m^2) in 2012 and finally 203 MWh (59 kWh/m^2) in 2013.

Table II - 4 Annual energy consumption

Annual energy consumption – annual heating and electricity Office tower building, Faculty of Technical Sciences							
no.	Month	2011		2012		2013	
		Electricity [kWh]	Heating [kWh]	Electricity [kWh]	Heating [kWh]	Electricity [kWh]	Heating [kWh]
1	Jan	19099	82306	19158	115993	19214	81610
2	Feb	18376	95210	14544	63473	17478	76527
3	Mar	18595	70106	21141	42323	18519	55891
4	Apr	16918	31934	15870	1415	16918	52467
5	May	16486	/	16411	/	14375	/
6	Jun	17519	/	19203	/	16706	/
7	Jul	17947	/	20164	/	17078	/
8	Aug	16707	/	18402	/	16652	/
9	Sept	18541	/	17014	/	14113	/
10	Oct	18009	18580	18883	9551	17245	21980
11	Nov	19124	63268	18922	45003	15282	30005
12	Dec	20398	80788	20111	61030	20230	60304
SUM		**217719**	**442192**	**219823**	**338788**	**203810**	**378784**

The energy expenses for heating were significantly high due to envelope's thermal inefficiency and the district heating systems hydraulic imbalance in the building. Therefore the energy consumption for heating resulted in 442 MWh (128 kWh/m^2) in 2011, 338 MWh (98 kWh/m^2) in 2012 and 378 MWh (110 kWh/m^2) in 2013.

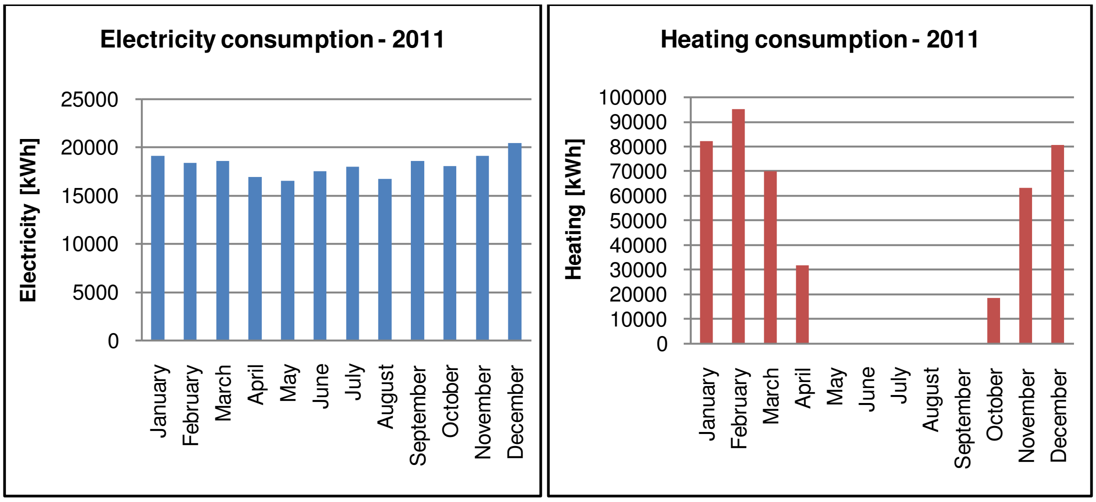


Figure II - 32 Electricity and heating energy consumption from 2011

Monthly electricity consumption from 2011, Figure II – 32 left, presented uniform expenses throughout the year between 16-20 MWh. Heating energy expenses presented the highest value (95 MWh) in February, due to a cold winter period, Figure II – 32 right. January and December had same expenses.

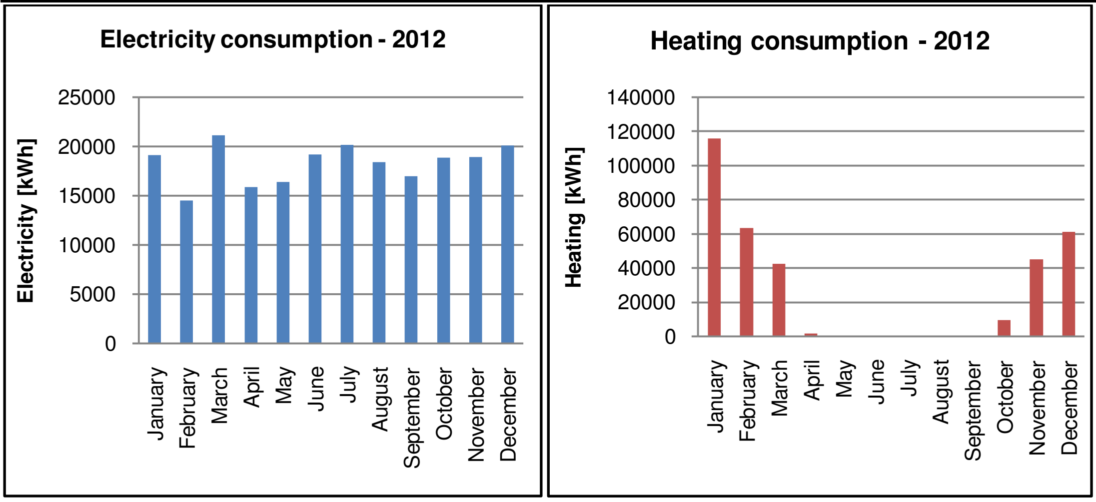


Figure II - 33 Electricity and heating energy consumption from 2012

Monthly electricity consumption from 2012, Figure II – 33 left, presented more deviation in electricity expenses compared to 2011. The deviation was between 14-21 MWh monthly. Heating energy expenses presented drastically lower values according to 2011, Figure II – 33 right. Annual total energy demand is 25% lower in 2012 compared to previous the year.

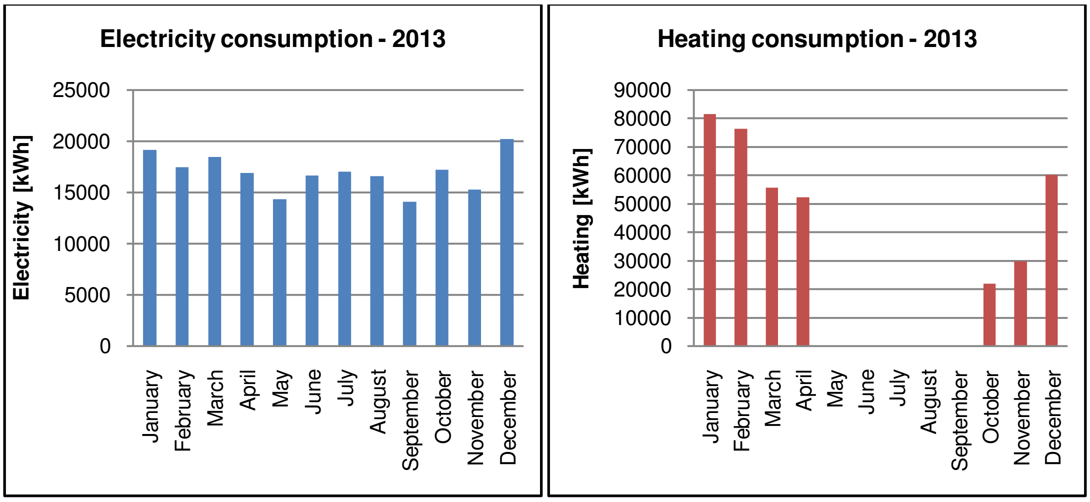


Figure II - 34 Electricity and heating energy consumption from 2013

Monthly electricity consumption from 2013, Figure II – 34 left, was in intervals between 14-20 MWh. Heating energy expenses presented higher values according to 2011, Figure II – 34 right.

Chapter 3

CAD building model, WWR & WG analysis and illumination simulation

3.1. Overview of the research topic

The research topic considering indoor illumination has been investigated in numerous papers via simplified models, daylight coefficient concept, window properties, building orientation, indoor space definition, passive technology application etc. The papers provided a qualitative overview in the research field of daylight analysis in architecture and gave useful scientific results and research methodology considering illumination analysis. (Li, Cheung and Lau 2006) (Dogrusoy and Tureyen 2007) (Li and Tsang 2005) (Mayhoub and Carter 2011) (Konis 2013) (Nabil and Mardaljevic 2006) (Leskovar and Premrov 2011) (Kim and Todorovic 2013) (Thalfeldt, et al. 2013) (Ochoa, et al. 2012) (Goia, Haase and Perino 2013) (Li 2010) (Ünver, et al. 2004) (O'Brien and Athienitis 2013) (C. E. Ochoa, et al. 2011) (Fanchiotti and Amorim 2001) (Didone and Pereira 2011)

3.2. Design of baseline CAD building model

The modeling process starts with the formulation of a Computer-aided design (CAD) model of the reference office tower building. The representation of the building model for Window to wall ratio (WWR) and window geometry (WG) analysis and illumination simulation requires a solid 3D geometry model designed in a BIM program were the model information can be exported in DXF format. As elaborated in the second section Autodesk Revit Architecture[5] will be used for model creation, as it allows the user to design the building structure and its components as a 3D geometric model. According to the gathered technical documentation and measurements' from the site the CAD model was created for a single floor. Since

[5] Autodesk Revit Architecture 2012, License: Type; Standalone-Locked, ID; REVIT_F_S, Expiration; 02.04.2016., Student version

the reference office building is freestanding and the surrounding buildings do not affect the environment by shading the reference building's exterior glazing one single level could be modeled. The CAD model of a single floor is rotated precisely as the whole building and has four orientations. A representation of the created baseline CAD model is presented in Figure III - 2. The number of CAD models was defined by the WWR and WG combinations for which the simulations were performed. The models and their properties will be elaborated in further text. The CAD geometric building model for WWR and WG analysis was created by using basic construction elements which are predefined in Autodesk Revit Architecture. Building elements in Revit are shown in the ribbon with editable properties, Figure III- 1.

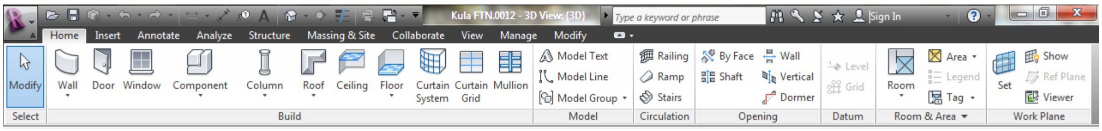


Figure III - 1 Building elements ribbon in Revit Architecture

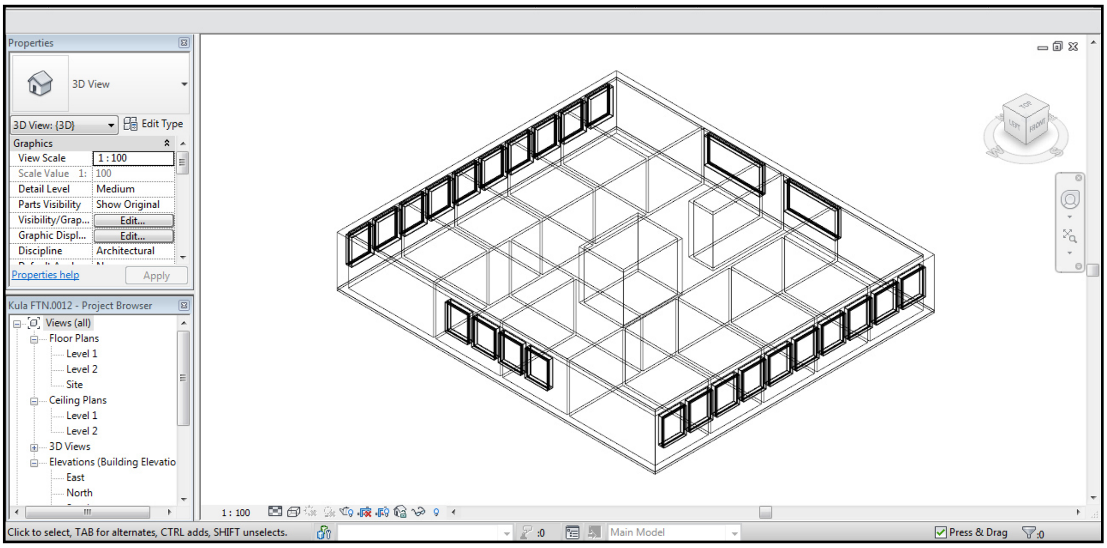


Figure III - 2 CAD geometry model, single floor – Office tower building

In the case of the CAD geometric model construction for WWR and WG analysis, the construction materials of walls, floors and ceilings did not have to be assigned since the illumination analysis in not affected by the material properties of these elements. The parameter which affects the distribution of rays is the However it was important to assign the properties of the glazing, since the interior illumination is affected by:

- Material properties of glass panel
- Low emission layer, and
- Reflective layer

Glazing properties for the simulation and analysis of illumination was assigned in Autodesk Ecotect Analysis where the simulation was calibrated.

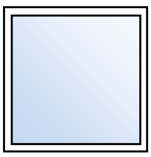
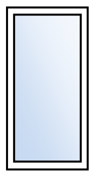
3.3. Analysis and simulation of building envelope performance in the function of visual comfort

3.3.1. WWR and WG

Visual comfort is only one of the previously specified criteria's to achieve occupant comfort in buildings. The quality of daylight is of great importance in office buildings since it affects the environmental comfort of occupants, improves the work environmental quality and does not affect the health and productivity. Furthermore the building envelope's glazing ratio - WWR affects the total annual energy demand for heating and cooling. Nevertheless the WWR influences the visual comfort quality in offices if designed in performable boundaries.

This Section will elaborate the dispersion of daylight in offices in the function of WWR and WG. Detailed simulations will be performed in order to analyze the illumination distribution in offices for four orientations for the reference office tower building. Glass visible transmittance factor of light is defined in the simulation, while it affects the amount of transmitted solar rays. The visible transmittance (VT) is an optical property that indicates the fraction of visible light transmitted through the window. Many modern windows include spectrally selective coatings that can allow different amounts of visible, infrared and ultraviolet light. In Section 5 the dissertation will elaborate the significance of glass material properties and window construction properties on the annual heating and cooling energy demand. VT theoretically varies between 0 and 1. Most values among double- and triple-pane windows are between 0.30 and 0.70. The higher the VT, the more light is transmitted, desirable to maximize daylight (Efficient Windows 2014). The reflectivity and roughness of material surfaces affects the ray dispersion and reflectance in the indoor environment. However the heating and cooling energy demand of an office building is mainly influenced by the U-value of glass and the Solar Heat Gain Coefficient factor. The research involves the analysis of glazing geometry - WG as a significant criterion of envelope optimization from the visual comfort aspect. Indoor illumination dispersion is analyzed for three geometric shapes as presented in Table III - 1.

Table III - 1 Window geometries applied for the building envelope analysis

Square (SQ)	Horizontal rectangle (HR)	Vertical rectangle (VR)
a x a 	a x b 	a x b 

The specified WG from Table III - 1 were applied for five WWR's considering offices separately; 20 %, 25 %, 30 % and baseline model's 50 % and 80 %.

From the conducted on-site daylight intensity monitoring it was concluded that the 50 % WWR with clear glass does not meet the visual comfort standards in offices.

The instruments have recorded high daylight levels during the working hours when the sky was clear. In contrary, during cloudy periods the daylight intensity was below the visual comfort limits.

The selected WWR and WG for which the simulations were run are presented in Table III - 2 below. The solar ray dispersion was simulated on an annual basis for different sky conditions which is explained in details in the following paragraph. According to the five WWR values eleven WG surfaces were generated of which the 50 % and 80 % WWR are part of the reference office building. For the WWR values separately, ten CAD models were created to investigate the daylight intensity interval and indoor daylight dispersion.

Table III - 2 WWR and WG properties

WWR [%] Single office exterior wall surface 8.96 m^2	Single office glazing surface [m^2]	Single window surface [m^2]	Single window geometry (WG) [m x m]
50 (Baseline model)	4.48	2.24	1.4 x 1.6
20	1.79	0.89	SQ 0.94 x 0.94 HR 1.40 x 0.64 VR 0.60 x 1.49
25	2.24	1.12	SQ 1.05 x 1.05 HR 1.40 x 0.80 VR 0.60 x 1.86
30	2.68	1.34	SQ 1.16 x 1.16 HR 1.40 x 0.96 VR 0.60 x 2.20
80 (Baseline model)	7.17	3.58	SQ / HR / VR 1.40 x 2.55

3.3.2. CAD building model and data conversion

3.3.2.1. CAD building model and format conversion

Ten separate CAD building models were created in Revit Architecture as separate 3D single floor models according to the previously specified WWR and WG values. For physically accurate and comprehensive lighting analysis, Ecotect can output RAD scene files data for direct input into the Desktop Radiance Lighting Simulation Software (Ward 2013). The modeling methodology and data conversion with program compatibility is presented in Figure III - 3.

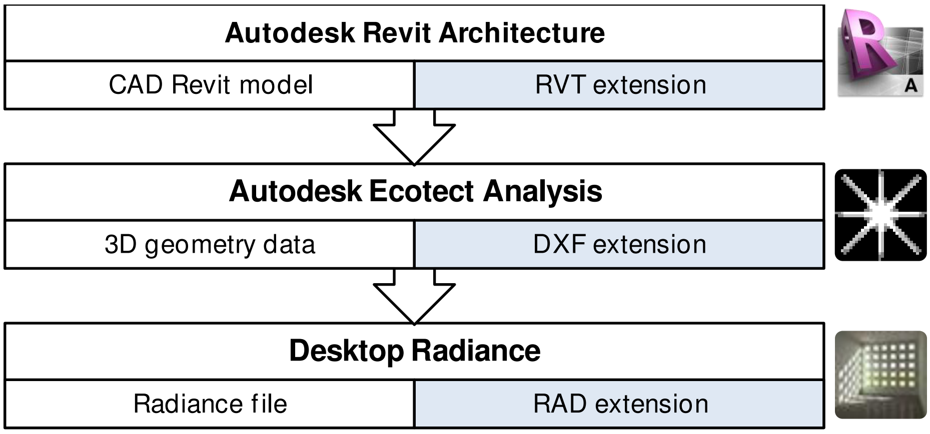


Figure III - 3 Modeling methodology and data conversion for illumination simulation

The Revit CAD model with RVT extension has to be converted into 3D geometry data with DXF extension in order to be importable into Ecotect Analysis program (Harmati and Magyar (no. 3) 2014). The selection of exporting exchange files in Revit Architecture is presented in Figure III - 4. The options of the exported files are set in the "export file" window. Location- orientation-, and climate-data were imported for the location of Novi Sad and material surface properties were assigned to the geometric analysis model. The lighting intensity assessment was conducted via advanced simulation for detailed analysis. Glazing properties, indoor and outdoor environment, and illumination were set up in Desktop Radiance (Harmati and Magyar (no. 3) 2014).

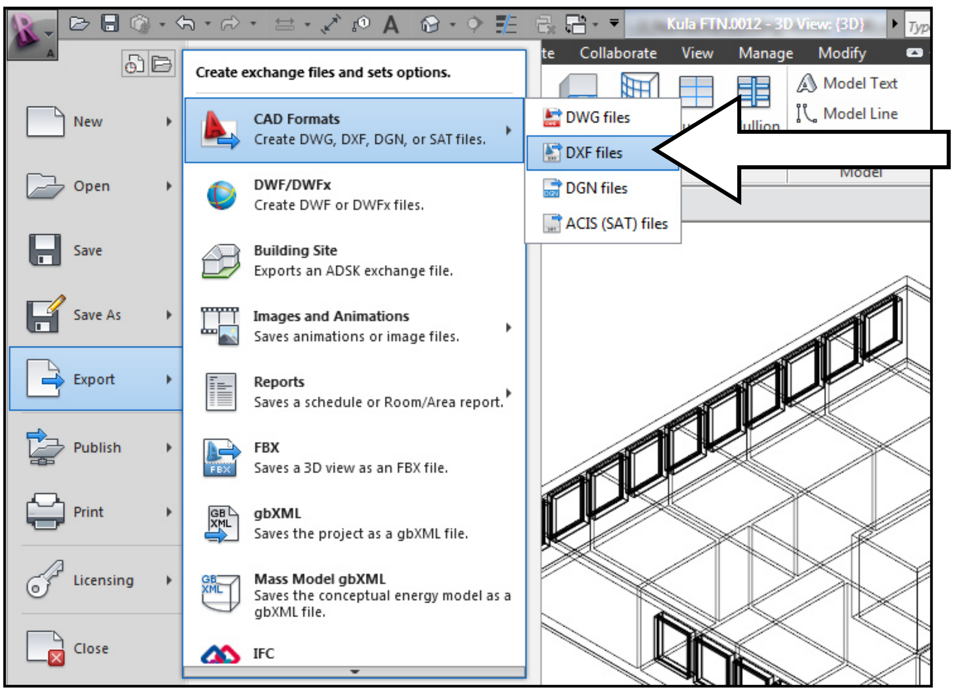


Figure III - 4 Exchange files from RVT to DXF

3.3.2.2. Model preparation for simulation in Desktop Radiance

The previously exported DXF file is imported into Ecotect Analysis where in the first window "Import Geometry" materials are needed to be defined according to the elements, Figure III - 5. Further, it is important to mark the automatic merging of triangles to avoid certain errors during the simulation. After confirmation of the setup the coincident surfaces will be automatically merged into rectangles.

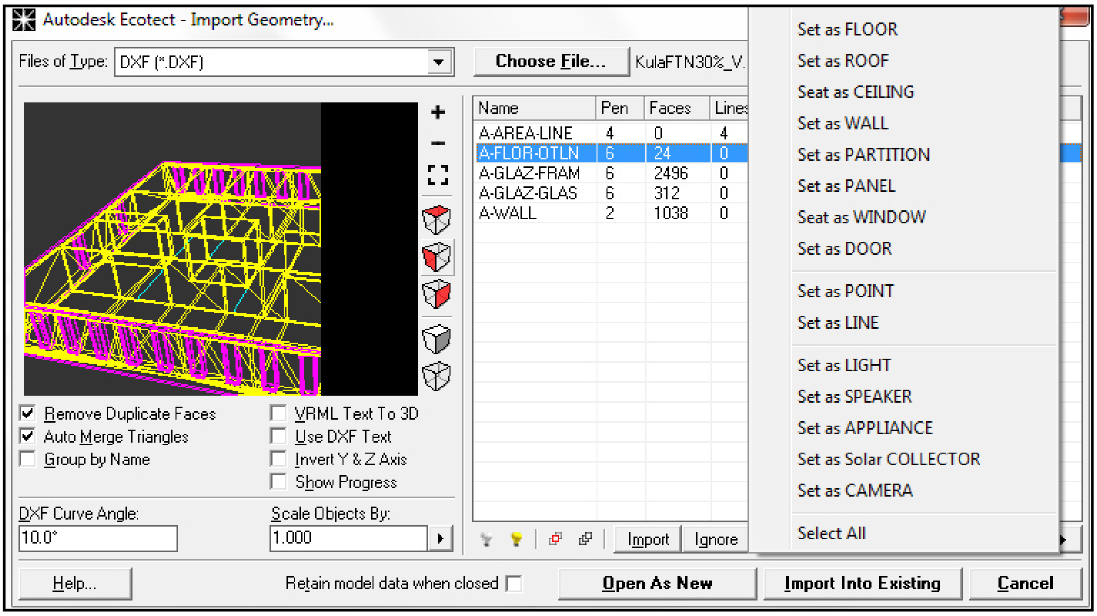


Figure III - 5 Importing DXF file into Ecotect Analysis

The imported DXF file is shown in Figure III - 6, where the orientation and wide angle camera views are set up for the output results from Radiance.

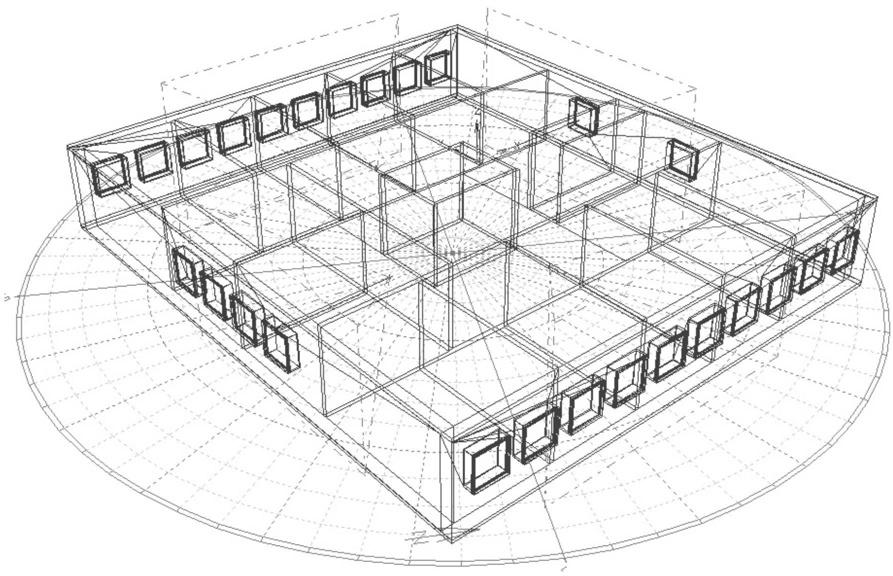


Figure III - 6 Imported DXF model in Ecotect Analysis

The DXF model imported into Ecotect Analysis for advanced solar analysis has to overcome a process of information implementation considering surface roughness and glazing material properties. Surface roughness affects the reflection of rays in the indoor environment and the glazing properties visible transmittance coefficient determines the percentage of light entering the building.

3.3.2.3. Calculation setup for illumination simulation in Radiance

The illumination simulation and image rendering was conducted via detailed setup in Radiance Control Panel (CP). The simulation setup was carried through 9 steps, which are divided in 5 major categories:

1. Exporting the DXF file to Radiance calculation wizard;
2. Radiance analysis setup;
3. Camera views and ambient light levels;
4. Calculation accuracy setup;
5. Exporting to Radiance CP – overview.

Detailed simulation setup is presented in Figure III - 7 for each category, with the overview window in Figure III - 8.

Exporting the DXF file to Radiance setup
Calculate > Lighting Analysis > Export to Radiance for more detailed analysis

↓

Radiance analysis setup
Illuminance image > Open Radiance CP > Luminance distribution, sky condition selection > Use Ecotect's Sun angle and design sky

↓

Camera views and ambient light levels
Interior views > Image size > View generator > Select camera views

↓

Calculation accuracy setup
Model detail > Lighting variability > Image quality

↓

Export to Radiance CP
Overview of: output options, sky definition, material definition, RIF file

Figure III - 7 Calculation setup for export to Radiance CP

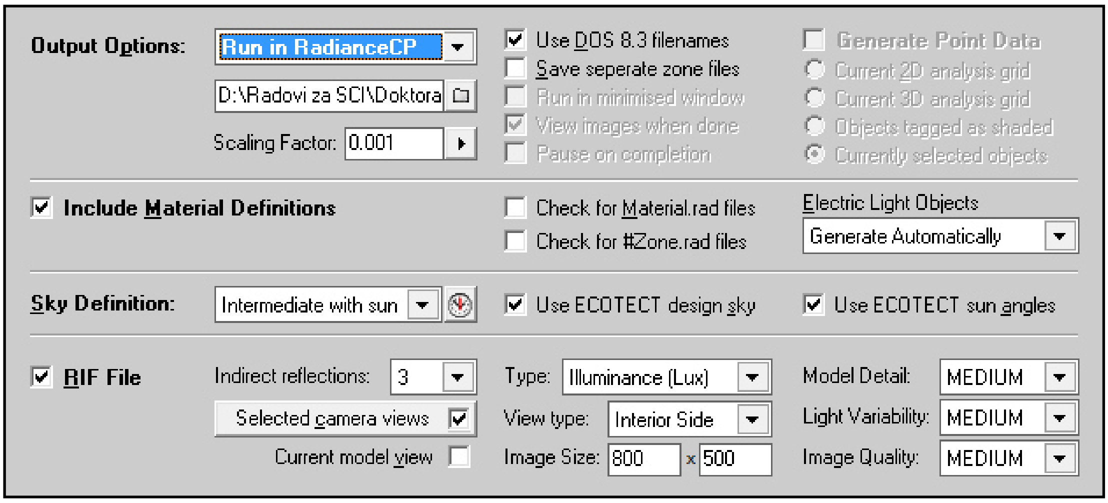


Figure III - 8 Setup overview prior to Radiance CP export

After the completion of the setup from Figure III - 8 the detailed setup and functions are controlled in Radiance CP, as shown in Figure III - 9. The rendering setup, camera views and image/material/system control are verified and supplemented. The rendering setup can be modified depending on the calculation accuracy and imported parameters.

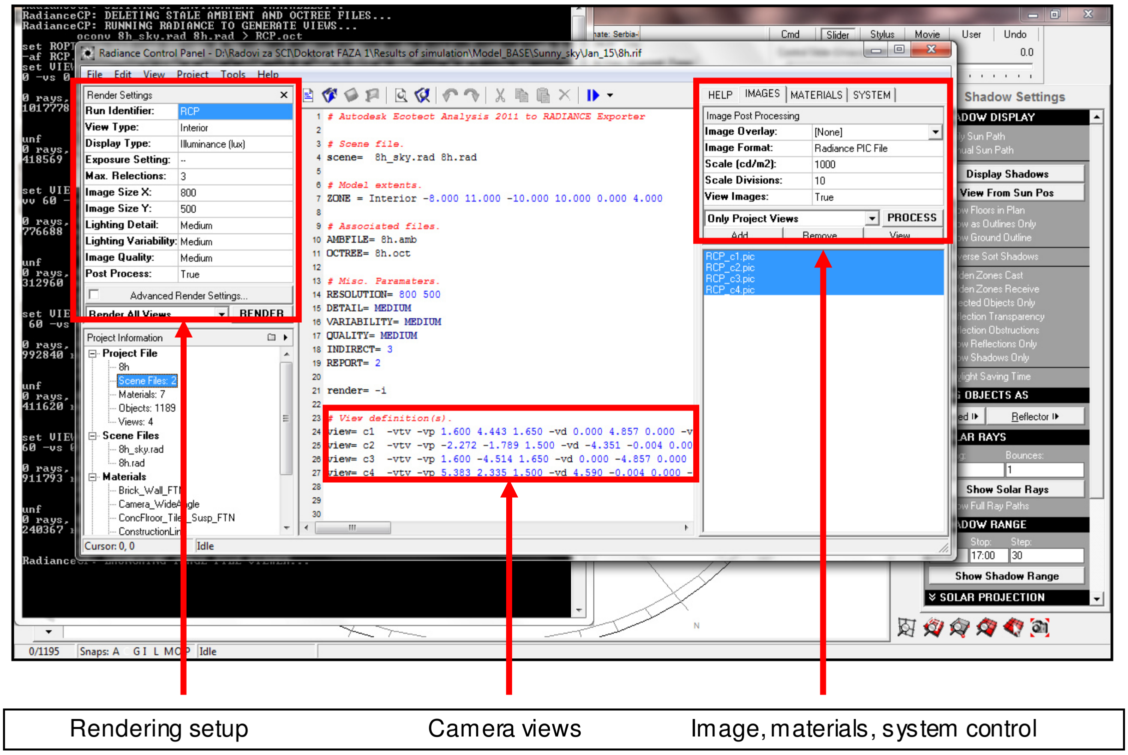


Figure III - 9 Rendering setup in Radiance CP

The rendering settings for the simulation are presented in Table III - 3 below. Interior daylight dispersion was simulated using 3 reflections with medium lighting detail and image quality. Simulated illumination scale was set from 0-1000 lx.

Table III - 3 Radiance CP rendering setting

Render settings		Illumination scale
Run identifier	RCP	
View type	Interior	
Display type	Illuminance [lx]	
Max. Reflections	3	
Lighting detail	Medium	
Lighting variability	Medium	
Image quality	Medium	
Scale	1000	
Scale division	10	
Image format	Radiance PIC file	

3.3.3. WWR & WG simulation and results

The simulations for WWR and WG were conducted on an annual basis with all possible combinations for the predefined geometries and glazing percentages.

In order to run multiple simulations 4 primary 3D models with different WWR values were created in Revit Architecture with 20%, 25%, 30% and baseline 50%, 80% glazing per single office, as presented in Figure III - 10 below.

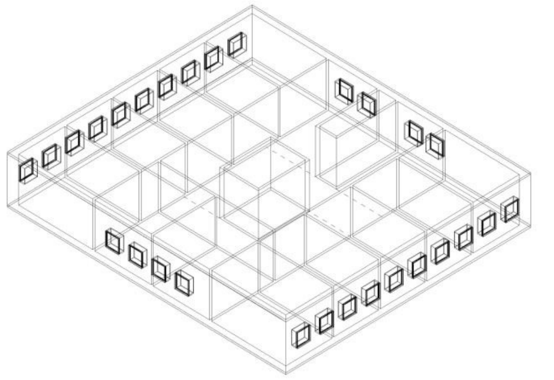
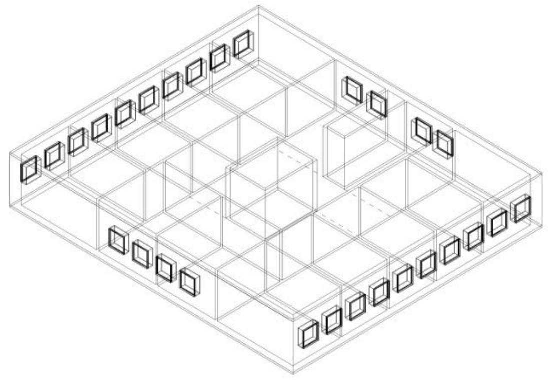
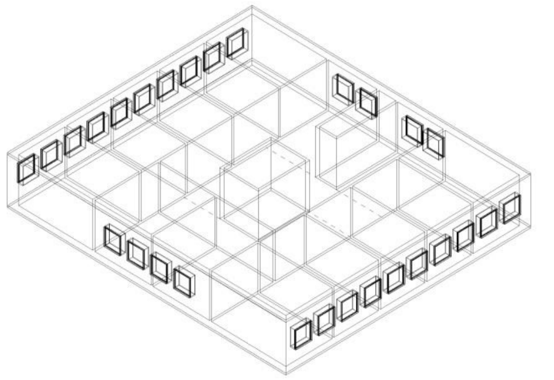
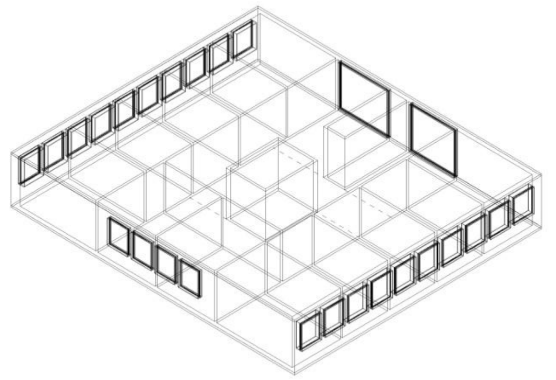
	
20% WWR	25% WWR
	
30% WWR	50% WWR per offices, 80% WWR per corridor

Figure III - 10 Primary 3D models

Afterwards three glazing geometries were applied for the 4 primary models. Horizontal rectangular windows, vertical rectangular windows and square windows were designed for the exterior envelope of the baseline building. The total number of models used in the simulations was 10.

3.3.3.1. Daylight intensity and daylight dispersion analysis

The daylight intensity analysis and daylight dispersion required numerous simulations which depended on the analyzed period, time, sky conditions and zone orientation. The period setup for the simulation was the 15^{th} of every second month on an annual basis. The months included in the simulation starting from the 15^{th} of January are March, May, July, September and November. The implemented sky condition for January was cloudy sky, for March was intermediate sky and for September sunny sky parameters were used. The simulation was conducted within intervals of 4h to determine the daylight intensity in offices at 8.00h, 12.00h and 16.00h. WWR analysis was performed in accordance with visual comfort / lighting intensity boundaries in office buildings. Visual comfort is satisfied if the lighting intensity holds a constant value between 350 and 500 lx throughout the occupied schedule, which is set from 8.00 to 16.00h. The lighting quality is demonstrated through daylight dispersion and intensity analysis. The number of conducted simulations was 720, as summarized in Table III - 4.

Table III - 4 Number of simulations performed

3D models	Months	Time	Orientation	Simulation no.
10	6	3	4	**720**

Window frames were disregarded in the simulations. Prior to the beginning of 720 simulations a short annual run-time 3D simulation was performed for a single level in order to determine whether the transparent glass materials were assigned correctly. The results of the simulation, Figure III - 11, expressed the annual average lighting levels for the reference building including four orientations where the illumination level was set from 0 to 900 lx in steps of 50 lx.

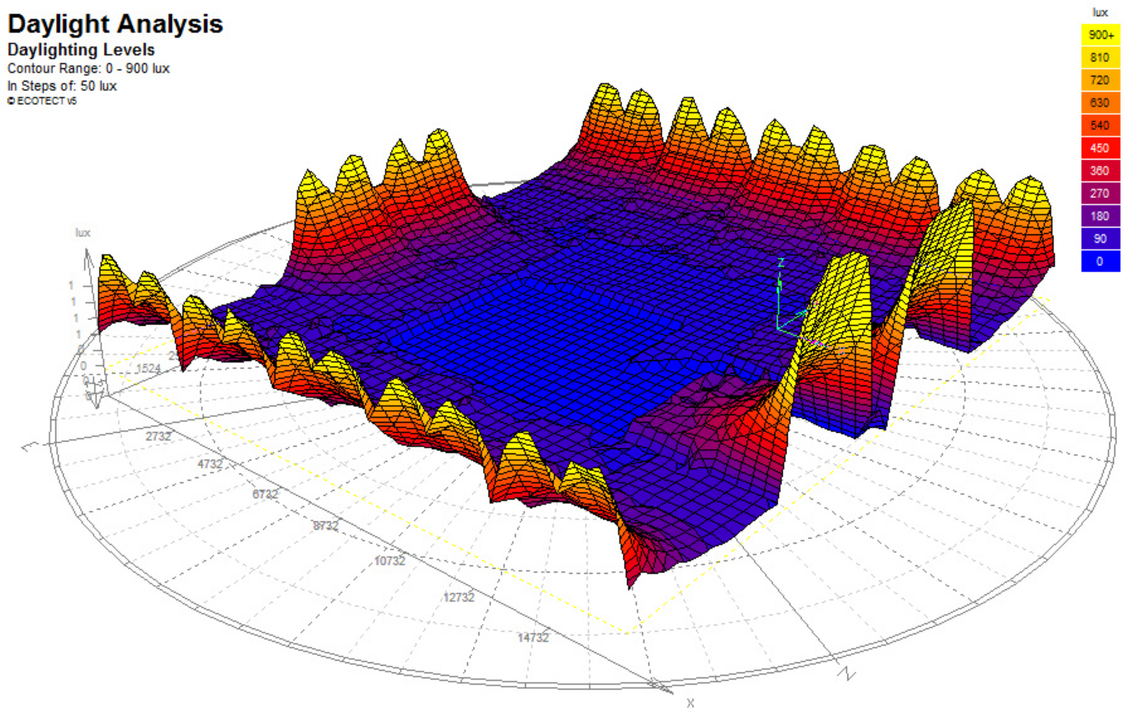
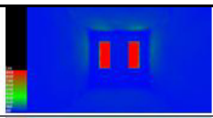
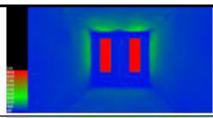
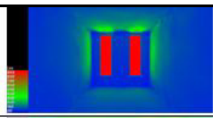
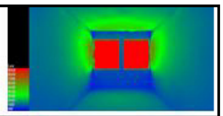
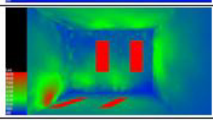
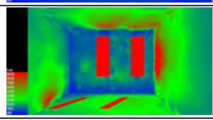
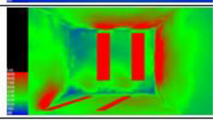
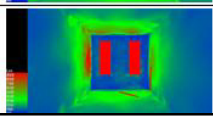
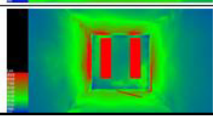
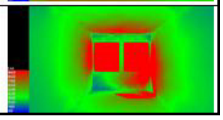
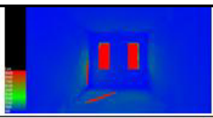
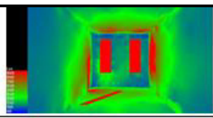
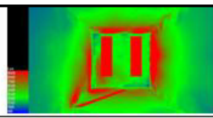
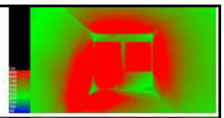
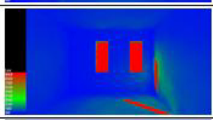
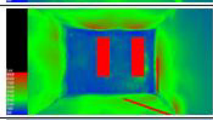
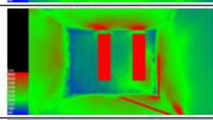
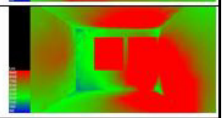
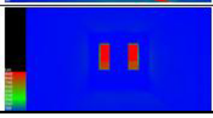
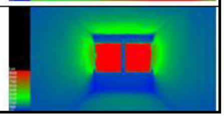
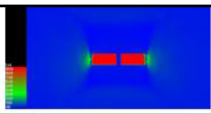
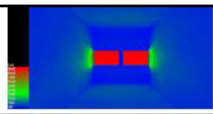
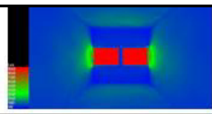
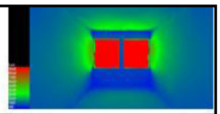
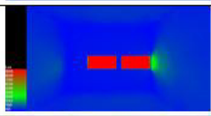
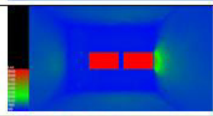
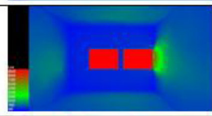
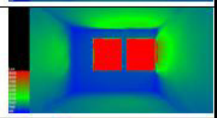
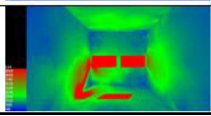
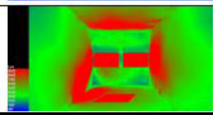
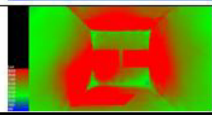
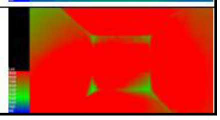


Figure III - 11 Annual illumination levels

Results were comparatively analyzed in the function of highest illumination dispersion and visual comfort. Simulation image renders are presented in **Appendix B.** Some selected daylight renders are presented in Table III - 5.

Table III - 5 Selected daylight renders in case of various WWR

Date/time Sky condition	Orient.	20%	25%	30%	Base Case 50%
Sept/12h Sunny Sky	E				
	S				
	W				
May/8h Sunny Sky	E				
	S				
	W				
Jul/16h Sunny Sky	E				
	S				
	W				

The calculation of daylight factor (DF) was made according to occupied intervals on an annual period, as shown in Figure III - 12. Test coordinates were zone centre points as BRE DF calculation at the geometric centre of the selected zones. Average annual DF simulation was performed for all four models at zone center point coordinates for WWR of 20%, 25%, 30%, and base case 50%.

Total number of performed simulations was 16, and the calculated DF's determined the final decision of WWR selection for the optimal building envelope. Two modes were simulated for electric lighting:

- On/off mode and
- Dimming switch mode.

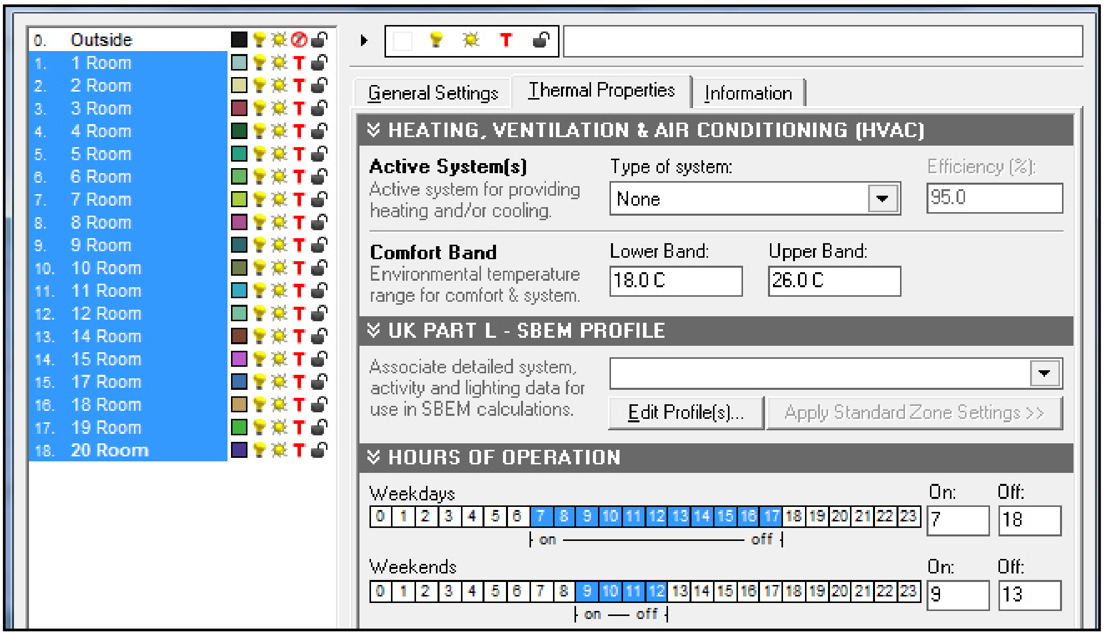


Figure III - 12 Zone operation hours

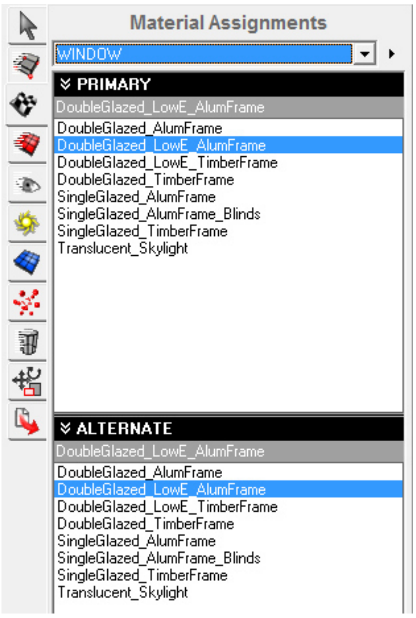


Figure III - 13 Window type

Windows which were applied for the daylight dispersion analysis and DF determination had the following properties.

Type: Double pane, Low-E, Aluminum frame

U-value: 0.7 W/m^{2}K
SHGC: 0.42
Visible transmittance: 0.54

Layers:

1. Glass panel Width: 6mm, Density: 2300 kg/m^3, Sp. Heat: 836.8 J/(kgK)
2. Argon gap Width: 15mm, Density: 1.784 g/L
3. Low-E layer
4. Glass panel Width: 6mm, Density: 2300 kg/m^3, Sp. Heat: 836.8 J/(kgK)

The simulations presented the annual percentage of unnecessary usage of electric lighting in the building according to each orientation. Illumination sensors were determined in geometric center points of zones. The on/off mode and the dimming switch mode adjusted the illumination intensity always to fulfill the minimal requirement of 350 lx. All simulated scenarios are presented in **Appendix C.** In conclusion the adopted WWR for all orientations is shown in Table III - 6.

Table III - 6 Daylight factor calculation with photoelectric dimming

East (min 350lx)			
WWR	DF	Percentage working year lighting OFF (%)	
20%	1.19 DF	53	-
25%	1.39 DF	58	-
30%	**1.97 DF**	**69**	**WWR 30% E / 30` rotation (Adopted)**
50%	3.49 DF	81	-
South (min 350lx)			
WWR	DF	Percentage working year lighting OFF (%)	
20%	1.73 DF	65	-
25%	**2.05 DF**	**70**	**WWR 25% S / 30` rotation (Adopted)**
30%	2.32 DF	74	-
50%	3.98 DF	83	-
West (min 350lx)			
WWR	DF	Percentage working year lighting OFF (%)	
20%	1.30 DF	56	-
25%	1.51 DF	60	-
30%	**1.78 DF**	**66**	**WWR 30% W / 30` rotation (Adopted)**
50%	3.49 DF	81	-
North (min 350lx)			
WWR	DF	Percentage working year lighting OFF (%)	
20%	**1.89 DF**	**67**	**WWR 20% N / 30` rotation (corridor) (Adopted)**
25%	**2.11 DF**	**71**	**WWR 25% N / 30` rotation (office) (Adopted)**
30%	2.21 DF	72	-
90%	16.85 DF	92	-

Total monthly solar exposure analysis was performed in order to assess the incident, transmitted and absorbed solar radiation for 20%, 25%, 30% and 50% WWR. This simulation is useful in order to determine internal gains and select appropriate glazing type for building envelope in further research.

Results from the solar exposure analysis are presented in Figures from III - 14 to III - 20, numerical data are presented in **Appendix D**.

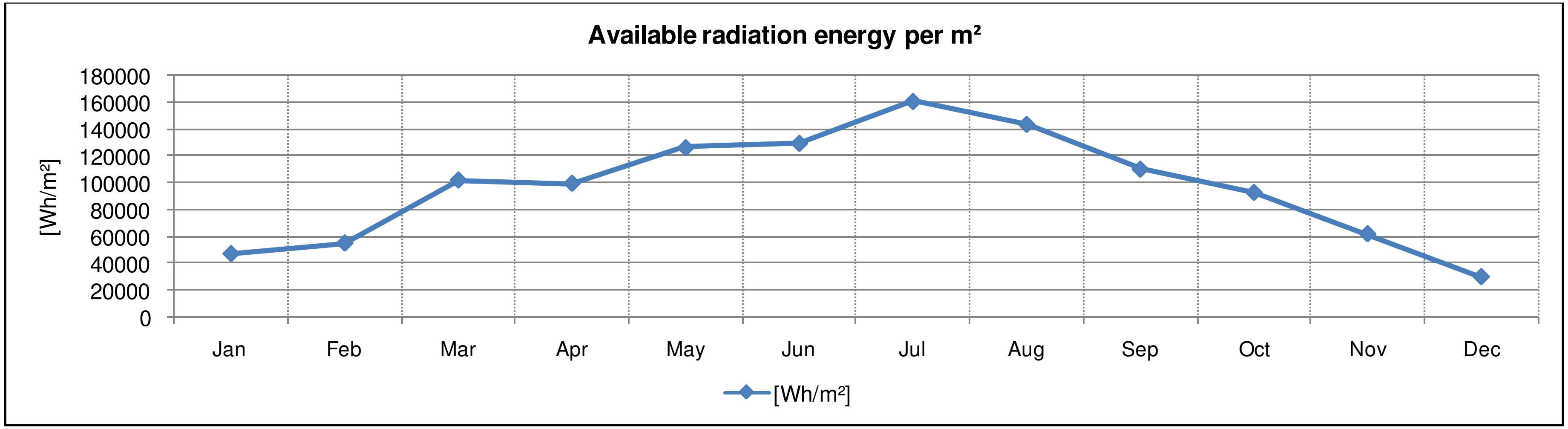


Figure III - 14 Available radiation energy

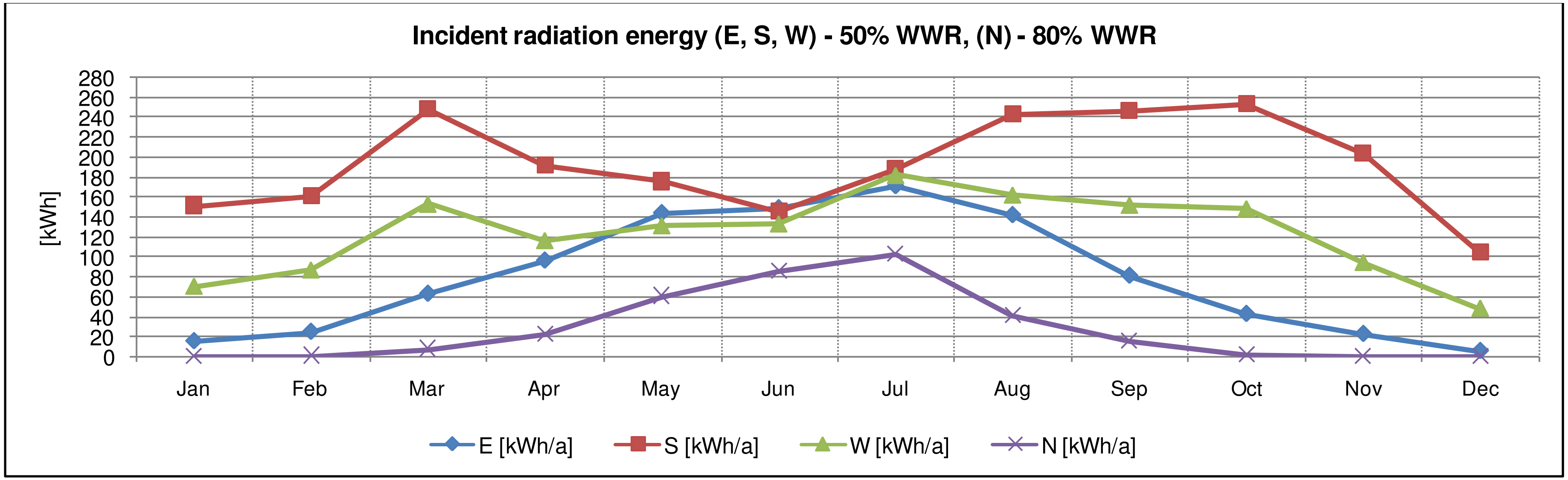


Figure III - 15 Incident radiation energy for FTS tower building

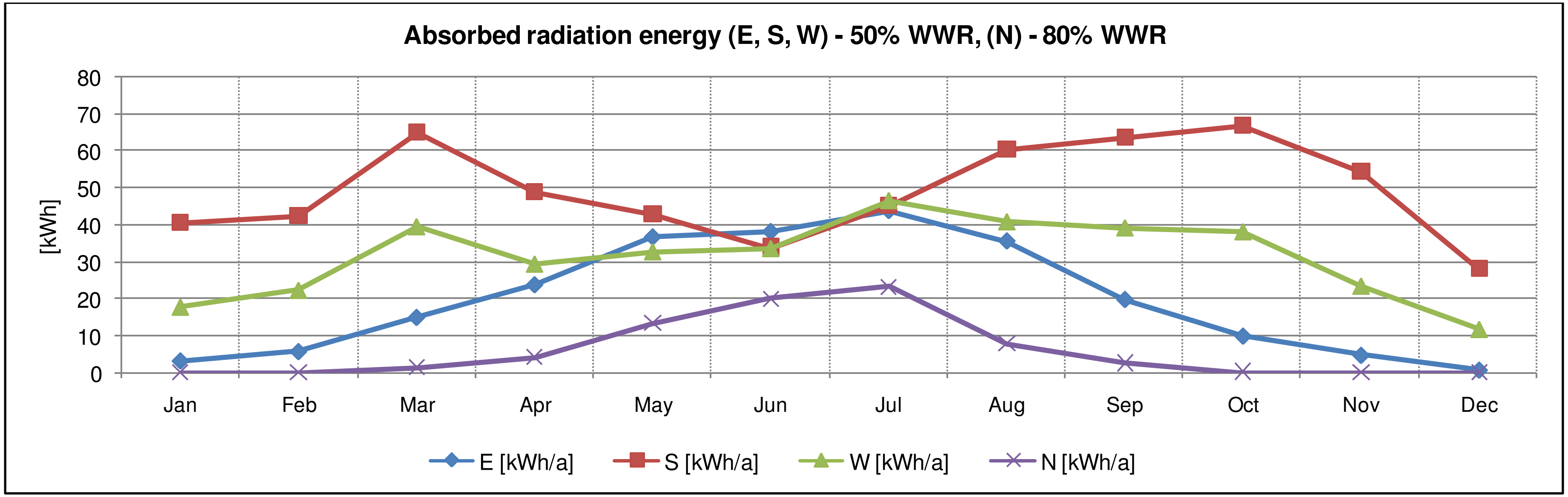


Figure III - 16 Absorbed radiation energy for FTS tower building

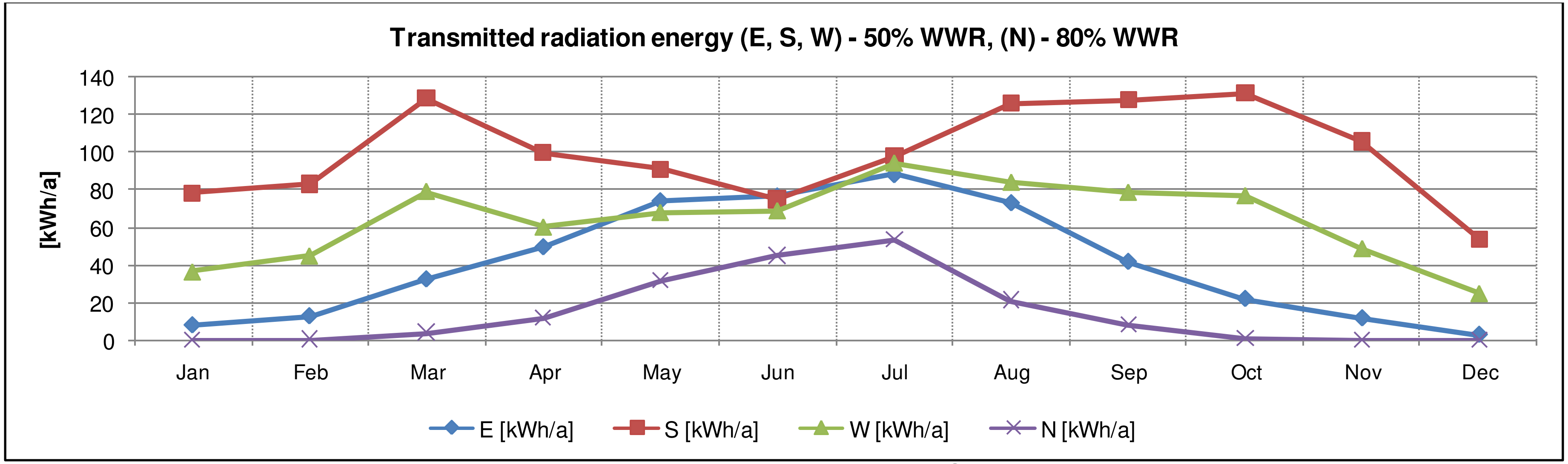


Figure III - 17 Transmitted radiation energy for FTS tower building

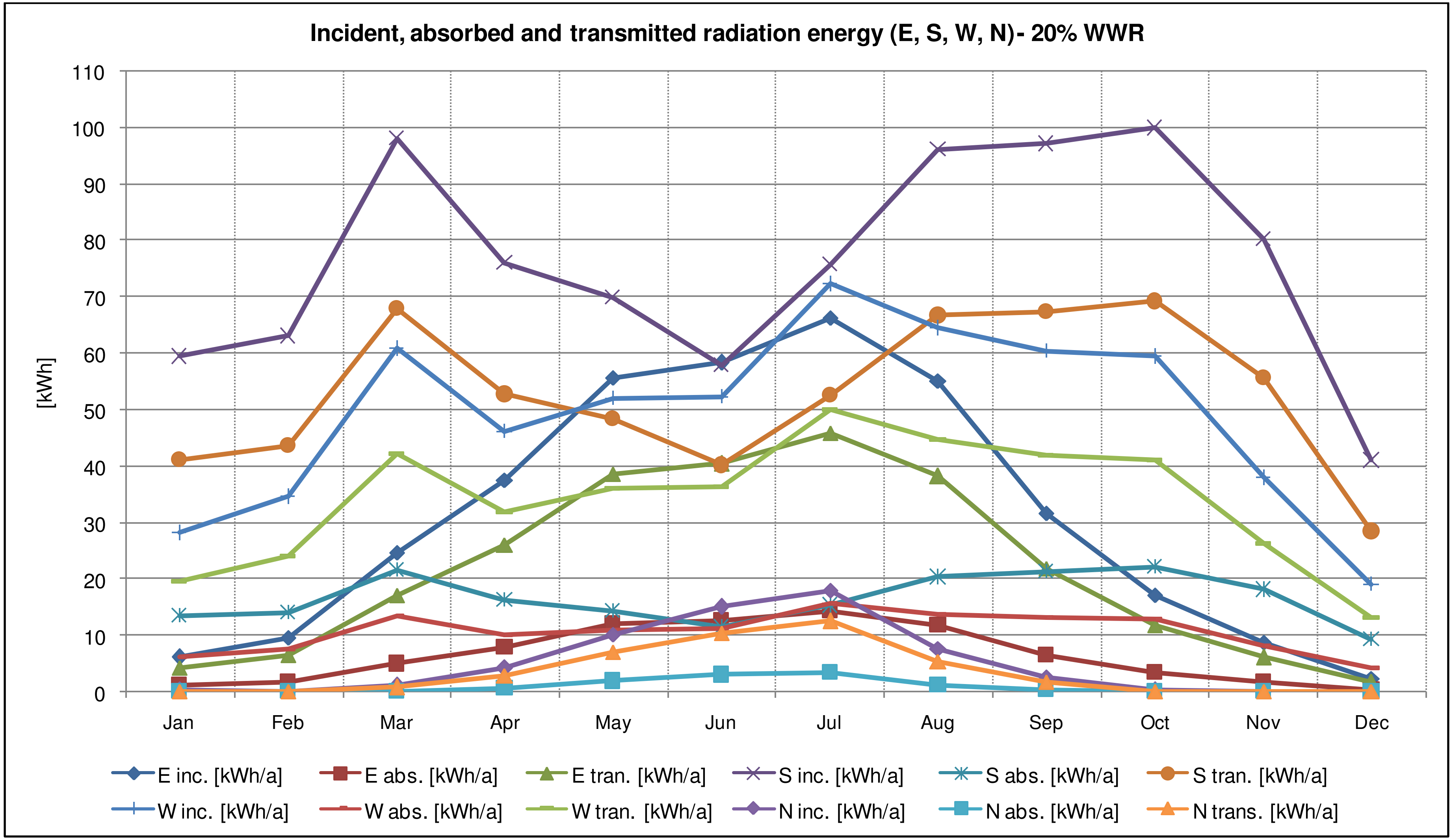


Figure III - 18 Incident, absorbed and transmitted radiation energy for 20% WWR

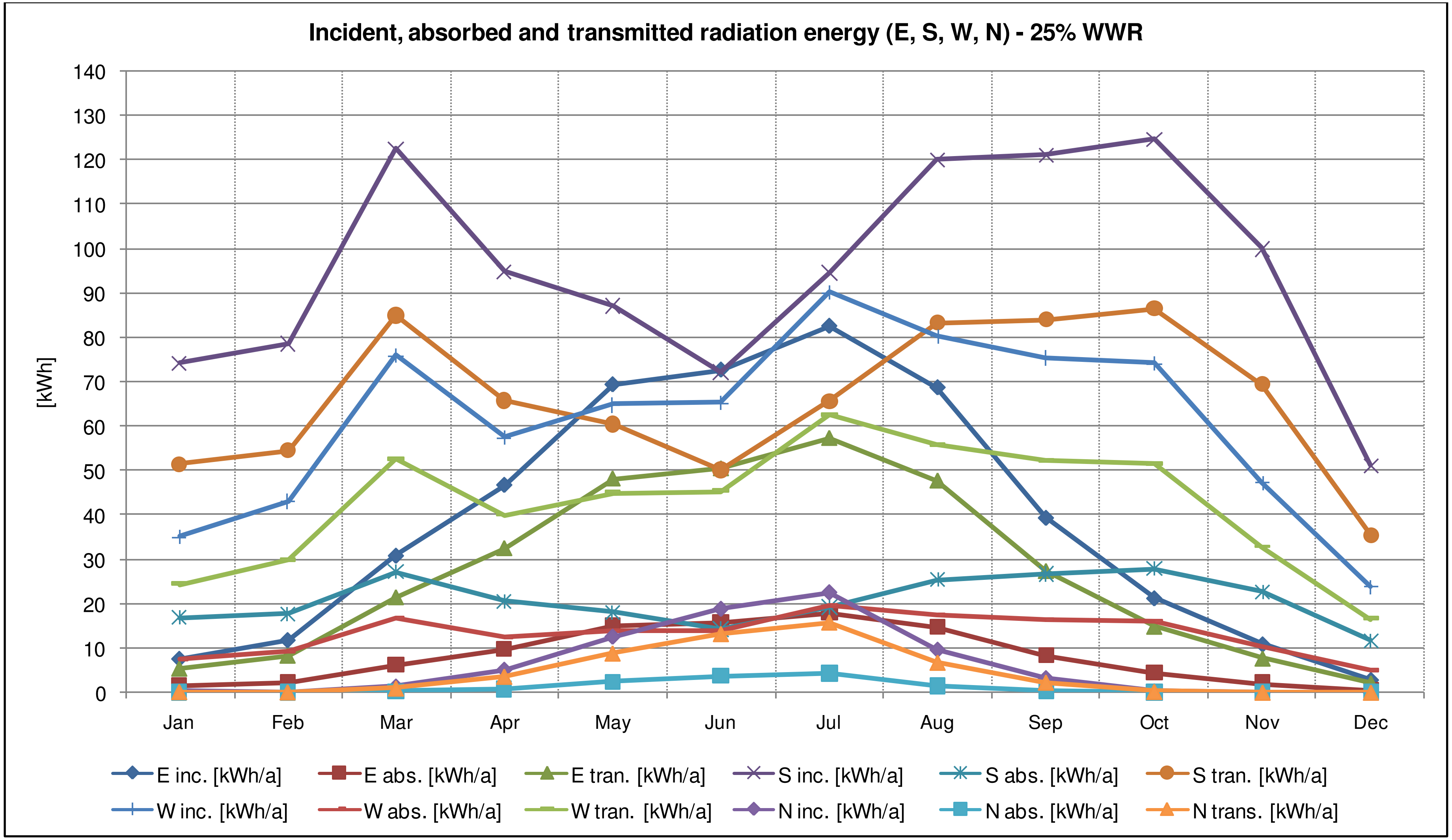


Figure III - 19 Incident, absorbed and transmitted radiation energy for 25% WWR

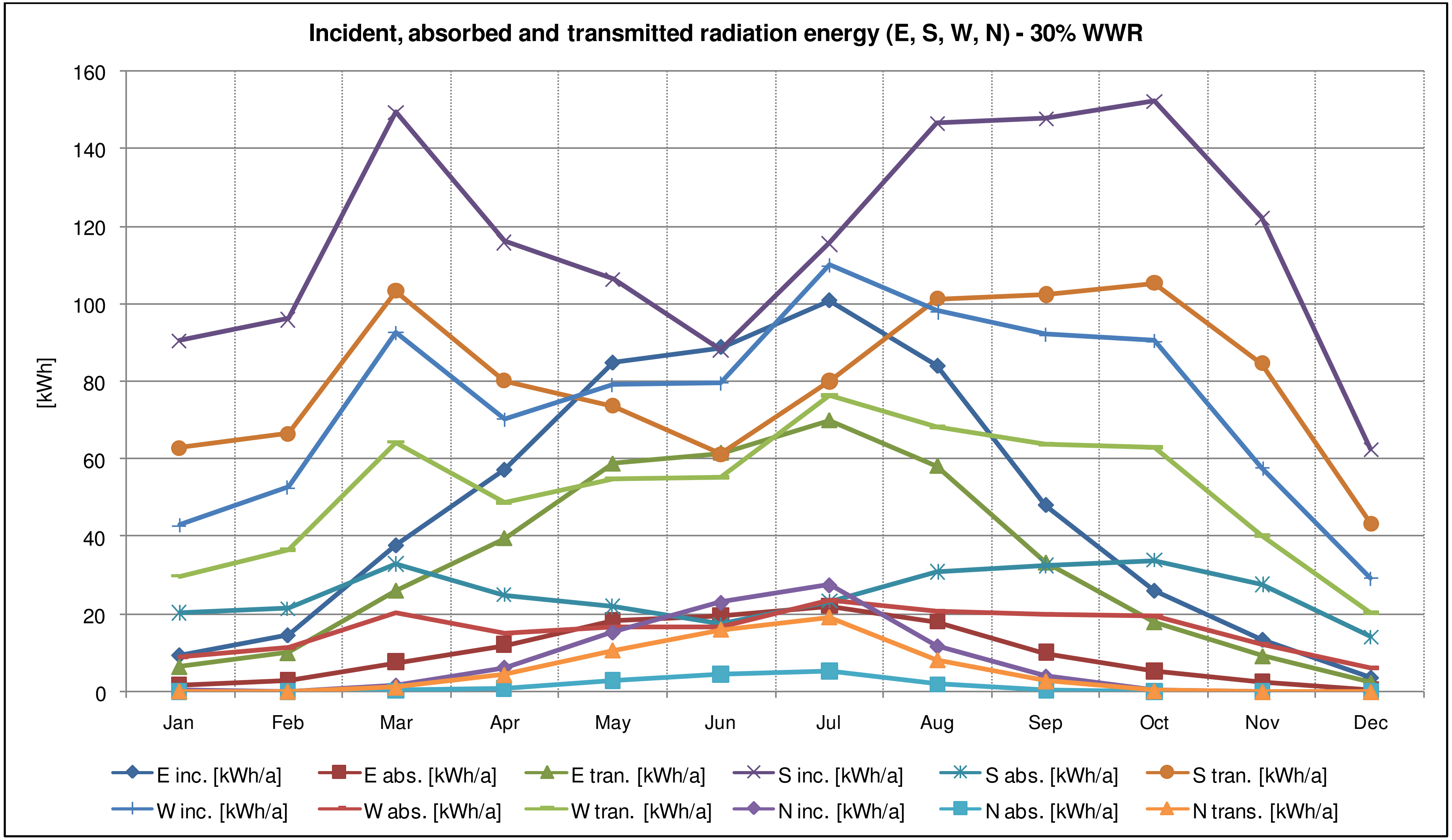


Figure III - 20 Incident, absorbed and transmitted radiation energy for 30% WWR

3.4. Optimized WWR and WG

In order to determine the best case scenario for WWR and WG the findings were elaborated in four simulation categories:

1. Illumination dispersion analysis (advanced lighting simulation, visual comfort);
2. Daylight factor calculation (visual comfort);
3. Photoelectric lighting simulation (electricity reduction);
4. Solar exposure analysis (radiation gains).

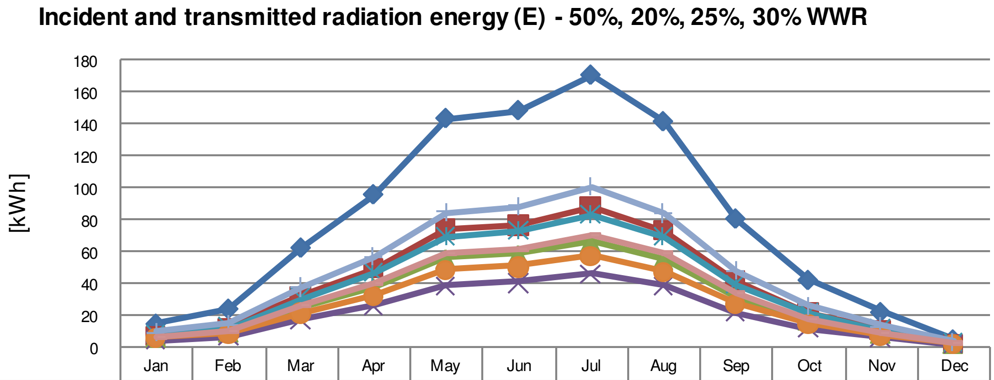
Primarily the WG analysis performed with the results of determining the optimal glazing geometry for the building envelope. As previously elaborated; square, rectangular (horizontal and vertical) glazing solutions were demonstrated. From the illumination dispersion analysis using advanced lighting simulation it was concluded from 720 indoor illumination dispersion renders that the vertical windows performed with the highest indoor lighting dispersion quality. The height of the windows contributes to deeper daylight dispersion in the indoor environment which results in achieving qualitative natural illumination in offices. Despite fulfilling qualitative natural illumination the glazing percentage, WWR, can be reduced. The next step referred to the daylight factor calculation in zone center points of spaces in order to select the most appropriate WWR for the building envelope. Table III - 7 presents the optimal WWR solution for the envelope from the daylight factor analysis and photoelectric lighting simulation.

Table III - 7 Optimal envelope WWR

Orient.	WWR [%]	DF [-]	Dimming mode Percentage working year lighting off [%]	Applied WWR
East	30	1.97	69	WWR 30% / 30` rot.
South	25	2.05	70	WWR 25% / 30` rot.
West	30	1.78	66	WWR 30% / 30` rot.
North	20	1.89	67	WWR 20% / 30` rot. (corridor, WC)

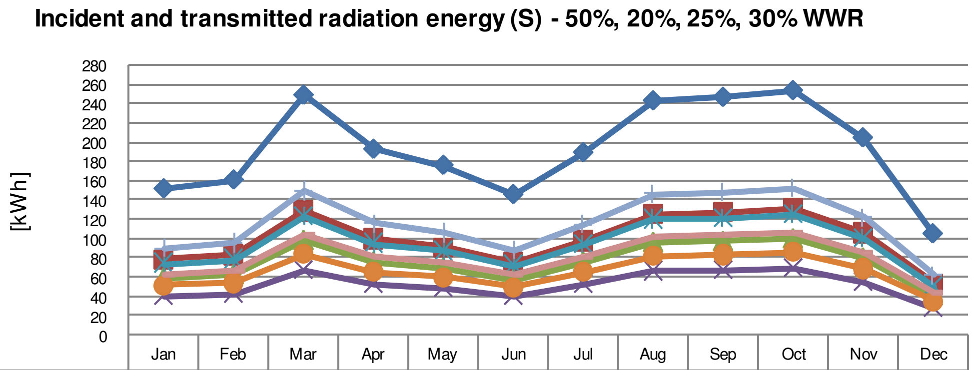
Photoelectric lighting simulation was applied in order to reduce the electricity requirement for the building. The dimming mode was adopted as the final solution since it performed in less electricity demand compared to the on/off switching mode. Finally the adopted WWR for the East orientation was 30% with an annual average 1.97 DF and dimming mode of 69% lighting turned off. The adopted WWR for the South orientation was 25% with an annual average 2.05 DF and dimming mode of 70% lighting turned off. For the West orientation the adopted WWR was 30% with an annual average 1.78 DF and dimming mode of 66% lighting turned off according to the results. And finally the adopted WWR for the North orientation was 20% with an annual average 1.89 DF and dimming mode of 67% lighting turned off, since the reference building's North oriented space is the corridor and the WC.

Furthermore the incident, absorbed and transmitted radiation energy from the sun was analyzed in order to evaluate the indoor radiation gains which will be used further in the internal gains simulations in EnergyPlus. The solar exposure analysis was performed for the same glazing type which was applied in the illumination dispersion simulation, to evaluate the amount of solar energy on the envelope. Further investigations in Chapter 5 will elaborate the affection of glazing material properties on the internal gains, and heating and cooling demands of the building. Figures from III - 21 to III - 24, show monthly incident and transmitted radiation energy values for all orientations where exterior surfaces are rotated 30° counter clockwise including four WWR's.



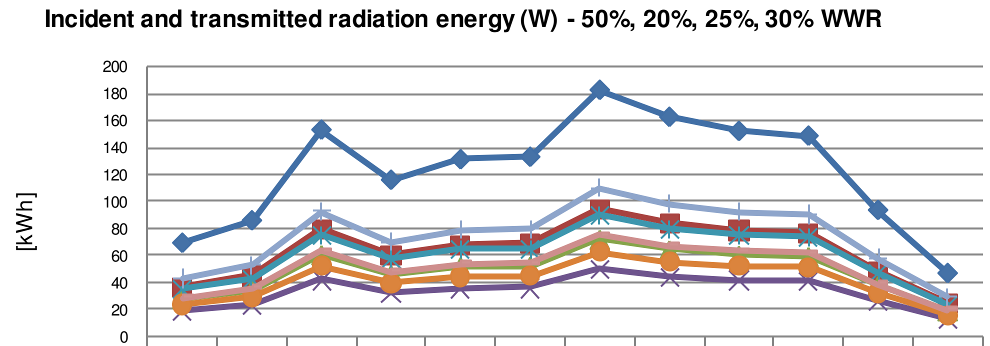
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
E inc. [kWh/a]	14.947	24.334	62.5	95.793	143.373	148.321	170.431	141.383	80.645	42.28	22.203	5.113
E tran. [kWh/a]	7.736	12.595	32.35	49.581	74.208	76.77	88.214	73.179	41.741	21.884	11.492	2.646
E inc. [kWh/a]	6.085	9.463	24.697	37.481	55.63	58.281	66.186	55.088	31.528	17.006	8.699	2.272
E tran. [kWh/a]	4.216	6.555	17.109	25.966	38.539	40.376	45.852	38.164	21.842	11.781	6.026	1.574
E inc. [kWh/a]	7.593	11.807	30.815	46.766	69.412	72.72	82.582	68.735	39.339	21.219	10.853	2.835
E tran. [kWh/a]	5.26	8.179	21.348	32.399	48.087	50.379	57.211	47.619	27.253	14.7	7.519	1.964
E inc. [kWh/a]	9.267	14.41	37.61	57.078	84.717	88.754	100.791	83.892	48.013	25.898	13.247	3.46
E tran. [kWh/a]	6.42	9.983	26.055	39.543	58.69	61.487	69.826	58.118	33.263	17.941	9.177	2.397

Figure III - 21 East orientation – incident and transmitted radiation energy



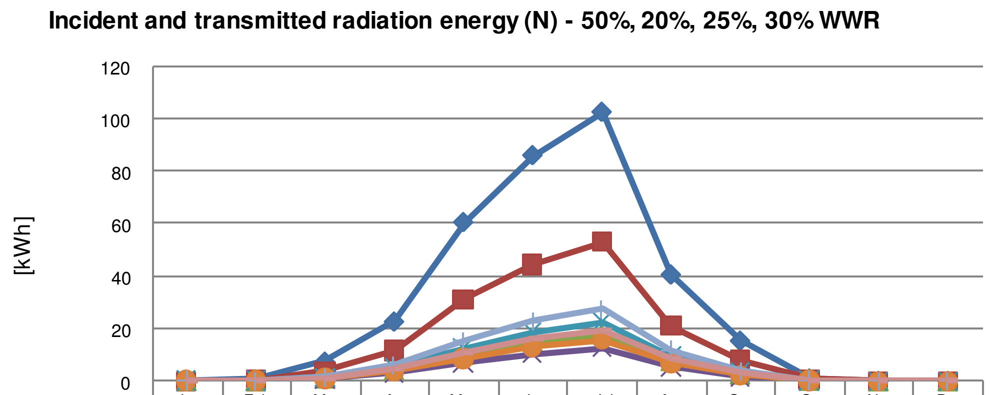
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S [kWh/a]	151.372	160.56	248.709	192.47	175.79	145.395	188.967	242.844	246.422	253.446	204.363	104.588
S [kWh/a]	78.349	83.104	128.729	99.62	90.987	75.255	97.807	125.693	127.545	131.181	105.776	54.134
S inc. [kWh/a]	59.426	62.979	98.097	76.033	69.827	57.866	75.805	96.165	97.079	99.885	80.164	40.983
S tran. [kWh/a]	41.169	43.631	67.96	52.674	48.375	40.088	52.516	66.621	67.255	69.198	55.536	28.392
S inc. [kWh/a]	74.149	78.581	122.4	94.869	87.126	72.201	94.584	119.989	121.129	124.63	100.023	51.136
S tran. [kWh/a]	51.369	54.439	84.796	65.723	60.359	50.02	65.526	83.126	83.916	86.341	69.294	35.426
S inc. [kWh/a]	90.498	95.908	149.389	115.787	106.337	88.122	115.44	146.446	147.838	152.111	122.078	62.412
S tran. [kWh/a]	62.695	66.443	103.494	80.215	73.668	61.049	79.975	101.455	102.419	105.379	84.573	43.238

Figure III - 22 South orientation – incident and transmitted radiation energy



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W [kWh/a]	69.832	86.301	152.917	116.091	131.149	132.971	182.134	162.295	151.934	148.476	93.929	47.588
W [kWh/a]	36.144	44.669	79.148	60.087	67.882	68.824	94.271	84.002	78.64	76.85	48.617	24.631
W inc. [kWh/a]	28.124	34.509	60.81	46.046	51.925	52.272	72.203	64.369	60.395	59.398	37.845	19.085
W tran. [kWh/a]	19.484	23.907	42.128	31.9	35.972	36.213	50.021	44.594	41.84	41.15	26.218	13.222
W inc. [kWh/a]	35.092	43.059	75.875	57.453	64.788	65.222	90.09	80.316	75.357	74.113	47.22	23.814
W tran. [kWh/a]	24.311	29.83	52.565	39.803	44.884	45.184	62.413	55.641	52.206	51.344	32.713	16.498
W inc. [kWh/a]	42.83	52.553	92.606	70.122	79.074	79.603	109.955	98.026	91.973	90.455	57.632	29.064
W tran. [kWh/a]	29.671	36.408	64.155	48.579	54.781	55.148	76.175	67.91	63.717	62.666	39.927	20.135

Figure III - 23 West orientation – incident and transmitted radiation energy



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N [kWh/a]	0	0.626	7.343	22.601	60.436	85.888	102.363	40.487	15.324	0.929	0	0
N [kWh/a]	0	0.324	3.801	11.698	31.281	44.455	52.982	20.956	7.931	0.481	0	0
N inc. [kWh/a]	0.162	0.083	1.068	4.093	10.045	15.039	18.006	7.688	2.579	0.21	0	0
N trans. [kWh/a]	0.112	0.058	0.74	2.835	6.959	10.419	12.474	5.326	1.787	0.145	0	0
N inc. [kWh/a]	0.202	0.104	1.332	5.107	12.533	18.764	22.467	9.593	3.219	0.262	0	0
N trans. [kWh/a]	0.14	0.072	0.923	3.538	8.683	13	15.565	6.646	2.23	0.181	0	0
N inc. [kWh/a]	0.246	0.127	1.626	6.233	15.297	22.902	27.421	11.708	3.928	0.319	0	0
N trans. [kWh/a]	0.171	0.088	1.126	4.318	10.597	15.866	18.997	8.111	2.721	0.221	0	0

Figure III - 24 North orientation – incident and transmitted radiation energy

3.4.1. Conclusion

Visual comfort can be achieved and maintained if building envelope is improved from the aspect of efficient window to wall ratio and window geometry determination. From the advanced illumination performance simulation (3D dispersion and intensity analysis) and photoelectric lighting simulation it was concluded that offices with identical window to wall ratio but different window geometry do not have identical effects on the visual comfort sensation of occupants. Vertical rectangular windows presented most efficient results among the analyzed geometries. Glazing ratio and geometry can improve the energetic aspect and indoor visual comfort of buildings.

Chapter 4

Building envelope performance

4.1. Building envelope standards and requirements

4.1.1. EU-27 building policies and programs overview

According to the "Overview of the EU-27 building policies and programs, Factsheets on the nine ENTRANZE target countries" the aim of this deliverable is to give an overview of the policies and measures already planned or taken by the member states to promote nearly Zero Energy Buildings (Buildings Performance Institute Europe 2014). Incorporating energy-related requirements during the design or retrofit phase of a building is a key driver for implementing energy efficiency measures which in turn highlights the role of building energy codes in reducing CO2 emissions and reaching the energy saving potential of buildings (Buildings Performance Institute Europe 2014). Understanding building codes however requires specific technical expertise which makes monitoring and evaluating the progress of what is happening from the political level difficult. Given the environmental and climate mitigation impacts of building codes, it is crucial to keep track of all the key transformations happening in the field of building energy codes in a simple, understandable way. Through its 2011 survey, BPIE has collected country-by-country information, making the first attempt to provide an overall picture of what is happening in Europe in the area of building codes (Buildings Performance Institute Europe 2014).

Member States have different prescriptive-based requirements for **new buildings**; element-based requirements associated with building energy codes such as maximum U-values, minimum/maximum indoor temperatures etc.

Considering the insulation, limiting the thermal conductivity of major construction elements is the most common thermal performance requirement for buildings.

These are based upon U-value requirements (expressed in W/(m^{2}K)) for the main building envelope construction elements. Given the diversity in climatic conditions, maximum U-value requirements vary widely across different countries (Buildings Performance Institute Europe 2014).

Building codes and requirements for **existing buildings**; despite being an EPBD requirement, not all countries have reported specific mandatory building codes associated with improving the energy performance of existing buildings. It is important to recognize that EPBD only applies to buildings over 1000 m^2 and most Member States have introduced requirements for consequential improvements associated with buildings over 1000 m^2 (Buildings Performance Institute Europe 2014).

4.1.2. Leading EU countries and Serbian thermal insulation requirements overview

4.1.2.1. Austria

In Austria all regions have implemented a type of supporting instrument with additional, stronger requirements regarding U-values and energy performance of buildings. Table IV - 1 below provides the maximum permitted U-values valid for new buildings and replacement and maintenance of a building component (Buildings Performance Institute Europe 2014).

Table IV - 1 U-value requirement for offices

Building component		U-value [W/(m^{2}K)]	
		New	Renovated
Wall	External wall	0.35	0.35
	Internal wall to non conditioned area	0.9	0.9
	Walls to other buildings	0.5	0.5
	Wall, basement in contact with ground	0.4	0.4
Window	Windows	1.4	1.4
	Roof windows	1.7	1.7
	Other external transparent components horizontal or slope	2.0	2.0
Roof/ceiling	Roof	0.2	0.2
	Internal ceiling to unconditioned areas	0.4	0.4
Floor	In contact to ground	0.4	0.4

4.1.2.2. Germany

For the renovation of buildings the EnEV sets component-specific minimum efficiency requirements which have to be complied with when it is necessary to change or modernize a building component (e.g. the roof, the windows or the exterior wall). The following Table IV - 2 shows the component based maximum U-values of the different reference buildings according to type of building and construction work (new construction or renovation) (Buildings Performance Institute Europe 2014).

Table IV - 2 U-value requirement for offices

Building component		U-value [W/(m²K)]	
		New	Renovated
Wall	External wall	0.28 – 0.35	0.24 – 0.35
Window	Windows and french doors	1.3 – 1.9	1.3 – 1.9
	Skylight	1.4 – 1.9	1.4 – 1.9
	Dome light	2.7	-
Roof/ceiling	Roof and top floor ceiling	0.2 – 0.35	0.2 – 0.35
	Glass roof	2.7	2.0 – 2.7
Floor	Basement	-	-

4.1.2.3. Italy

The thermal insulation requirement according to the Decree Law 311/2006 sets the following U-values, as shown in Table IV - 3, applying to the various components of the building envelope and according to the climatic zone (Buildings Performance Institute Europe 2014).

Table IV - 3 U-value requirement for offices

Building component	U-value [W/(m²K)]	
	New	Renovated
Wall	0.33 – 0.62	-
Window	2.0 – 4.6	-
Roof	0.29 – 0.38	-
Basement	0.32 – 0.65	-

4.1.2.4. Hungary

Cost-optimized level of requirements for the boundary and closing systems heat transfer factors can be seen in Table IV - 4 (Regulation 20/2014. (III. 7.) BM of the Minister of Interior 2014).

Table IV - 4 U-value requirement

Building component	U_{max}-value [W/(m²K)]
Exterior wall	0.24
Flat roof above heated space	0.17
Flat roof above non-heated space	0.26
Floor and attic space under the shelter	0.17
Arcade and slabs above passage	0.17
Windows	1.0
Special windows	1.2
Front glass wall, curtain wall	1.4
Skylight	1.45
Wall between heated and unheated spaces	0.26
Heated wall between adjacent buildings and parts of buildings	1.5
Ground floor (new buildings)	0.3

4.1.2.4. Serbia

The maximum permissible heat transfer coefficient values for thermal building envelope elements and elements between two adjacent thermal zones are contained in Table IV - 5. These values apply to the internal building structures bordering the premises where the air temperature at the design temperature of the outside air (during the heating period) is less than 12°C (Official Gazette RS: 61/2011 (In Serbian) Zakon o planiranju i izgradnji 2011).

Table IV - 5 Maximum U-value requirement for offices

Building component	U_{max}-value [W/(m^{2}K)]	
	New	Renovated
Exterior wall	0.3	0.4
Walls to other buildings	0.35	0.5
Walls and ceilings between heated rooms of different units, different users or owners	0.9	0.9
Flat roof above heated space	0.15	0.2
Flat roof above non-heated space	0.3	0.4
Hip roof above heated space	0.15	0.2
Hip roof above non-heated space	0.3	0.4
Ceiling above open space	0.2	0.3
Windows, french doors, glass winter gardens	1.5	1.5
Basement wall	0.35	0.5
Basement floor	0.3	0.4

The U-values are calculated in accordance with standard SRPS EN ISO 13789 and specific standards: for non-transparent construction elements, except for floors and walls in the ground and curtain-wall, in accordance with SRPS EN ISO 6946; for floors and walls in the soil in accordance with SRPS EN ISO 13370; construction element types of windows, doors and shutters in accordance with SRPS EN ISO 10077-1 and SRPS ISO 10077-2; curtain-wall in accordance with SRPS EN 13947; the glass in accordance with the standards SRPS EN 673 and SRPS EN 410; elements for masonry brick walls and masonry walls, in accordance with standard SRPS EN 1745 (Official Gazette RS: 61/2011 (In Serbian) Zakon o planiranju i izgradnji 2011).

4.2. Existing envelope analysis

The existing building envelopes thermal performance was recorded with thermal camera in January 2015 during heating season. The images were taken between 11h and 13h while the heating was fully active and the building was occupied. Outside air temperature was - 3˚C during the recording period. Figure IV – 1 shows thermal images of the building envelope on a temperature scale from – 4.9 ˚C to +12.5˚C. From the thermal imaging in can be concluded that the envelope does not meet the minimal standards of thermal insulation properties. Energy escapes to the outdoor atmosphere mostly through inadequate glazing, Figure IV – 1 (left) and through concrete cold beams and columns which are highlighted in the thermal images (right).

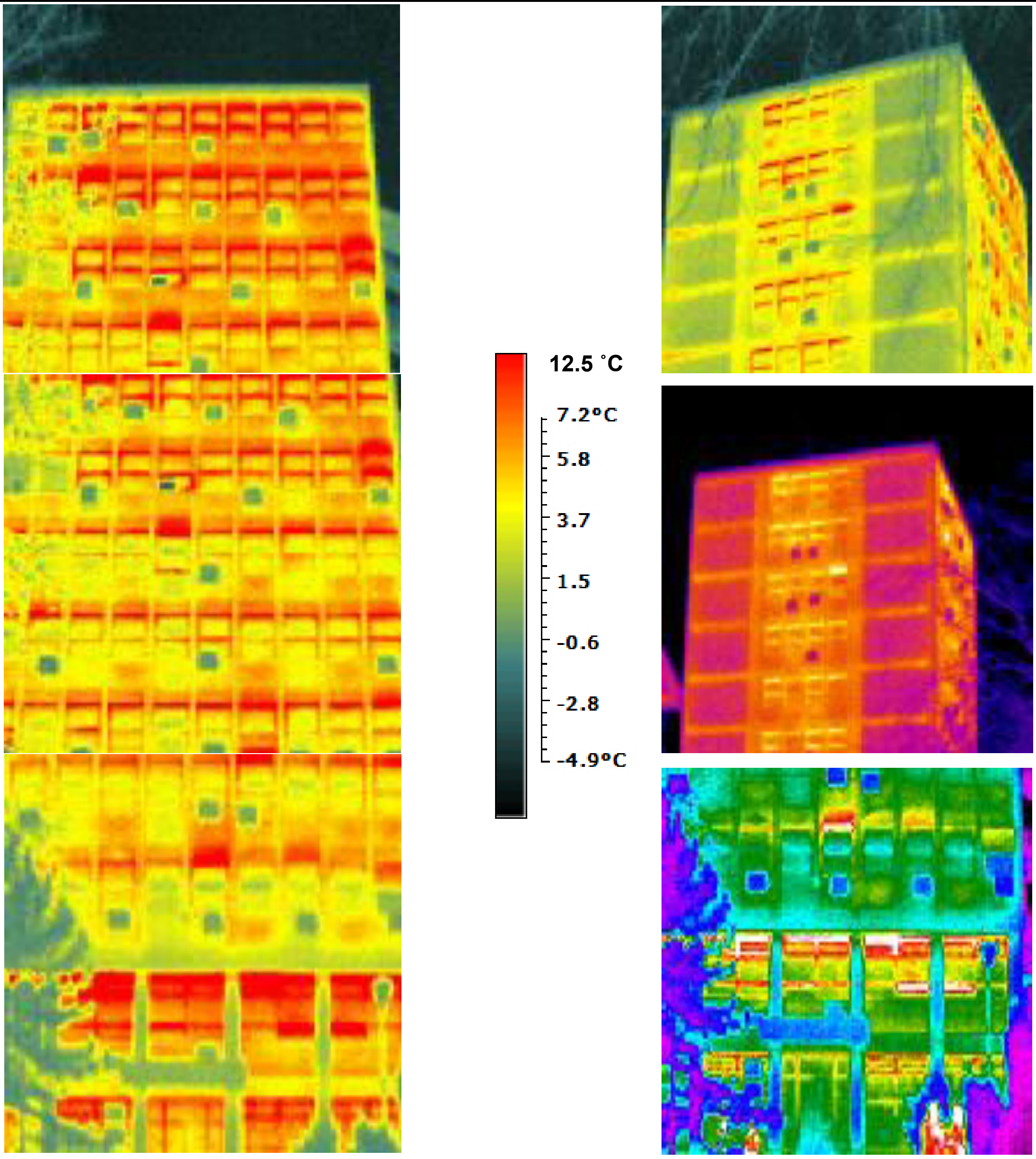


Figure IV - 1 Thermal camera images of FTS tower

4.3. Improved building envelope construction with optional glazing – Best Case building envelope

4.3.1. Optional building envelope construction and materials

The building envelope applied in the simulation was selected and applied according to the thermal insulation requirements. It was mainly important to find a preferable solution with minimum interventions, while achieving high quality thermal performance. The construction of the reference office-tower building is made of reinforced concrete. The concrete skeleton consists of columns (which are lined up on the façade) and reinforced concrete slabs with 20 cm thickness. Since the building was constructed in 1968 thermal insulation requirements and regulation significantly deviate from recent. This resulted in a solution that an exterior wall made of fired clay brick with 25 cm thickness meets the prescribed requirements.

The building envelope construction was improved in order to reduce the heat transfer coefficient, U-value. The U-value of the existing office building's exterior walls is 2.32 W/(m^{2}K) since the walls are constructed from 25 cm fired clay brick, without insulation layer. The modified exterior wall construction compared to the existing is presented in Table IV - 6 below, where the new U-value equals 0.22 W/(m^{2}K). Furthermore it was recorded that the existing total 37.5% glazing also has a significant U-value, 2.788 W/(m^{2}K).

Table IV - 6 Exterior wall construction with material properties

EXISTING			MODIFIED (Optional)		
No.	**Exterior wall**	**Material properties**	**No.**	**Modified exterior wall**	**Material properties**
1	Cement mortar	d = 10 mm	**1**	Stucco Portland cement mortar	d = 20 mm λ = 0.6918 W/(mK) ρ = 1858 kg/m^3 Q = 837 J/kgK
2	Fired clay brick	d = 250 mm λ = 0.675 W/(mK) ρ = 1601.84 kg/m^3 Q = 790 J/kgK	**2**	Expanded polystyrene molded beads	d = 140 mm λ = 0.0352 W/(mK) ρ = 24 kg/m^3 Q = 1210 J/kgK
			3	Fired clay brick	d = 250 mm λ = 0.675 W/(mK) ρ = 1601.84 kg/m^3 Q = 790 J/kgK
3	Cement mortar	d = 5 mm	**4**	Stucco Portland cement mortar	d = 10 mm λ = 0.6918 W/(mK) ρ = 1858 kg/m^3 Q = 837 J/kgK
U = 2.32 W/(m^{2}K)			**U = 0.22 W/(m^{2}K)**		

Different window types will be investigated in the energy simulations. The purpose of selecting 10 window types with different properties will contribute to the analysis and evaluation of the glazing parameters which influence the annual energy performance of modified office-tower building. Table IV - 7 presents 10 optional solutions which can be applied and meet the regulations according to the Serbian standards of maximum thermal insulation requirements for renovated buildings. Glass types were collected from manufacturers as Pilkington, Guardian and other typical dual and tri-pane glasses (Pilkington 2014) (Pilkington Planar 2014) (All Weather Windows Ltd. 2014) (Guardian Industries Corp. 2014).

Table IV - 7 Window types with material properties

EXISTING			
Windows		**Material properties**	
2 x 3 mm Clear glass panel		U-value SHGC Visible Transmittance	2.78 W/(m^{2}K) 0.76 0.81
MODIFIED (Optional)			
No.	**Windows**	**Material properties**	
W1	Window 1 Dual pane Pilkington Optifloat-clear	U-value SHGC Visible Trans.	1.70 W/(m^{2}K) 0.60 0.70
W2	Window 2 Dual pane Pilkington Optifloat-clear	U-value SHGC Visible Trans.	1.30 W/(m^{2}K) 0.50 0.73
W3	Window 3 Tri-pane Pilkington Planar + Optifloat + K Glass	U-value SHGC Visible Trans.	0.90 W/(m^{2}K) 0.34 0.57
W4	Window 4 Tri-pane Pilkington Planar + Optifloat + Optitherm	U-value SHGC Visible Trans.	0.70 W/(m^{2}K) 0.23 0.42
W5	Window 5 Dual pane Pilkington Energy Advantage, Argon, Low-E, #3 Surface	U-value SHGC Visible Trans.	1.67 W/(m^{2}K) 0.75 0.77
W6	Window 6 Dual pane Guardian Clima-Guard 80/70	U-value SHGC Visible Trans.	1.53 W/(m^{2}K) 0.69 0.81
W7	Window 7 Tri-pane One pane with Sun-Stop coating and Argon	U-value SHGC Visible Trans.	1.05 W/(m^{2}K) 0.34 0.63
W8	Window 8 Tri-pane Two panes with Sun-Stop coating and Argon	U-value SHGC Visible Trans.	0.70 W/(m^{2}K) 0.31 0.54
W9	Window 9 Tri-pane Pilkington Planar + Optifloat + K Glass	U-value SHGC Visible Trans.	0.80 W/(m^{2}K) 0.22 0.39
W10	Window 10 Tri-pane Pilkington Planar + Optifloat + Optitherm	U-value SHGC Visible Trans.	0.70 W/(m^{2}K) 0.26 0.52

The modified construction of the roof terrace is presented in Table IV - 8 with optional solution that meets the thermal insulation regulations in Serbia.

Table IV - 8 Roof terrace layers and properties

ROOF TERRACE - MODIFIED (Optional)		
No.	**Layers and construction**	**Specification**
1	Lightweight concrete tiles	d = 40 mm λ = 0.530 W/(mK) ρ = 1280 kg/m^3 Q = 840 J/kgK
2	Air gap	R = 0.15 m^{2}K/W
3	Styrodur C – molded beads	d = 180 mm λ = 0.040 W/(mK) ρ = 33 kg/m^3 Q = 1450 J/kgK
4	Waterproof membrane (3 layers)	d = 0.009 mm (x3) λ = 0.160 W/(mK) ρ = 1121.29 kg/m^3 Q = 1460 J/kgK
5	Heavyweight concrete	d = 200 mm λ = 1.95 W/(mK) ρ = 2240 kg/m^3 Q = 900 J/kgK
6	Stucco Portland cement	d = 10 mm λ = 0.692 W/(mK) ρ = 1858 kg/m^3 Q = 837 J/kgK
7	Air gap	R = 0.15 m^{2}K/W
8	Gypsum board	d = 19 mm λ = 0.160 W/(mK) ρ = 800 kg/m^3 Q = 1090 J/kgK
U = 0.18 W/(m^{2}K)		

4.3.2. Applied building envelope

According to the research in Chapter 3 CAD building model, WWG/WG analysis and illumination simulation, the final WWR and WG was selected from the multi-criteria analysis conducted in four categories:

1. Illumination dispersion analysis (advanced lighting simulation, visual comfort),
2. Daylight factor calculation (visual comfort),
3. Photoelectric lighting simulation (electricity reduction),
4. Solar exposure analysis (radiation gains).

The Best Case Scenario for WWR and WG for all orientations are shown in Table IV - 9.

Table IV - 9 Best Case Scenario for WWR and WG

Orient.	WWR [%]	Applied WWR	WG	Dimensions [mxm]
E	30	WWR 30% / 30` rot.	Vertical Rectangular	Single Window 0.60 x 2.20
S	25	WWR 25% / 30` rot.	Vertical Rectangular	Single Window 0.60 x 1.86
W	30	WWR 30% / 30` rot.	Vertical Rectangular	Single Window 0.60 x 2.20
N	20	WWR 20% / 30` rot. (corridor, WC)	Vertical Rectangular	Single Window 0.60 x 1.49

The building was completely re-modeled in Sketchup Make 3D program since further analysis considering energy simulation requires the model to be transformed to importable numerical data via Open Studio plug-in into EnergyPlus simulation engine. Thus, the selected WWR and WG from the previous investigation were modeled for each orientation of the basement, ground floor and nine levels of the office-tower building. Figure IV - 2 presents a 3D section of the model, where the office and the corridor borders are expressed with bold lines in the section plane.

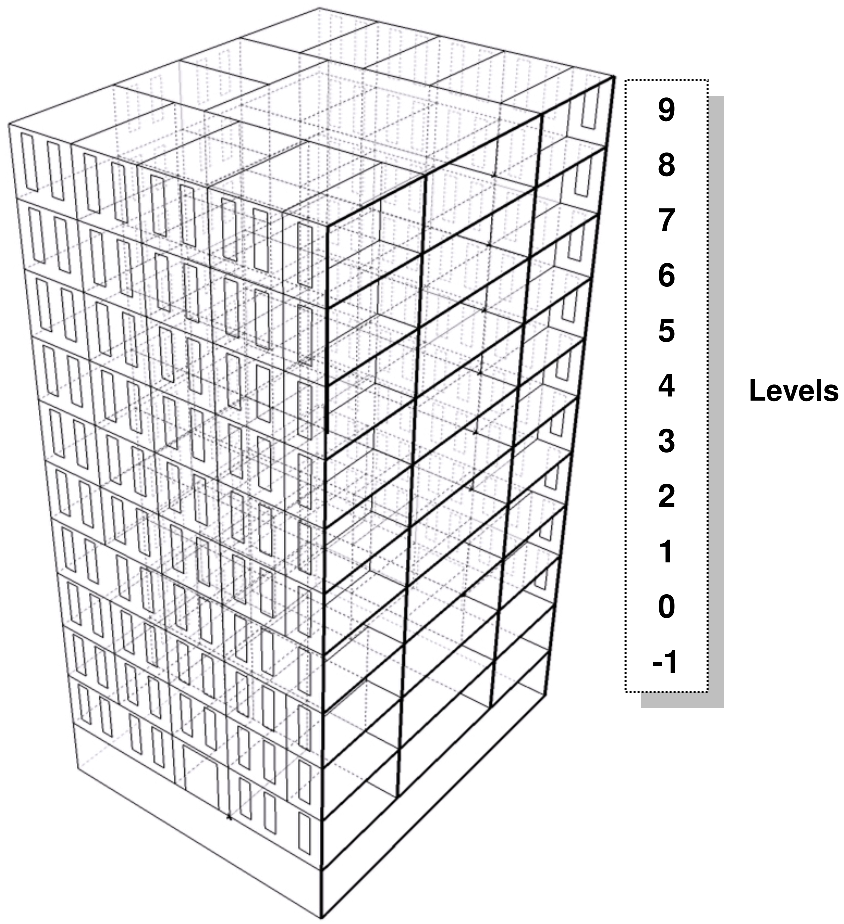


Figure IV - 2 3D building section

The 3D model of the building envelope is presented in Figure IV - 3.

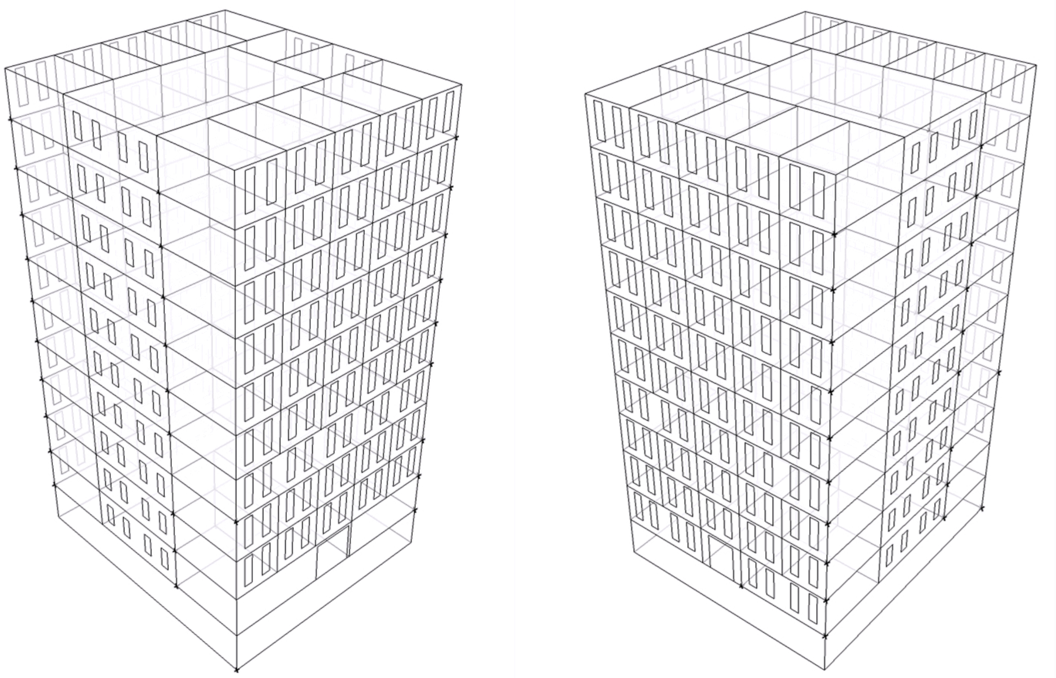


Figure IV - 3 3D building envelope

The model which was created in Skethup Make 3D was the first step in developing a thermal model for simulation using Open Studio plug-in for thermal zone construction. The multi-zone thermal model properties will be elaborated in the following Chapter 5 “Energy performance simulation”.

Chapter 5

Energy performance simulation

5.1. Multi-zone thermal model

5.1.1. Zone modeling

5.1.1.1. Thermal zone definition

Zoning is the division of a building's heating and cooling systems into sections that permit independent control of mean air temperatures, humidity, air velocity and air quality from one space to another. A thermal zone is a space or collection of spaces within a building having sufficiently similar space conditioning requirements so that those conditions could be maintained with a single thermal control device. A thermal zone is a thermal and not a geometric concept: spaces need not be contiguous to be combined within a single thermal zone (Comercial Energy Services Network 2014).

An HVAC zone is a physical space within the building that has its own thermostat and zonal system for maintaining thermal comfort. HVAC zones are identified on the HVAC plans. HVAC zones should not be split between thermal blocks, but a thermal block may include more than one HVAC zone (Comercial Energy Services Network 2014).

5.1.1.2. Multi-zone thermal model

Most buildings have more than one thermal zone, and each zone can have significantly different gains and losses at a single instant. The energy gains refer to solar radiation and internal gains from occupants and equipment. Considering for instance, an office tower with spaces facing four orientations; during the morning, the east facing rooms may be receiving a significant solar gain, while the rest of the building is receiving only diffuse sky radiation. Heat gains would be much greater for the east facing rooms, which may require cooling, while the rest of the building may require heating. Interior spaces without exterior walls, roof or ground floor have only internal gains from people, electric lighting and equipment. These zones may require cooling almost all of the time. Mechanical systems in most large buildings are designed to serve the needs of all the thermal zones in the building and must be capable of simultaneously heating or cooling the zones for predefined criteria.

During construction of a multi-zone thermal model the building is divided into multiple thermal zones if numerous space types exist in the project. The control of the energy simulation depends from the engineer who selects the thermal zones for simulation. In order to perform a dynamic simulation the following groups of information are needed:

1. Building materials;
2. Building components
3. Electrical lighting and equipment;
4. Occupancy and schedules;
5. HVAC system (ideal air loads mode can be applied if the HVAC system is not modeled).

The multi-zone thermal model with the Best Case WWR and WG envelope was constructed in SketchUp Make 3D program using OpenStudio[6] plug-in tools for zone boundary definitions (Trimble Navigation 2013) (National Renewable Energy Laboratory 2013). Prior to zone definition and construction assignment it was important to assign boundary conditions (horizontal and vertical) between zones and exterior boundaries. Using OpenStudio plug-in for SketchUp[7] two models were created which are the following:

- 3D model (containing building geometry, surface areas and space volumes);
- OpenStudio model containing information assigned to thermal zones.

The construction of the geometric model and information model was parallel. Spaces were created with the following tools; “New space” and “Create spaces from diagram”, as shown in Figure V - 1.

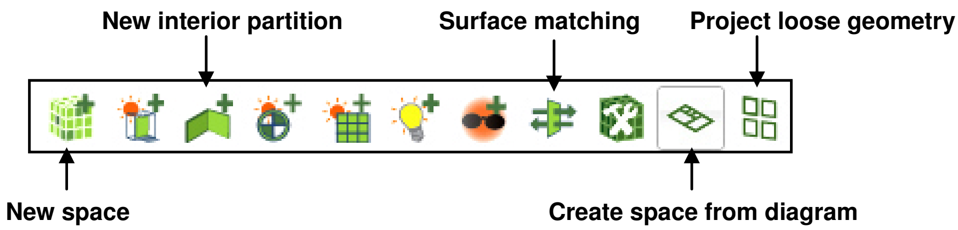


Figure V - 1 Space creation tools

Windows were modeled after the building geometry was constructed and the loose geometry was projected onto the exterior surfaces with the “Project loose geometry” tool, Figure V - 1. The spaces were modeled as separate geometries; therefore each space had its own surface boundaries. In order to prepare the model for thermal zone assignment and energy simulation, double surfaces needed to be matched in the whole geometric model with the surface matching tool, Figure V - 1. This tool automatically matches all surfaces which have the same coordinates.

[6] NREL OpenStudio Version 1.0.0., 2013, Build no. 12393, Copyright © 2013 National Renewable Energy Laboratory

[7] Program Sketchup Make 3D, 2013, http://www.sketchup.com/products/sketchup-make

Surface matching is mainly important since the material assignment in further model preparation applies only for single surfaces. The automatic surface matching was performed for the whole model in horizontal and vertical direction. The final result is shown in Figure V - 2 as a 3D section, where interior surfaces are green, exterior surfaces are in blue and ground surfaces in brown color.

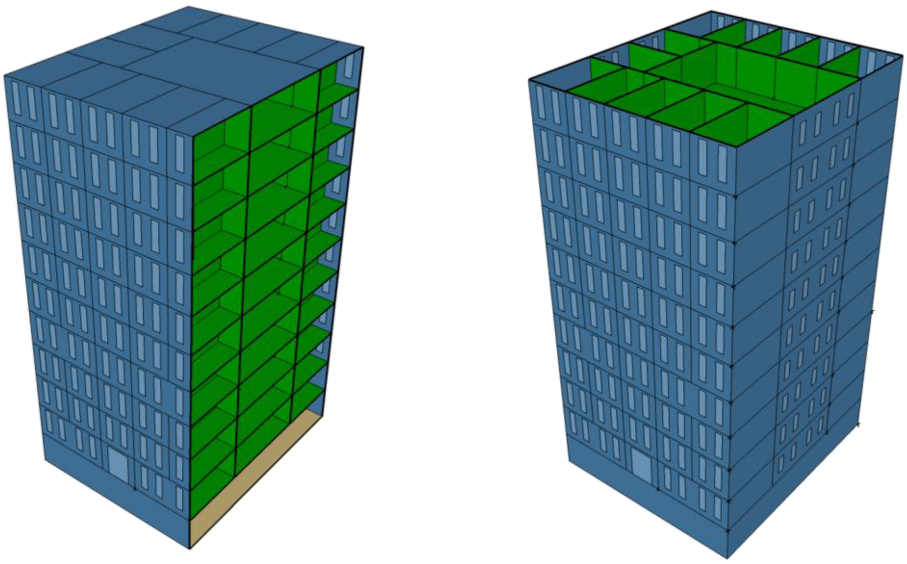


Figure V - 2 Surface matching

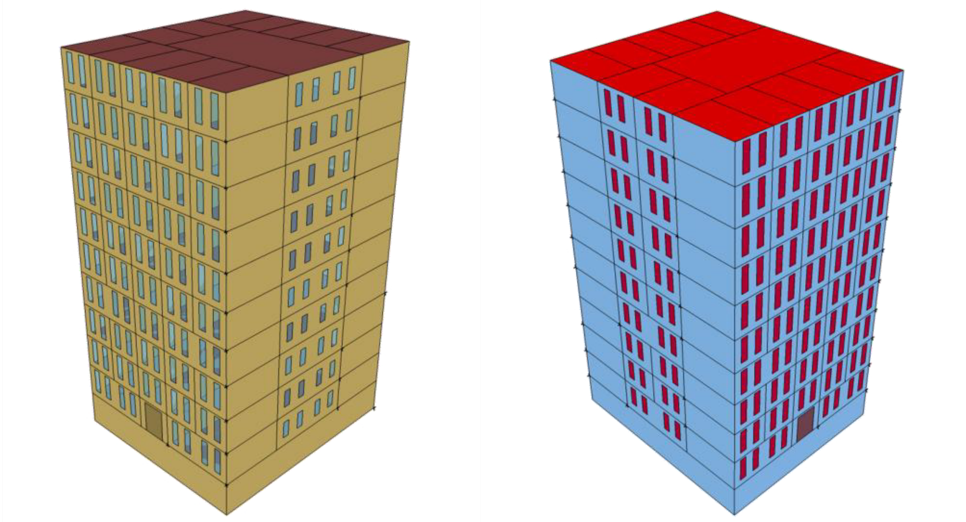
After surface boundary condition definition the following steps included the assignment of:

- Surface types, Figure V - 3;
    - Interior surfaces (partitions, ceiling),
    - Exterior (exterior wall, roof, basement wall and ground slab) and
    - Sub-surfaces (windows, doors).
- Construction type, Figure V - 3;
    - Reinforced concrete (slabs),
    - Masonry construction (exterior walls).
- Building stories, Figure V - 3;
    - Basement,
    - Ground floor, and
    - 1 – 9 floors.
- Space types;
    - Large office building spaces.
- Thermal zones, Figure V - 4;
    - Defined according to the space type and zone properties.

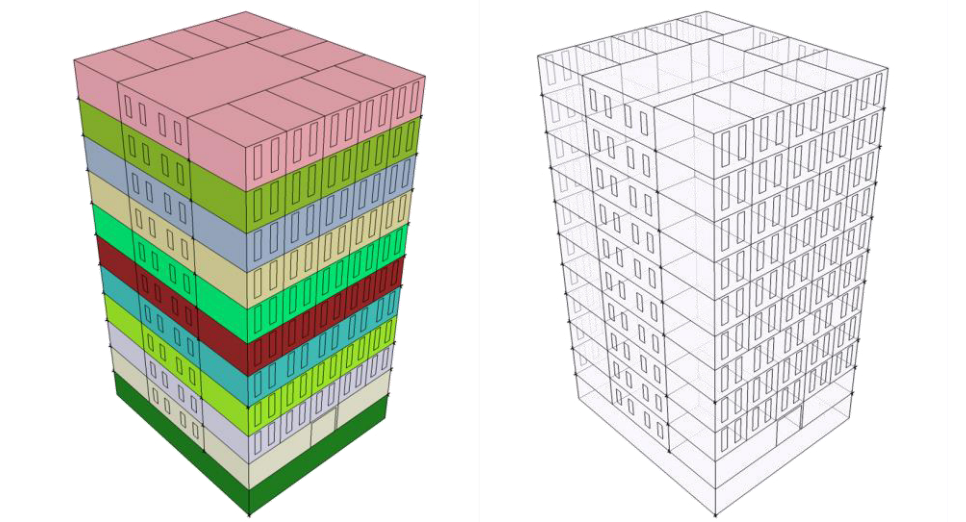
The total number of assignments is shown in Table V - 1.

Table V - 1 Model properties

OpenStudio geometry	No.	OpenStudio zones, construction and resources	No.
OS Space	118	OS thermal zones	24
OS Surface	831	OS construction	282
OS Subsurface	270	OS building story	11

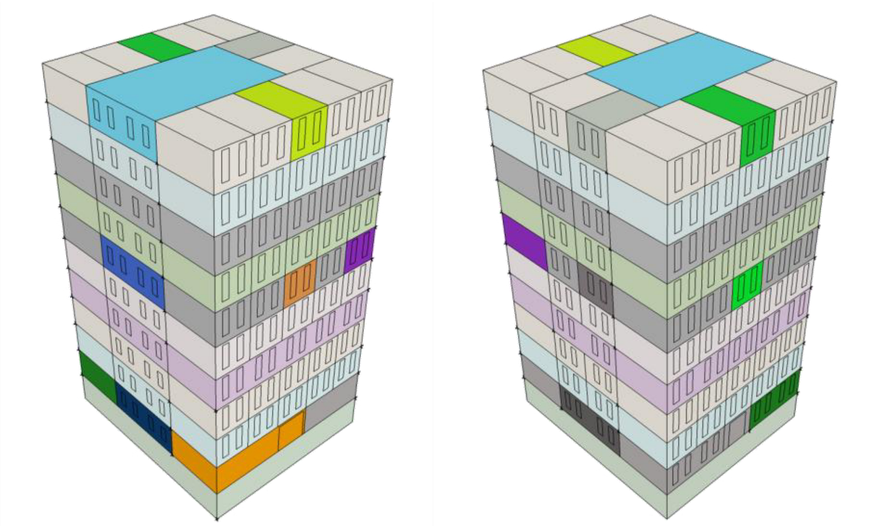


Rendering by surface type **Rendering by construction type**



Rendering by stories **Rendering by interior partitions and ceilings**

Figure V - 3 Surface type, construction type, building stories and interior partitions



Comfort parameters were simulated for highlighted zones on ground floor, 5th and 9th floor

Figure V - 4 Thermal zones

5.1.2. Zone loads

5.1.2.1. Internal heat gains

Internal heat gain is the major component of the total building cooling load for non-residential buildings; commercial, institutional and industrial. The cooling load is not always equal to the internal heat gains, since it depends from the mechanical equipment which is used in the building. Heat can be extracted by equipment resulting in cooling load decrement (ASHRAE Handbook 2005). The process is presented in Figure V - 5.

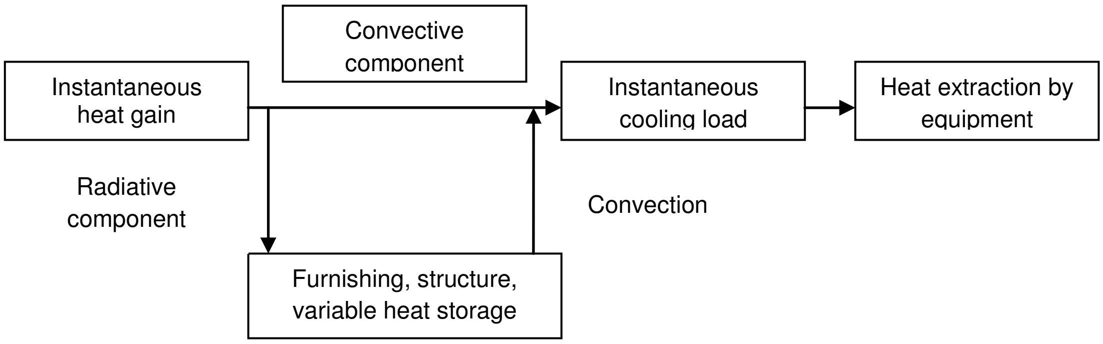


Figure V - 5 Heat gain ≠ cooling load

Latent heat (moisture or water vapor) from people and equipment added to the space is an instantaneous cooling load. Sensible heat generated by internal heat sources (people, lights and equipment) is a time-delayed cooling load. As with solar radiation heat entering the space, part of sensible heat generated by internal sources is first absorbed by the surroundings and then gradually released into the air increasing its temperature. The air temperature is sensed by the control system (thermostat) which operates the cooling system and equipment. So there is a time-delay in the corrective action also (Adref 2012).

Internal heat gains from people are assigned according to the metabolic rate of the occupants which is defined by the activity. For office buildings the activity of occupants is majorly sedentary. Internal loads for lights and equipment have to be implemented in the simulation according to the schedules and operation intensity. Internal heat gains for an hourly run-time energy simulation are estimated on an annual basis. The weather data will significantly affect the internal gains in the indoor environment due to building envelope's thermal performance, infiltration and ventilation. Heat gain sources in a space are the following:

- Solar radiation;
- Conductive heat gain;
- Electric lighting;
- Equipment, and
- Occupants.

The heat gain sources are also presented in Figure V - 6 (University of Strathclyde Glasgow n.d.).

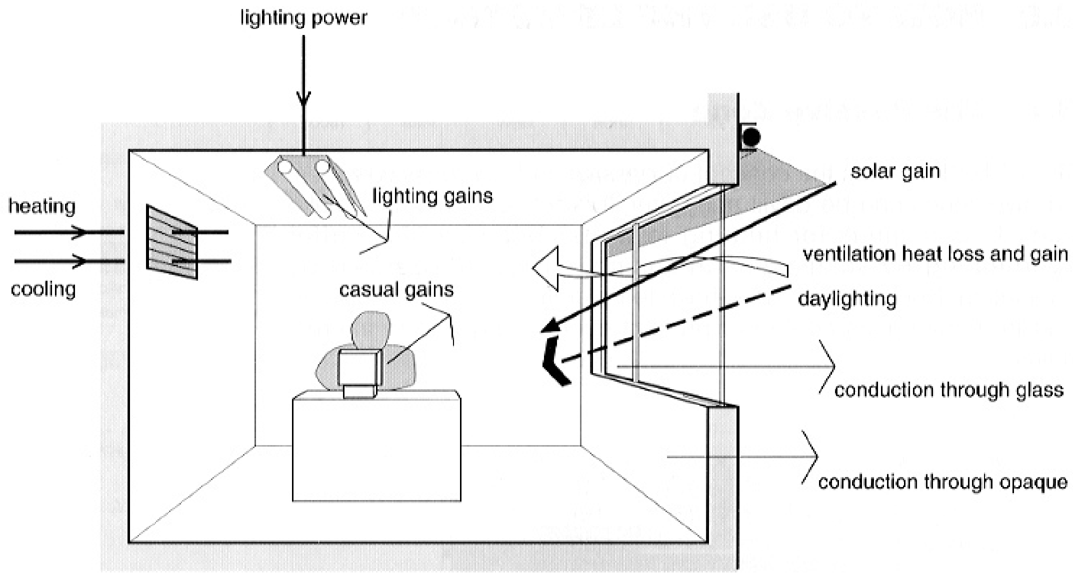
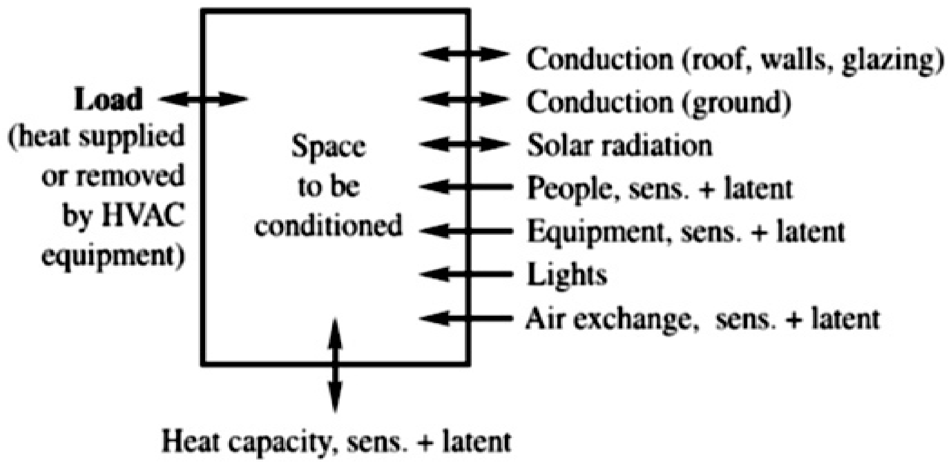


Figure V - 6 Sources of heat gain

Energy simulations in the investigation will be performed with the utilization of the heat balance (HB) method with algorithms applying system thermodynamics. Sensible and latent heat gain are the principle terms of determining heat gains and losses in buildings via HB method as shown in Figure V - 7 (ASHRAE Handbook 2005).

Sensible heat gain is the heat added to space by conduction, convection and/or radiation (Adref 2012).

Latent heat gain is the energy added to space when moisture is added to space by means of vapor emitted by occupants, generated by process or through air infiltration from outside or adjacent areas (Adref 2012).



(Source: ASHRAE Handbook Fundamentals 2005)

Figure V - 7 Heat Balance – Principal terms of heat gains and losses

5.1.2.2. Occupants

Internal gains from occupants were assigned in OpenStudio in the “people definition” dialog box. The number of occupants and internal gains were implemented in the energy simulation setup by the following steps:

- Expected number of occupants was calculated – possibility analysis;
- Occupied office areas were calculated;
- Unoccupied areas were calculated.

The expected number of occupants on building levels is shown in Table V - 2. Areas of the office spaces on each level are shown in the third column. Office areas, communication areas and utilities are presented respectively.

Table V - 2 Occupant number and approximated office areas

No. of occupants	Building level	Office area approx. [m^2]
(18 x 6) 108 pers.	4^{th} – 9^{th} level	(196 x 6) 1176
8 pers.	3^{rd} level	196
12 pers.	2^{nd} level	196
16 pers.	1^{st} level	196
10 pers.	Ground level	133
Rarely occupied	Basement	0
Total no. 154 pers. Adopted no. 160 pers.	Total no. 11 levels	Total area: 3430 m^2 Office area: 1897 m^2 Entrance, hall, corridor, staircase, elevators, WC, sub-station spaces, installation spaces, archive, other: 1533 m^2

From the 4^{th} to 9^{th} level the space floor area per person equals 10.8 m^2/pers. On the 3^{rd} level equals 24.5 m^2/pers and on the 2^{nd} level is 16.33 m^2/pers. Finally on the ground level if approximated to total office area on a single level, as done previously, the space floor per person is 13.3 m^2/pers.

5.1.2.3. Electric equipment and electric lights

Electric equipment definition

Electric equipment definition was imported in OpenStudio from the Building component library (BLC) as “ASHRAE_189.1-2009 Climate Zone 1-3 Large Office Whole Building Electric Equipment Definition”. The specified electric equipment energy requirements were imported as a default value from the BLC library, 5.812514 W/m^2. Electric equipment schedules were modified and adjusted to the equipment definition of the office tower building. Three priorities were formulated according to the lighting schedule, which are the following:

- Priority 1 – Weekday schedule
- Priority 2 – Saturday schedule
- Priority 3 – Sunday schedule

The equipment schedules were formulated for a period of one year from 1st of January to the 31st of December. Highest intensity 0.9 was set up in interval from 8.00h to 17.00h continuing in stepwise descent until 20.00h in case of Priority 1, weekday schedule, presented in Figure V - 8. Priority 2, Figure V - 9, refers to Saturday electric equipment schedule and is setup for an occupied period of 4 hours with the intensity of 0.5. Finally Priority schedule 3 presents the equipment intensity on Sundays which was approximated to 0.3 throughout the day, Figure V - 10. Some electric equipment are necessary to be activated on Sundays respectively which takes into account the security system and "standby" mode of computers and other appliances.

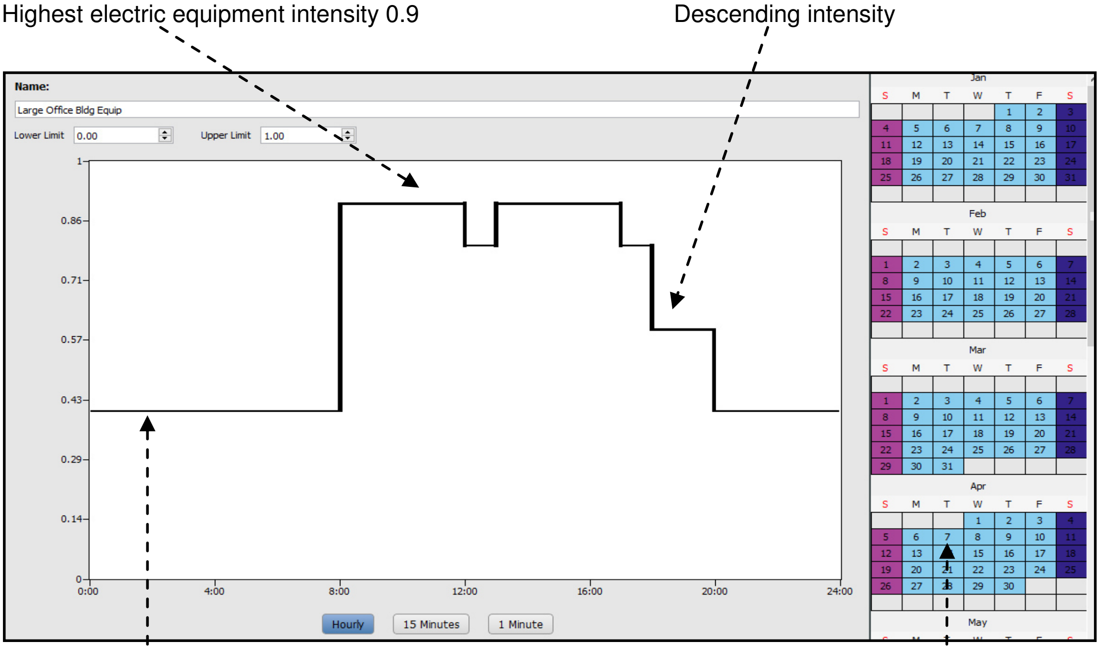


Figure V - 8 Priority 1 electric equipment intensity – Weekday schedule profile

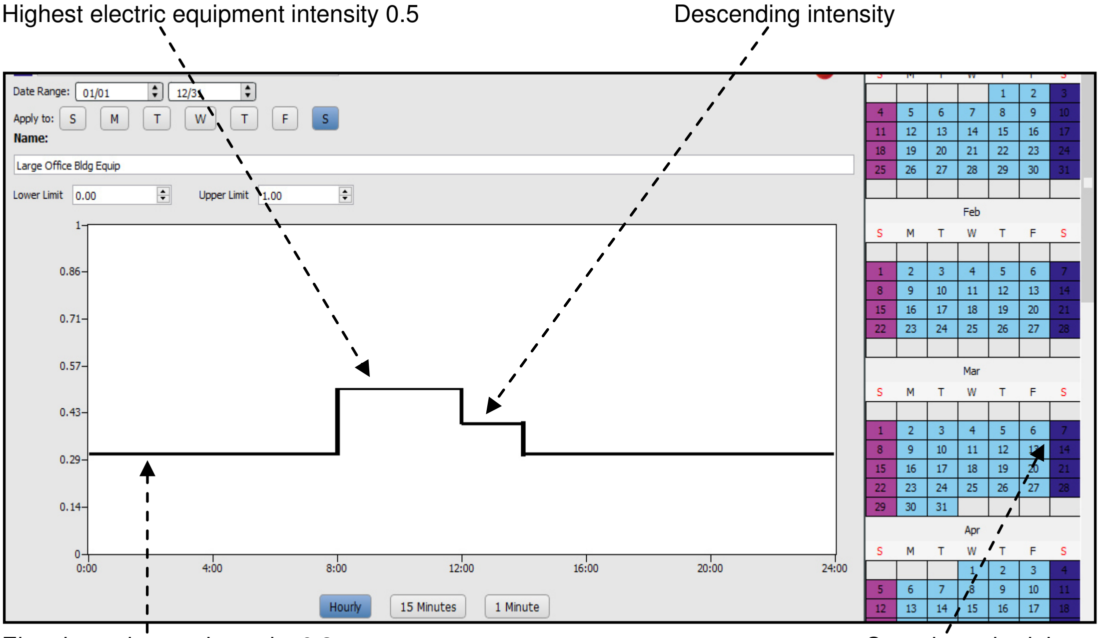


Figure V - 9 Priority 2 electric equipment intensity – Saturday schedule profile

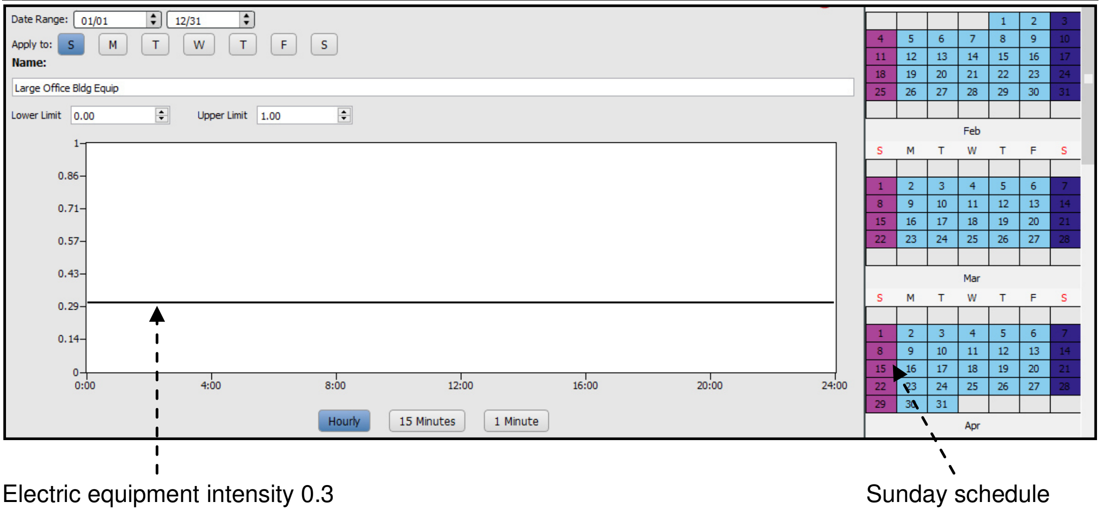


Figure V - 10 Priority 3 electric equipment intensity – Sunday schedule profile

Electric lights definition

Light definitions were imported identically from the BLC library in OpenStudio as “ASHRAE_189.1-2009 Climate Zone 1-3 Large Office Whole Building Lights Definition”. The energy demand of electric lights was 9.687519 W/m^2. Lighting schedules were modified and adjusted to the lighting definition of the office-tower building. Three priorities were formulated according to the lighting schedule, which are the following:

- Priority 1 – Weekday schedule
- Priority 2 – Saturday schedule
- Priority 3 – Sunday schedule

The schedules were defined for a period of one year from 1st of January to the 31st of December. Highest intensity 0.9 was set up in interval from 8.00h to 17.00h continuing in stepwise descent until 20.00h in case of Priority 1, weekday schedule, presented in Figure V - 11.

Priority 2, Figure V - 12, refers to Saturday electric lighting schedule and is setup for an occupied period of 4 hours with the intensity of 0.5. Finally Priority schedule 3 presents the lighting intensity on Sundays which was set to 0.06 throughout the day, as shown in Figure V - 13. Since the office building is not occupied on Sundays the electric lighting intensity was approximated to 0.06 as a “standby mode” considering the main entrance with hall on the ground floor.

Considering the Priority schedules, all lighting profiles were setup as a constant graph throughout an annual period in the energy simulation. Previously performed simulations elaborated in Chapter 3 “CAD model, WWR and WG analysis and illumination simulation”, two modes were simulated in Radiance CP for electric lighting:

- On/off mode and
- Dimming switch mode.

The results indicated the percentage of unnecessary usage of electric lighting in the building according to each orientation. Results in Table V - 3 present the selected mode with the best performance.

Table V - 3 Annual percentage of electric lighting needlessness

Orientation	Dimming mode - Annual percentage of lighting turned off [%]
East	69
South	70
West	66
North	67

Photoelectric simulations were performed using the weather data of Novi Sad which contained solar radiation data of and sky conditions. Considering Table V - 3 the annual percentage of electric lighting energy which will be deducted from the annual energy demand for lighting is 68%.

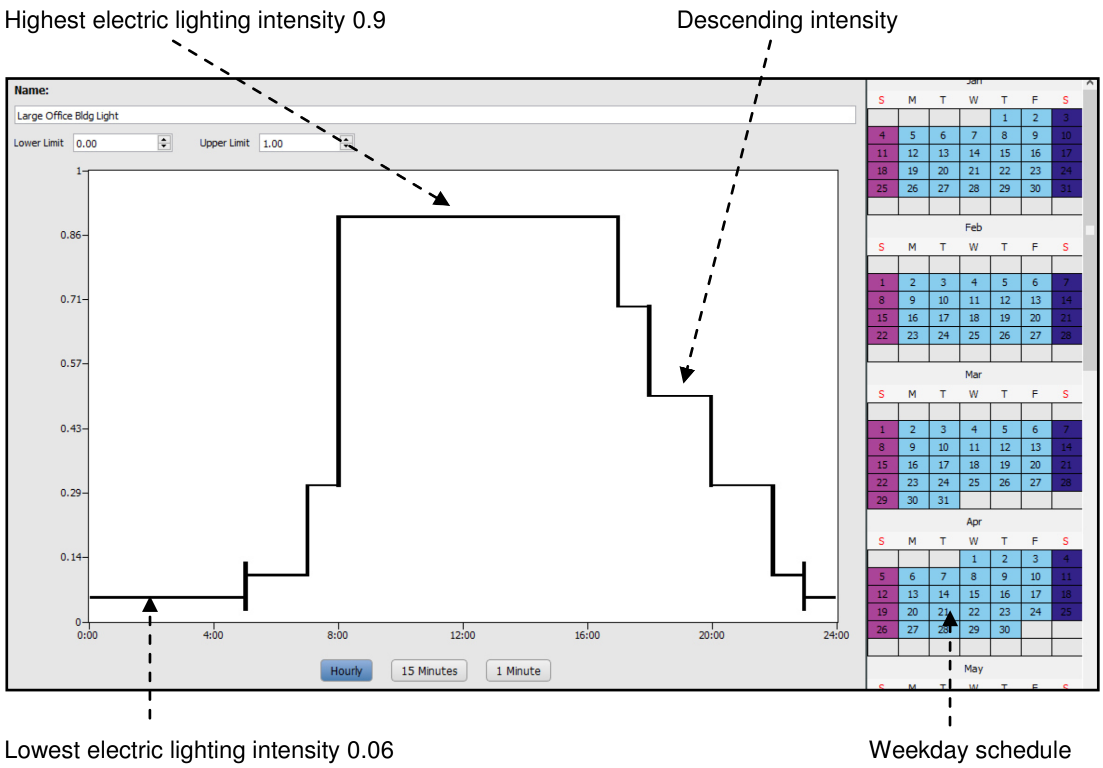


Figure V - 11 Priority 1 electric lighting intensity – Weekday schedule profile

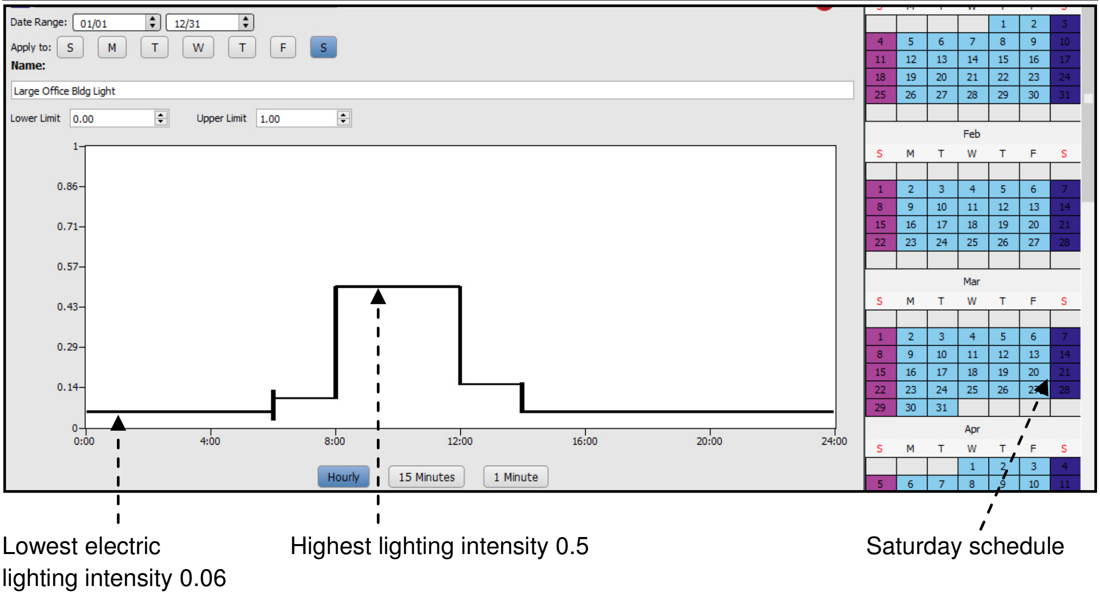


Figure V - 12 Priority 2 electric lighting intensity – Saturday schedule profile

Figure V - 13 Priority 3 electric lighting intensity – Sunday schedule profile

5.1.3. Occupancy

5.1.3.1. Occupancy intensity, activity and schedules

Buildings occupancy is the act of occupying spaces during a period of time. In the following energy simulation the occupancy is defined according to the:

- Occupancy intensity in the function of occupied period, and
- People activity in the function of the occupied period

The number of occupants for the building was approximated to 160 people and the schedules were assigned primarily for the occupancy intensity in the function of occupied period. The “Run Period Profiles” were formulated as a Priority 1 profile for weekdays followed by Priority 2 for Saturday and Priority 3 for Sunday. The Default weekday profile occupancy intensity of 160 people is presented in Figure V - 14. The limits of occupancy intensity is defined on the vertical axes from 0 – 1, while the horizontal axes present the occupied hours from 0 – 24h. Occupancy period starts from 6.00h in the morning with a lowest intensity. The workday starts from 8.00h with the highest intensity until 17.00h. A lunch break has been added with lower occupancy intensity with a probabilistic prediction that the intensity is decreased to half. After 17.00h the occupancy descends stepwise since occupants have in major instances extended working hours.

Priority 2 for Saturday is shown in Figure V - 15, where the occupancy was set to its highest intensity 0.5 from 8.00h to 12.00h. After 12.00h the intensity is descending to half and finally 0.0 at 14.00h. Priority 2 was assigned in order to simulate a Scenario with possible high internal loads and to analyze the energy performance for a significantly occupied environment.

Priority 3 for Sundays in presented in Figure V - 16, where the occupancy intensity was set to 0.0 throughout the day. The occupancy was approximated to 0.0 since the office building on Sundays is almost never occupied. All Priorities were implemented for a period of one year starting from the 1st of January until the 31st of December. The occupancy intensity affects the internal heat gains of offices which will be significant in the heating and the cooling demand calculation. According to the thermostat schedule setup the HVAC system demands will be simulated adhering to the temperature limits.

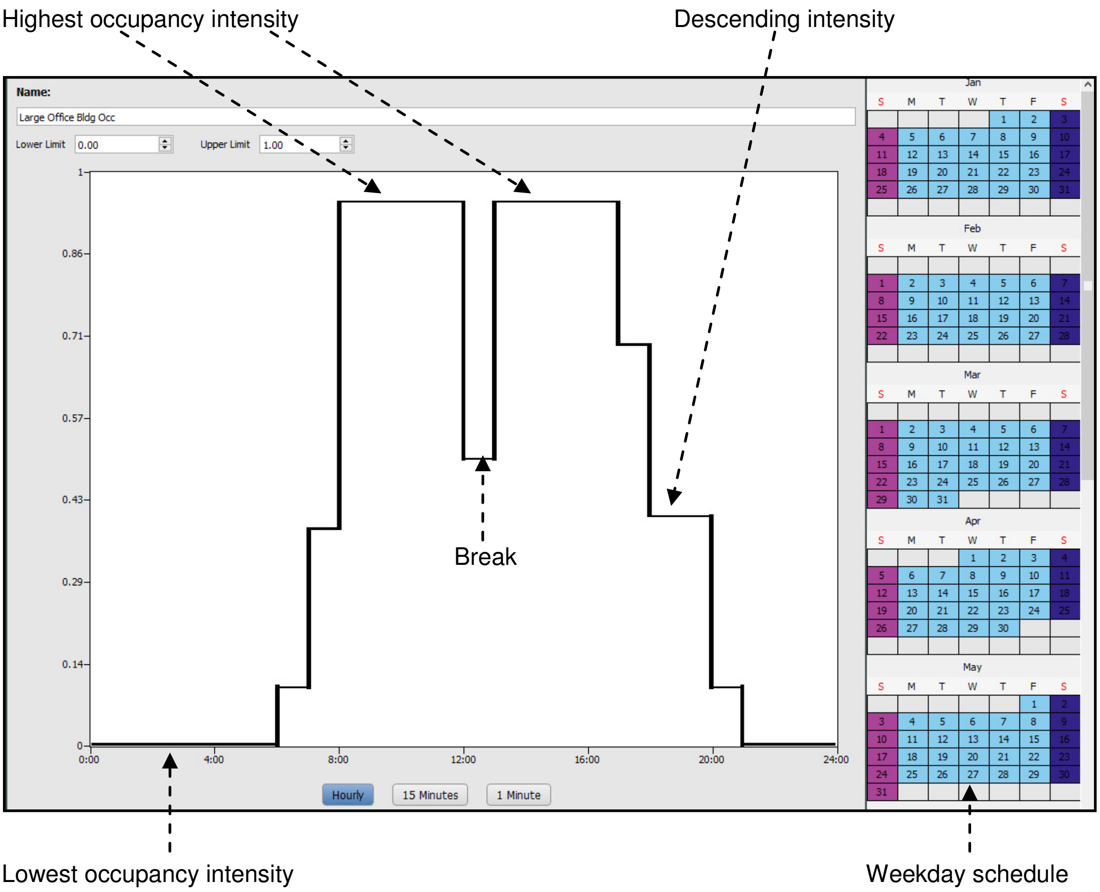


Figure V - 14 Priority 1 occupancy intensity – Weekday schedule profile

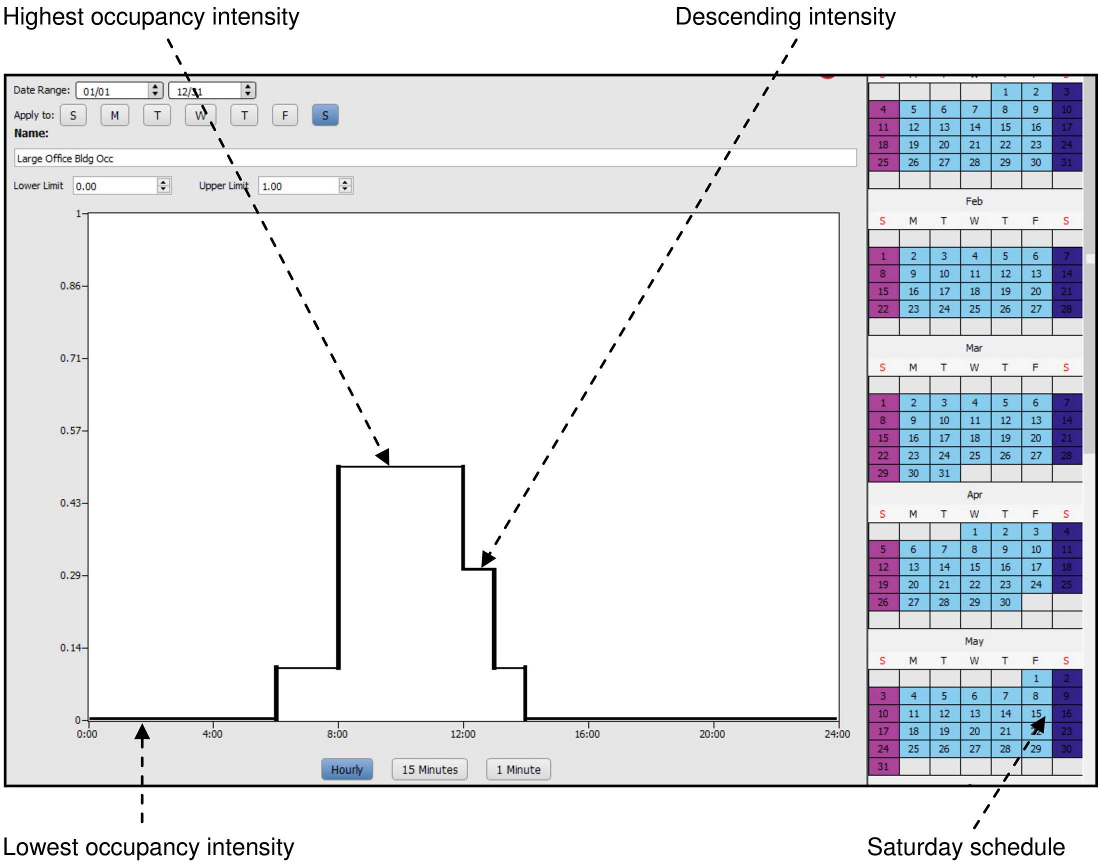


Figure V - 15 Priority 2 occupancy intensity – Saturday schedule profile

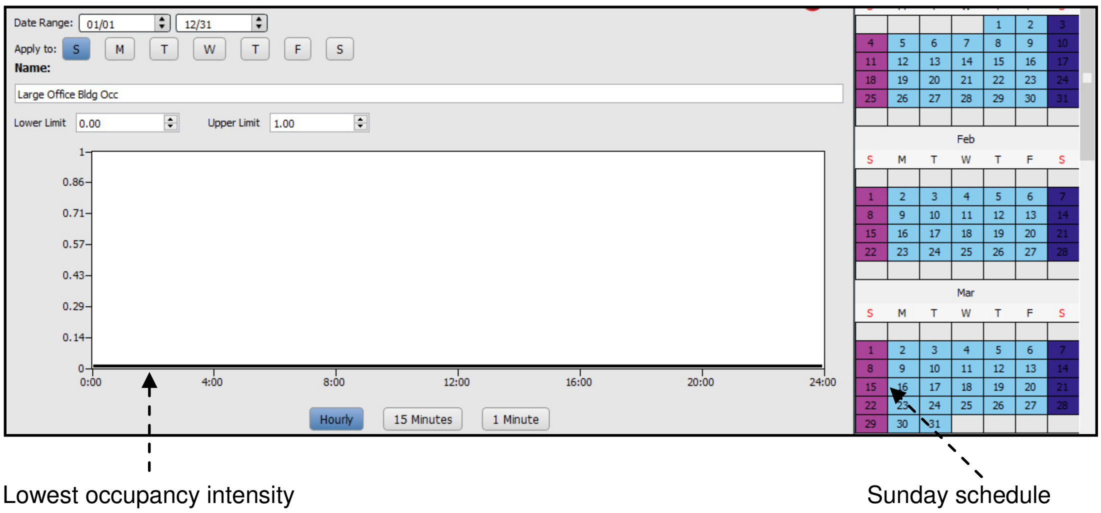


Figure V - 16 Priority 3 occupancy intensity – Sunday schedule profile

The activity schedule was set up according to the metabolic rate of the occupants which equals 1.2 met of a grown person. In a sedentary environment the metabolic rate is 70 W/m^2, the surface area of a normal adult is 1.7 m^2 which results in 119 W/person (Chadderton 2007). The interior heat gain from occupants was adapted 120 W/person in the simulation in the function of occupancy intensities and schedules elaborated previously. Internal gains from occupants will be simulated in accordance with the intensity scales presented in Figures V - 14, V – 15 and V - 16.

5.1.3.2. Thermostat schedules

Thermostat schedules were set up for the heating and cooling period. Temperature limits were defined according to the comfort criteria for minimum and maximum temperature values. Considering a sedentary environment typical for offices the minimum temperature limit for the heating period was set to 21°C and for the cooling period the maximum temperature limit was 25°C in compliance with the requirements of the II comfort category limits from EN 15251 (EN 15251 2007) . Since limit values were set up thermostats in the multi-zone model needed to be scheduled. Thermostat schedules were assigned according to occupancy periods, which were previously elaborated and presented in Figures V - 14, V - 15 and V -16.

Heating schedule definition

Thermostat schedules for the heating period are set up from the 15th of October to the 14th of April. Priority schedule 1 has the following characteristics, shown in Figure V - 17. The heating of zones was set up from 7.00h (one hour before start of the workday) to 17.00h. Limits for the thermostat have the following values; 21°C was the upper limit and 15.6°C was set as the lower limit (the lower limit which was imported into OpenStudio with the definition "ASHRAE large office thermostat definition heating setup").

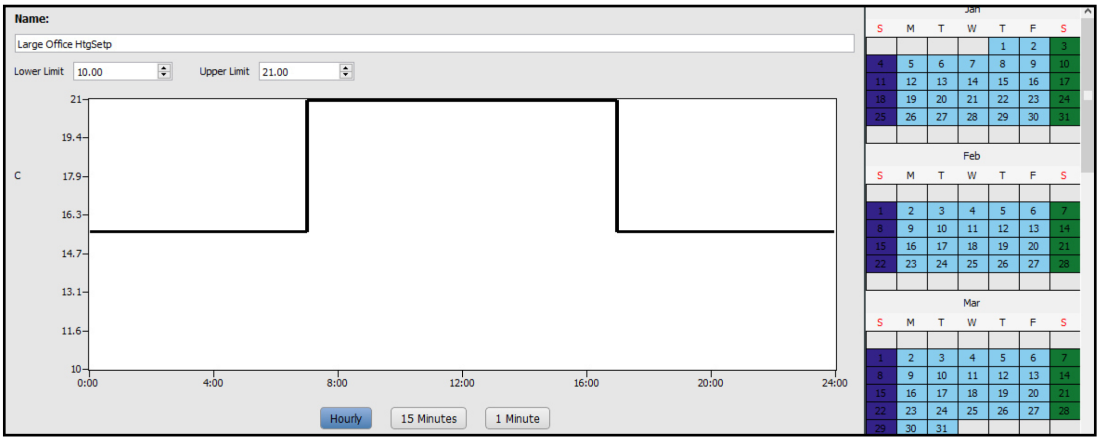


Figure V - 17 Priority 1 thermostat schedule for the heating period – Weekday schedule profile

Priority schedule 2 refers to Saturdays when the approximated occupancy is 4 hours, from 8.00 to 12.00h, which is presented in Figure V - 18. Temperature limits are identical as defined in Priority 1 and the heating starts from 7.00h. Heating can be operated manually since all zones will not be occupied.

Simulations calculated a significantly loaded scenario considering that the building is loaded on Saturdays for 5 hours. Since the occupancy intensity for weekends cannot be verified accurately the probabilistic prediction referred to a constantly loaded environment. If the heating on/off switching is manually activated during these 5 hours, heating demand can be reduced since only occupied offices will require energy. By 12.00h the heating will be automatically turned off in the whole building according to the schedule and energy will be saved.

Priority schedule 3 refers to Sundays when the building is not occupied. The heating is turned off and the lowest temperature limit is set to 15.6 °C which means that the heating system is only activated if the temperature falls below the critical boundary, Figure V - 19. To prevent this scenario the thermal characteristics of building envelope have to demonstrate high quality.

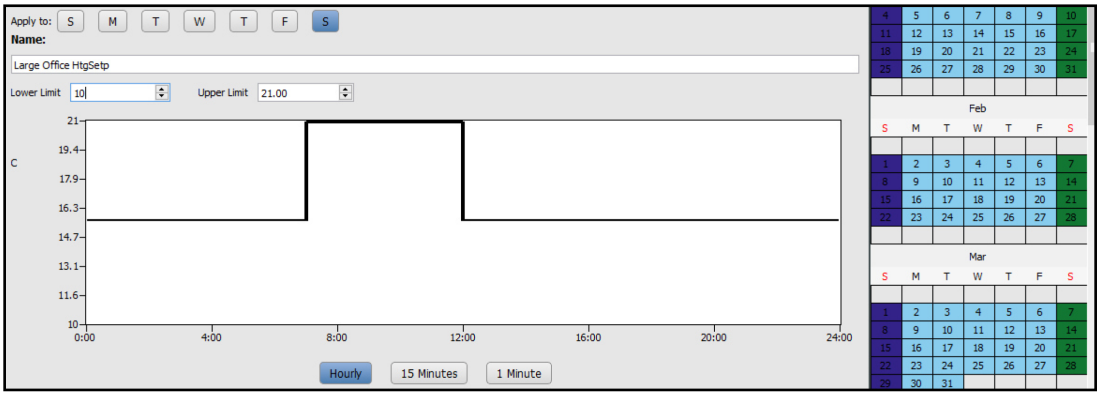


Figure V - 18 Priority 2 thermostat schedule for the heating period – Saturday schedule profile

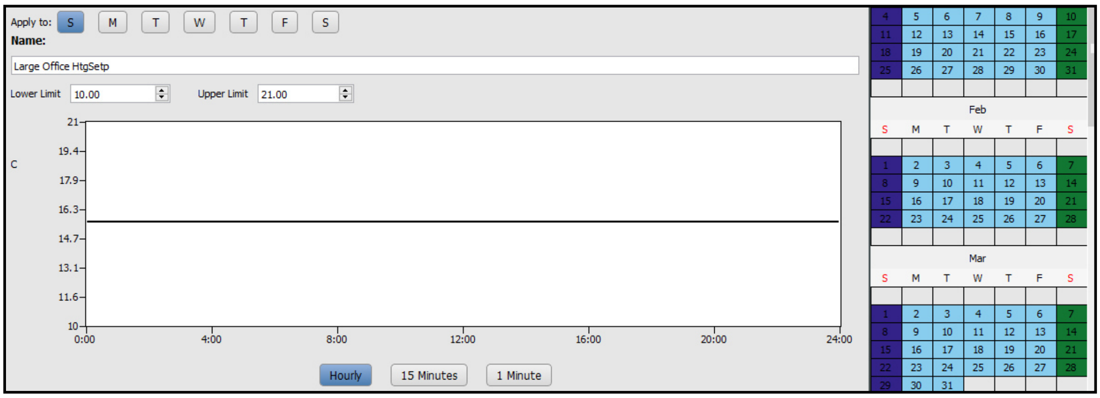


Figure V - 19 Priority 3 thermostat schedule for the heating period – Sunday schedule profile

Cooling schedule definition

Thermostat schedules for the cooling period are set up from the 15th of April to the 14th of October. Priority schedule 1 has the following characteristics, shown in Figure V - 20. The cooling of zones starts from 7.00h (one hour before start of the workday) to 17.00h. Limits for the thermostat have the following values; 26.7 °C was the upper limit and 25 °C was set as the lower limit.

Priority schedule 2 refers to Saturdays when the approximated occupancy is 4 hours, from 8.00 to 12.00h, which is presented in Figure V - 21. Temperature limits are identical as defined in Priority 1 and the cooling starts from 7.00h. Cooling can be operated manually since all zones will not be occupied. Simulations calculated a significantly loaded scenario identically as formulated for the heating period. After 13.00h the cooling will be automatically turned off in the whole building according to the thermostat schedule and energy will be saved.

Priority schedule 3 refers to Sundays when the building is not occupied. The cooling system is turned off and the highest temperature limit was set to 26.7°C (the highest limit was imported into OpenStudio with the definition "ASHRAE large office thermostat definition cooling setup") which means that the cooling is only activated if the temperature rises above the critical boundary, Figure V - 22.

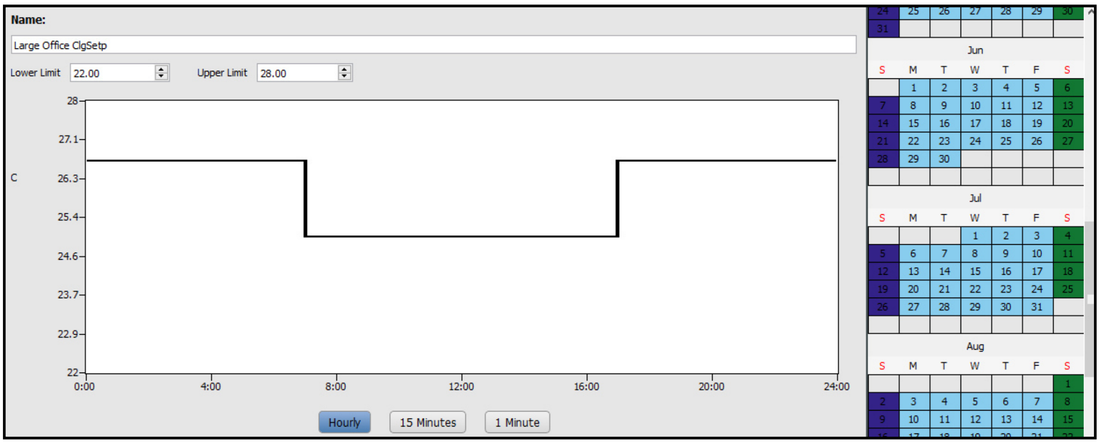


Figure V - 20 Priority 1 thermostat schedule for the cooling period – Weekday schedule profile

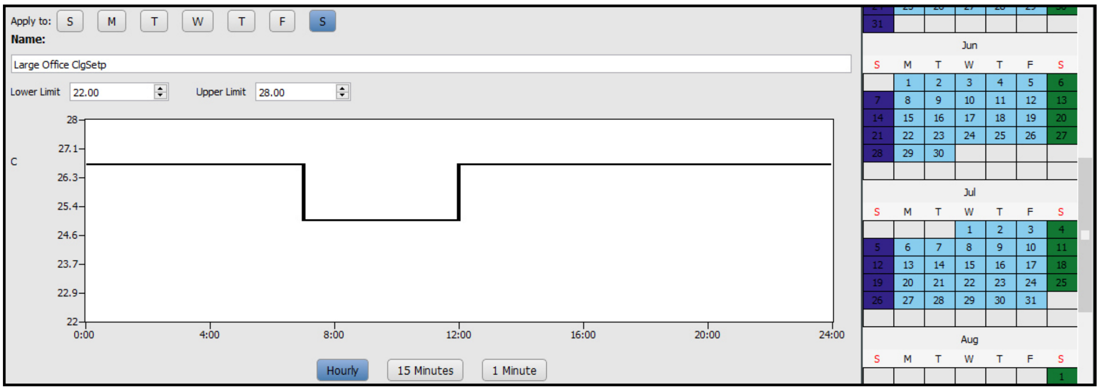


Figure V - 21 Priority 2 thermostat schedule for the cooling period – Saturday schedule profile

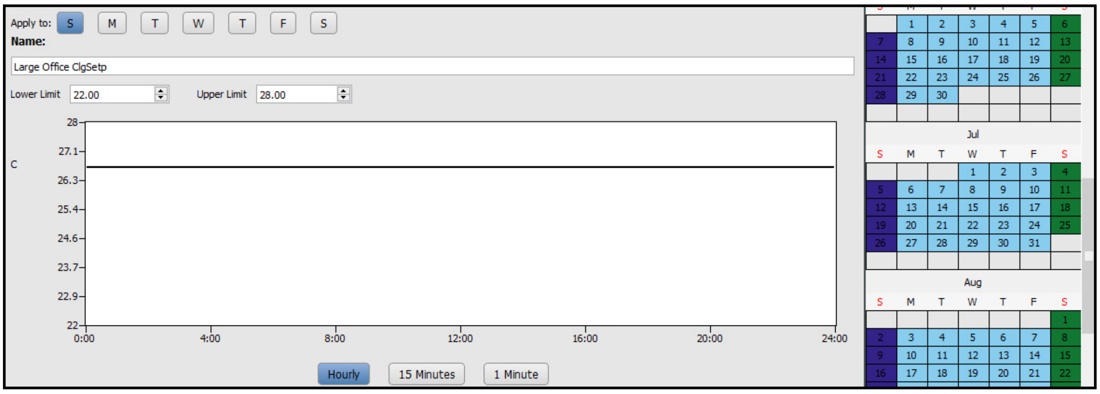


Figure V - 22 Priority 3 thermostat schedule for the cooling period – Sunday schedule profile

5.2. Energy performance simulation

5.2.1. Simulation methodology

EnergyPlus has been selected in the research since today this engine is one of the most widespread dynamic energy simulation engines which calculates with significant accuracy. EnergyPlus uses the heat balance method for building energy load analysis which requires more data and more details for all the load component definitions. The construction of an EnergyPlus multi-zone thermal model, which includes property definitions and simulation calibration, requires undertaking numerous steps. The exploration of the annual building energy performance has to overcome the following steps:

1. **Geometric modeling of the reference building via BIM technology**
2. **Designing the building envelope with improved WWR and WG in the function of illumination dispersion analysis and photoelectric CIBSE analysis**
3. **Development of a simulation base multi-zone thermal model and definition of thermal zones, building levels and surfaces and space types**
4. **Exporting the multi-zone thermal model to OpenStudio in order to implement construction and envelope properties, assign material properties and parameters, internal loads, schedules and zone definitions**
5. **Converting the model to EnergyPlus numerical data with IDF extension**
6. **Importing the weather data and coordinates into EnergyPlus, and setting up the simulation environment, calculation algorithms a runtimes**
7. **Analyzing and evaluating the results**
8. **Selecting performable Scenarios and predicting PMV and PPD indexes from the Fanger comfort model**
9. **Optimizing the Scenario with detailed comfort parameter analysis**

5.2.2. Dynamic energy simulation in EnergyPlus engine

Prior to running the simulation in EnergyPlus the simulation properties, functions parameters, intervals and run-times are mandatory to be defined in OpenStudio. An overview of the simulation setup complexity is presented in this section referring to the type and amount of data necessary to be imported and defined in a numerical energy model. Before running a dynamic simulation in time function a detailed energy model preparation is mandatory, since the admission of numerous aspects interpretation plays a key role in energy performance assessment. A detailed energy simulation requires all phases of the project to be designed carefully and precisely, so the integrated parameters create a virtual environment approximated to real physical conditions (Harmati, Folić and Magyar (no. 1) 2014).

Simulation setup requires the definition of the following data:

- **Weather file – EPW file path;**
    1. Climate data, weather data and coordinate download from Meteonorm 7,
    2. Data conversion into EPW file importable into EnergyPlus,
    3. Setup of the conversion file into hourly-data export.
- **Schedules;**
    1. Large office building schedule set,
        - Large office building occupancy,
        - Large office building activity,
        - Large office building electric lighting,
        - Large office building electric equipment,
        - Large office building thermostat schedules,
        - Large office building heating setup,
        - Large office building cooling setup.
    2. Simulation run-time schedule
- **Construction;**
    1. Construction materials,
    2. Construction sets,
        - Exterior surface construction,
        - Interior surface construction,
        - Ground contact surface construction,
        - Exterior sub-surface construction,
        - Interior sub-surface construction,
        - Interior partitions.
    3. Large office building construction - “FTS office-tower building construction”
- **Internal loads;**
    1. Occupants definition,
    2. Electric lights definition,
    3. Equipment definition.
- **Facility;**
    1. Building stories,
    2. Space types,
    3. Thermal zones,
        - HVAC system,
        - Thermostat,
        - Sizing parameters.
- **Output variables definition;**
    1. People latent heat gain,
    2. People sensible heat gain,
    3. People radiant heat gain,
    4. People total heat gain,
    5. Zone air relative humidity (RH),

6. Zone mean air temperature (AT),
7. Zone mean radiant temperature (MRT),
8. Zone operative temperature (OT),
9. Zone transmitted solar energy,
10. Zone window heat gain energy,
11. Zone window heat loss energy,
12. Zone outdoor dry bulb,
13. Zone outdoor wet bulb,
14. District cooling facility,
15. District heating facility.

- **Simulation settings;**
  1. Heat Balance algorithm,
  2. Radiance parameters,
  3. Simulation control,
  4. Shadow calculation,
  5. Run periods;
     - Date range,
     - Time step.

Most of the listed categories were elaborated previously;

- Chapter 2 “Methodology and materials” presented the weather data downloaded from the global climatological database Meteonorm and its conversion to EPW extension file importable into EnergyPlus
- Chapter 4 “Building envelope performance” considered the selection of materials and glazing for the building envelope. Thermal characteristics of the envelope were selected according to the standards. The energy simulations will demonstrate the energy performance of the building and confirm which glazing type will perform with highest quality. The influence of material parameters on the annual heating and cooling energy demand will be considered in detail
- Finally, the first part of Chapter 5 considered in details the internal gains and schedule definitions

In following section the EnergyPlus dynamic simulation setup will be presented in detail.

5.2.2.1. EnergyPlus dynamic simulation setup

The investigation applies a complex dynamic simulation to determine detailed annual energy performance, since this type of simulation describes the function and behavior of a thermal multi-zone model. Dynamic simulations are run in time intervals in order to create a realistic environment for detailed investigation of the energy demand.

This section refers to the facility, output variables and simulation setting. Therefore the thermal zone property assignment, output variable selection, simulation algorithms will be emphasized.

5.2.2.1.1. Facility setup

The facility setup considered the assignment of building stories, thermal zones and spaces types of the building model. Since EnergyPlus operates with thermal zones, zone definitions are mandatory in the facility setup.

In the building stories section the following predefined properties need to be assigned:

- Building type (Commercial building – large office);
- Space type (Large office);
- Construction set (FTS Office-tower construction set);
- Schedule set (FTS Office-tower schedule set).

Figure V - 23 shows the setup of building stories with subcategories; roof/ceilings, walls, floors, space shading, interior partitions, lighting objects and loads. Each category was previously created and in the facility setup section depending from the building story and space type dragged and inserted from the model's library. In Figure V - 23 and example is presented for Space 1019 with its subcategories.

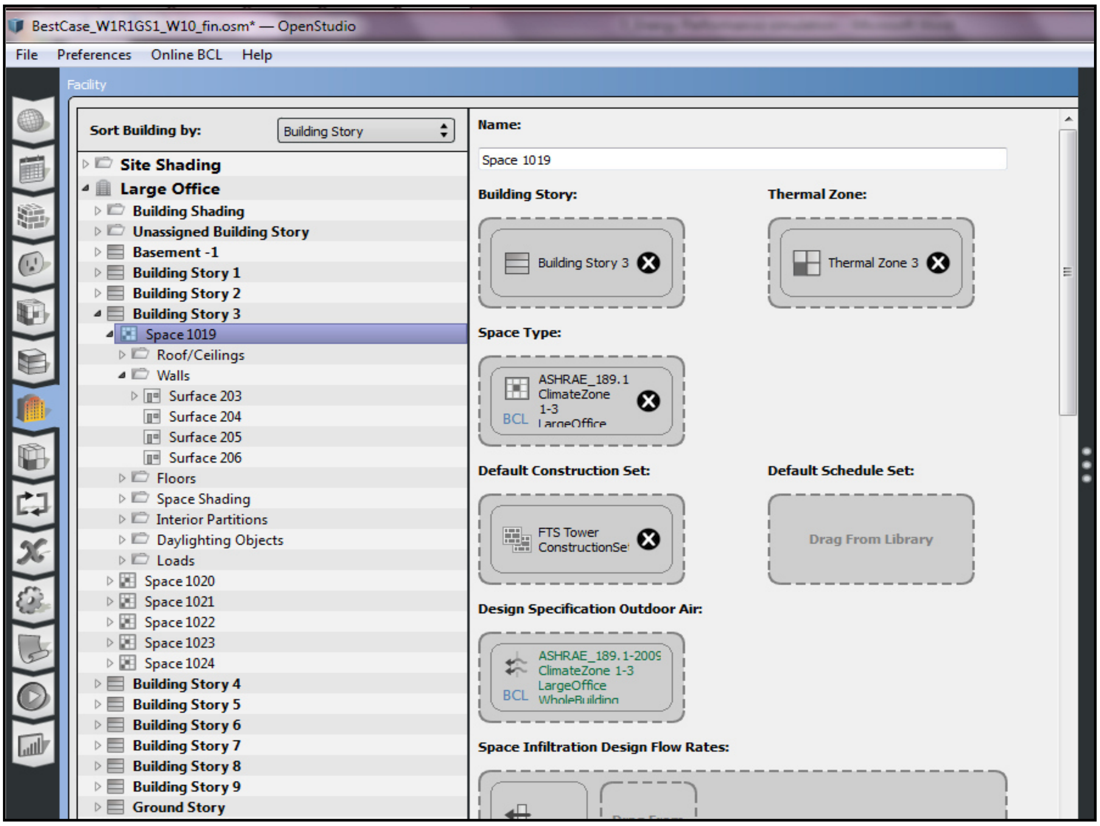


Figure V - 23 Space definition

Figure V - 24 presents the internal loads and schedules elaborated previously in this section for occupancy, electric lights and equipment is case of Space 1019. All 118 spaces in the building model have undertaken the same procedure off subcategory property assignment. The properties were not assigned for each space separately, since OpenStudio has an automatic assignment procedure if identical loads are assigned for identical spaces. Considering an office building, the building loads for an office work environment multiplied by the office spaces crated in the building. Identical office volumes were assigned with identical internal loads.

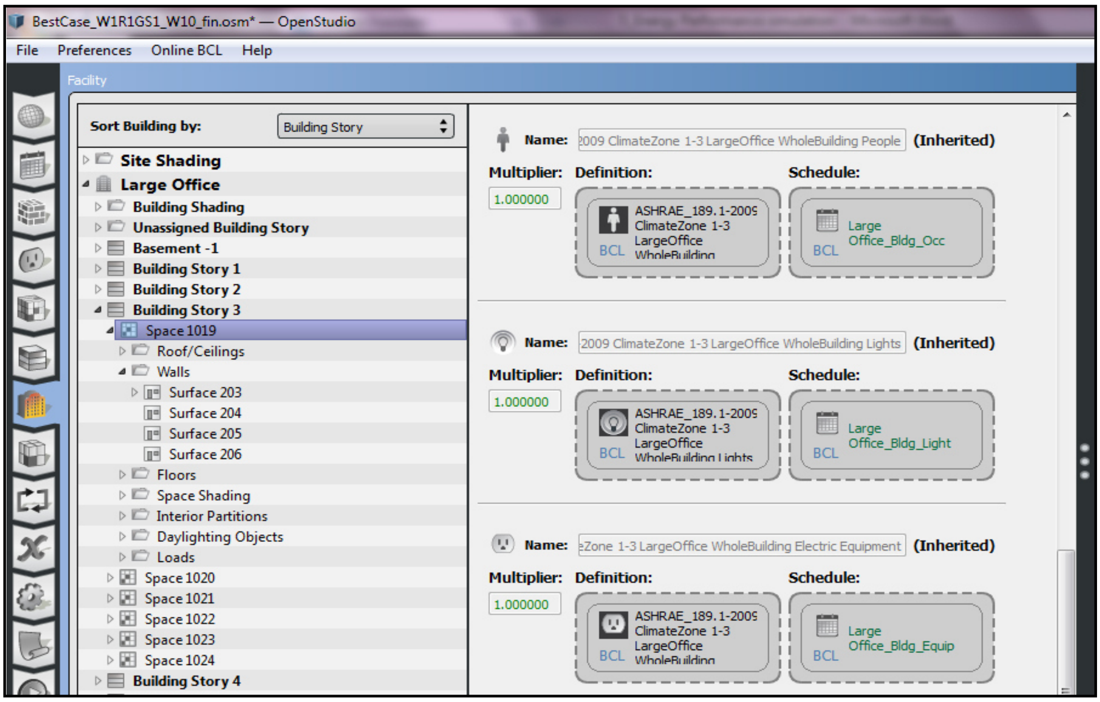


Figure V - 24 Space load assignment

Surface properties were assigned likewise with the following categories as shown in Figure V - 25 for Surface 881 on building story 5. The categories of definition were:

- Surface type;
- Construction;
- Outside boundary condition;
- Outside boundary condition object (depends of surface position);
- Sun exposure calculation;
- Wind exposure calculation.

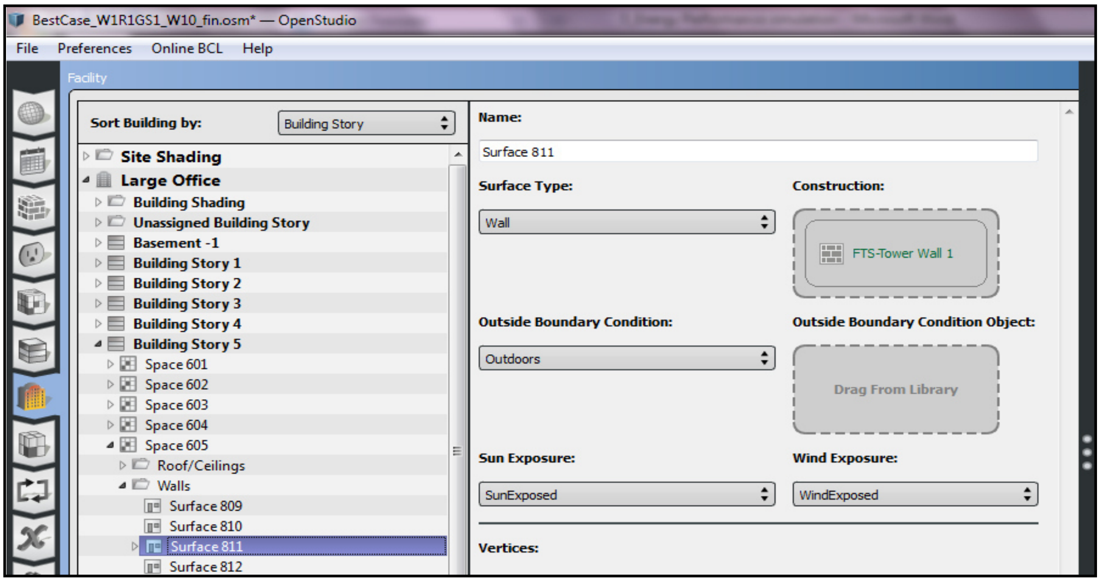


Figure V - 25 Surface definition

The multi-zone thermal model consists of 24 thermal zones, which were assigned according to the building level and orientations. Numerous thermal zones consist of more than one space. Spaces which have identical internal loads and properties were connected into a single thermal zone. Figure V - 26 shows 24 thermal zones in the building model where zones on the ground level (0), 5th and 9th level were divided by orientation (E, S, W and N) for further simulation in order to:

- Investigate the comfort parameters;
- Compare the monitored data with the simulated, and
- Improve the energy performance in the function of comfort parameters.

An example of space connection is presented for thermal zone 0 which consists of space 1017, 1018 and 106.

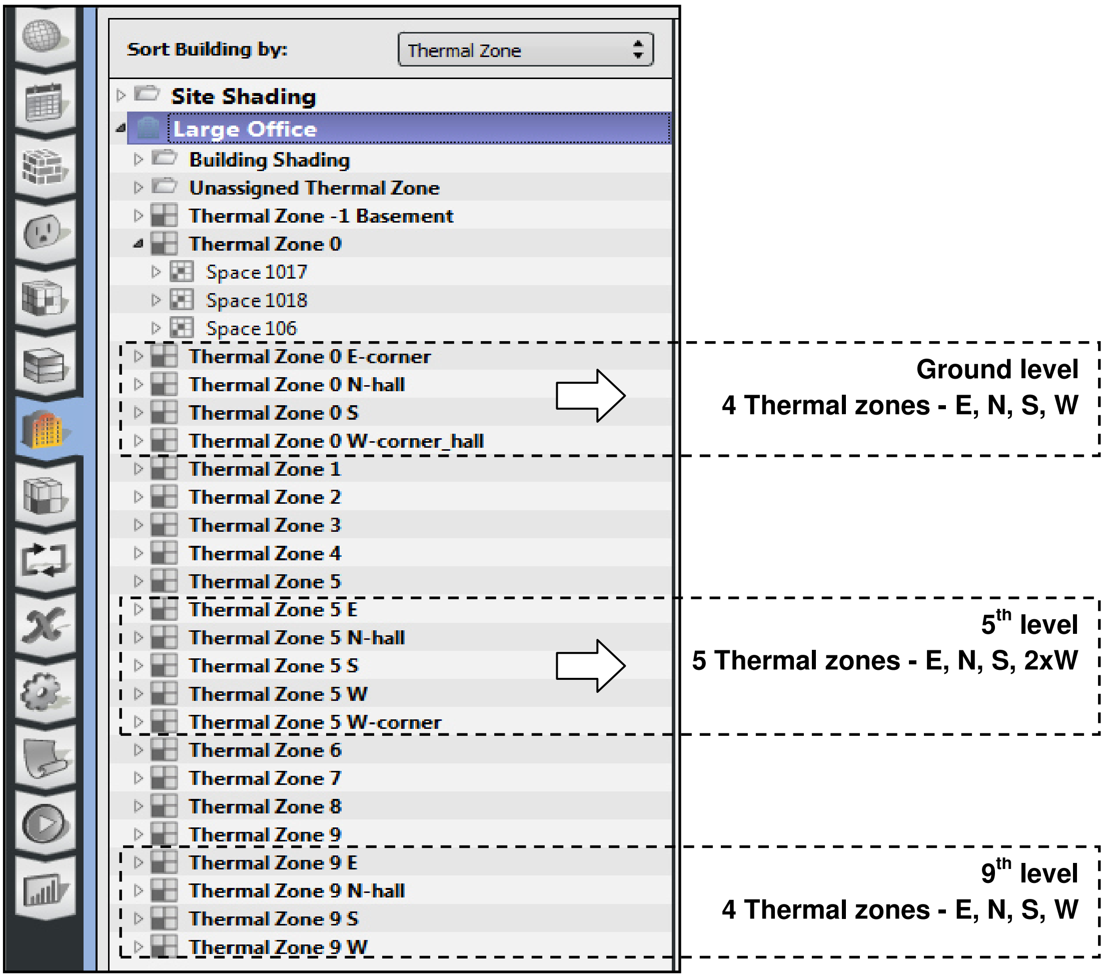


Figure V - 26 Thermal zones

Thermal zones have zone definition options, which are the following;

- HVAC system definition;
- Thermostat, and
- Sizing parameters.

The HVAC system and components were not designed in the building model because the goal was to calculate the heating and cooling energy demand while maintaining comfort parameters in defined limits of the comfort zone. In this investigation the “Ideal load air system” option was activated for all thermal zones.

“The input object *ZoneHVAC: IdealLoadsAirSystem* provides a model for an ideal HVAC system. It occupies a place in the program hierarchy corresponding to a zone HVAC unit. It is not connected to a central air system – instead each *ZoneHVAC: IdealLoadsAirSystem* object supplies cooling or heating air to a zone in sufficient quantity to meet the zone load or up to its limits, if specified. The supply air conditions are controlled based on specifications in the *ZoneHVAC: IdealLoadsAirSystem* input. The system has options for humidity control, outdoor air, economizer, demand controlled ventilation, and heat recovery.” (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012)

The thermostat was assigned for large office building with two previously defined thermostat set-points and schedules for heating and cooling. Set-points and schedules were presented previously in this section from Figure V - 17 to V - 22.

Sizing parameter for thermal zones in OpenStudio for ideal air loads were the following, shown in Figure V - 27.

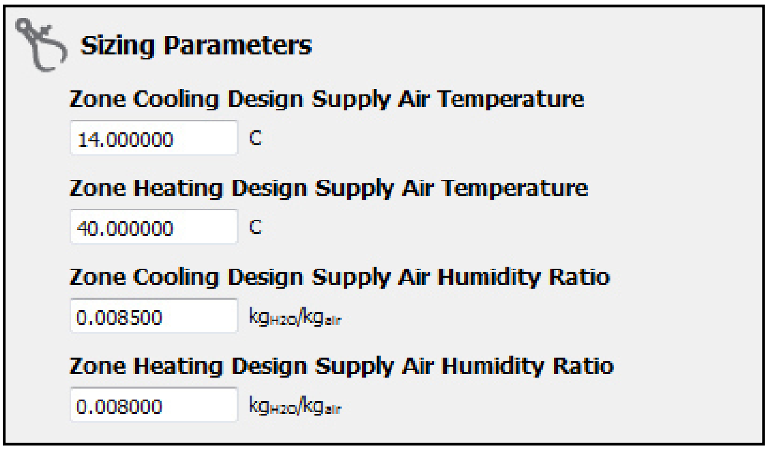


Figure V - 27 Sizing parameters

5.2.2.1.2. Output variables definition

Output variables were selected considering the analysis of comfort parameters and necessary variables for the static comfort model equations; PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied).

Parameters which are necessary for the determination of the PMV and PPD index are the following:

1. Zone mean air temperature,
2. Zone mean radiant temperature,
3. Relative air velocity,
4. Zone relative humidity.

The mean radiant temperature (MRT) is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure (ISO 7726 1998). MRT also has a strong influence on thermo physiological comfort indexes such as physiological equivalent temperature (PET) or predicted mean vote (PMV) (Fanger 1970). The estimation of MRT can be calculated. Since the amount of radiant heat lost or received by human body is the algebraic sum of all radiant fluxes exchanged by its exposed parts with the surrounding sources, MRT can be calculated from the measured temperature of surrounding walls and surfaces and their positions with respect to the person. Therefore, it is necessary to measure those temperatures and the angle factors between the person and the surrounding surfaces. (ISO 7726 1998) Most building materials have a high emittance ε, so all surfaces in the room can be assumed to be black. Because the sum of the angle factors is unity, the fourth power of MRT equals the mean value of the surrounding surface temperatures to the fourth power, weighted by the respective angle factors. (ISO 7726 1998) The following Equation 1 is used: (ASHRAE Standard 55 2013) (ISO 7726 1998)

$$T_{mr}^4 = T_1^4 F_{p-1} + T_1^4 F_{p-2} + ... + T_n^4 F_{p-n} \tag{1}$$

T_{mr} - Mean radiant temperature

T_n - Temperature of surface "n"

F_{p-n} - Angle factor between a person and surface "n"

If relatively small temperature differences exist between the surfaces of the enclosure, the equation can be simplified to the following linear form, Equation 2 (ASHRAE Standard 55 2013) (ISO 7726 1998):

$$T_{mr} = T_1 F_{p-1} + T_1 F_{p-2} + ... + T_n F_{p-n} \tag{2}$$

This linear formula tends to give a lower value of MRT, but in many cases the difference is small (ISO 7726 1998).

Further variables were simulated in order to analyze their values in time steps for the assigned run time period of one year:

1. People latent heat gain,
2. People sensible heat gain,
3. People radiant heat gain,
4. People total heat gain,
5. Zone operative temperature,
6. Zone transmitted solar energy,
7. Zone window heat gain energy,
8. Zone window heat loss energy,
9. Zone outdoor dry bulb,
10. Zone outdoor wet bulb,
11. District cooling facility,
12. District heating facility.

5.2.2.1.3. Simulation setting

Simulation settings refer to the environment setup and calculation method in EnergyPlus. The run period for the simulation was set up on an annual basis from the 1st of January until the 31st of December. The number of time-steps per hour was set to 1. Further Radiance parameters were set to “coarse” with the following properties show in Table V - 4:

Table V - 4 Radiance parameter

Property	Value	Property	Value
Accumulated rays per record	1	Direct threshold	0.0
Direct certainty	1.0	Direct jitter	1.0
Direct pretest	1.0	Ambient bounces VMX	6
Ambient bounces DMX	2	Ambient divisions VMX	4050
Ambient divisions DMX	512	Ambient supersamples	256
Limit weight VMX	0.001	Limit weight DMX	0.001
Klems sampling density	500	Sky discretization resolution	146

Simulation control panel was setup for the weather file run periods with temperature convergence tolerance value of 0.4 K, loads convergence tolerance value 0.04 and solar distribution was assigned for full exterior. Shadow calculation frequency was 7 and figures in shadow overlap calculation were set to 15000.

As specified in Chapter 3 “Methodology and materials” EnergyPlus engine has an integrated system solution manager consisting of three managers; surface heat balance manager, air heat balance manager and building system simulation manager. (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012) The surface heat balance manager and the air heat balance manager are applied in the simulations, while the system simulation manager for this investigation will not be present since the HVAC system will not take part in the energy performance estimation. The heat balance method consists of volume and surface heat balance in every time step and conduction, convection and radiation modules. The configurations and modules of the surface and air heat balance managers will be concisly stated further from the EnergyPlus engineering reference (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012) (GARD Analytics 2012).

Surface heat balance manager consist of Conduction transfer function module expressed by basic time series solution which is the response factor equation relating the flux at one surface of an element to an infinite series of temperature histories at both sides as shown by Equation 3 (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012):

$$q''_{ko}(t) = \sum_{j=0}^{\infty} X_j T_{o,t-j\delta} - \sum_{j=0}^{\infty} Y_j T_{i,t-j\delta} \tag{3}$$

Where:

q''	-	Heat flux,
T	-	Temperature,
i	-	Signifies the inside of the building element,
o	-	Signifies the outside of the building element,
t	-	Represents the current time step,
X, Y	-	Response factors.

Fortunately, the similarity of higher order terms can be used to replace them with flux history terms. The new solution contains elements that are called conduction transfer functions (CTFs). The basic form of a conduction transfer function solution is shown by the following Equations 4 and 5 (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012):

$$q''_{ki}(t) = -Z_o T_{i,t} - \sum_{j=1}^{nz} Z_j T_{i,t-j\delta} + Y_o T_{o,t} + \sum_{j=1}^{nz} Y_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ki,t-j\delta} \tag{4}$$

for the inside heat flux, and

$$q''_{ko}(t) = -Y_o T_{i,t} - \sum_{j=1}^{nz} Y_j T_{i,t-j\delta} + X_o T_{o,t} + \sum_{j=1}^{nz} X_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ko,t-j\delta} \tag{5}$$

for the outside heat flux (q″=q/A).

Where:

X_j	-	Outside CTF coefficient, j= 0,1,...nz.,
Y_j	-	Cross CTF coefficient, j= 0,1,...nz.,
Z_j	-	Inside CTF coefficient, j= 0,1,...nz.,
Φ_j	-	Flux CTF coefficient, j = 1,2,...nq.,
T_i	-	Inside face temperature,
T_o	-	Outside face temperature,
q''_{ko}	-	Conduction heat flux on outside face,
q''	-	Conduction heat flux on inside face.

Conduction finite difference solution algorithm

EnergyPlus models follow fundamental heat balance principles very closely in almost all aspects of the program. EnergyPlus includes two different options for the specific scheme or formulation used for the finite difference model. Although the two different schemes differ in their fundamental heat transfer equations, they share nearly all the same supporting models for material properties, data storage, solution schemes, and spatial discretization algorithms (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012).

The Crank-Nicholson scheme is semi-implicit and based on an Adams-Moulton solution approach. It is considered second-order in time. The algorithm uses an implicit finite difference scheme coupled with an enthalpy-temperature function to account for phase change energy accurately. The implicit formulation for an internal node is shown in the Equation 6 below (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012) (GARD Analytics 2012).

$$C_p \rho \Delta x \frac{T_i^{j+1} - T_i^j}{\Delta t} = \frac{1}{2}\left[\left(k_W \frac{\left(T_{i+1}^{j+1} - T_i^{j+1}\right)}{\Delta x} + k_E \frac{\left(T_{i-1}^{j+1} - T_i^{j+1}\right)}{\Delta x}\right) + \left(k_W \frac{\left(T_{i+1}^{j} - T_i^{j}\right)}{\Delta x} + k_E \frac{\left(T_{i-1}^{j} - T_i^{j}\right)}{\Delta x}\right)\right] \quad (6)$$

Where:

T	-	Node temperature
Subscripts:		
i	-	Node being modeled
$i+1$	-	Adjacent node to interior of construction
$i-1$	-	Adjacent node to exterior of construction
$j+1$	-	New time step
j	-	Previous time step
Δt	-	Calculation time step
Δx	-	Finite difference layer thickness (always less than const. layer thickness)
C_p	-	Specific heat of material
k_W	-	Thermal conductivity for interface between i node and $i+1$ node
k_E	-	Thermal conductivity for interface between i node and $i-1$ node
ρ	-	Density of material

Equations such as 6 are formed for all nodes in a construction. The formulation of all node types is basically the same. EnergyPlus uses the following four types of nodes, as shown in the Figure V - 28 below (1) interior surface nodes, (2) interior nodes, (3) material interface nodes and (4) external surface nodes (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012).

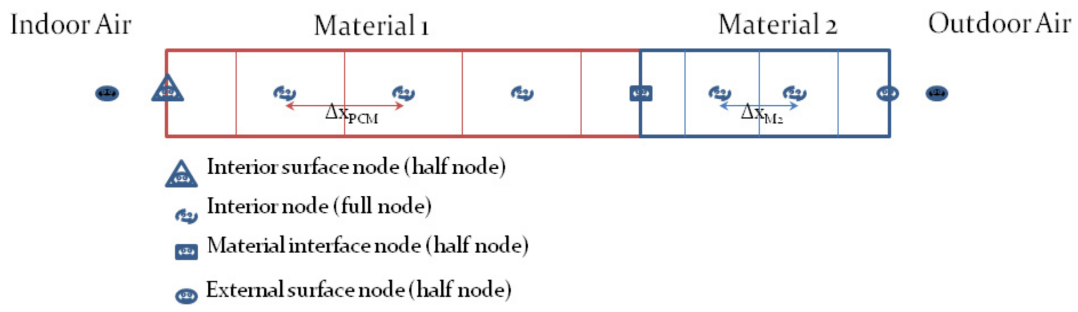


Figure V - 28 Node depiction for conduction finite difference model

Combined heat and moisture transfer (HAMT) model

The combined heat and moisture transfer finite (HAMT) solution algorithm is a completely coupled, one-dimensional, finite element, heat and moisture transfer model simulating the movement and storage of heat and moisture in surfaces simultaneously from and to both the internal and external environments (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012).

HAMT model description - Equations 7 and 8 are derived from heat and moisture balance equations and are taken from Künzel. They describe a theoretical model for the transfer of heat and moisture through a material (Künzel 1995) (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012).

$$\frac{\partial H}{\partial T}\frac{\partial T}{\partial \tau}=\frac{\partial}{\partial x}\left(k^{w}\frac{\partial T}{\partial x}\right)+h_{v}\frac{\partial}{\partial x}\left(\frac{\delta}{\mu}\frac{\partial T}{\partial x}\right) \quad (7)$$

The three terms in Equation 7 describe the storage, transport and generation of heat respectively.

$$\frac{\partial w}{\partial \phi}\frac{\partial \phi}{\partial \tau}=\frac{\partial}{\partial x}\left(D^{w}\frac{\partial w}{\partial \phi}\frac{\partial \phi}{\partial x}\right)+\frac{\partial}{\partial x}\left(\frac{\delta}{\mu}\frac{\partial T}{\partial x}\right) \quad (8)$$

The three terms in Equation 8 describe the storage of moisture, the transport of liquid moisture and the transport of vapor respectively.

In the EnergyPlus engineering references all equations are elaborated in detail, numerous complex modules are used in dynamic simulations which are not necessary to be underlined in the dissertation. Modules used to describe a physical environment apply numerous equations as heat transfer, moisture transfer, moisture dependant thermal conductivity, moisture dependant moisture diffusion coefficient, convective heat transfer, convective vapor transfer etc.

The Heat Balance model operates with the outside surface Heat Balance and inside Heat Balance algorithms. In Figure V - 29 and Equation 9 the outside heat balance control volume diagram is presented from the engineering reference in EnergyPlus (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012).

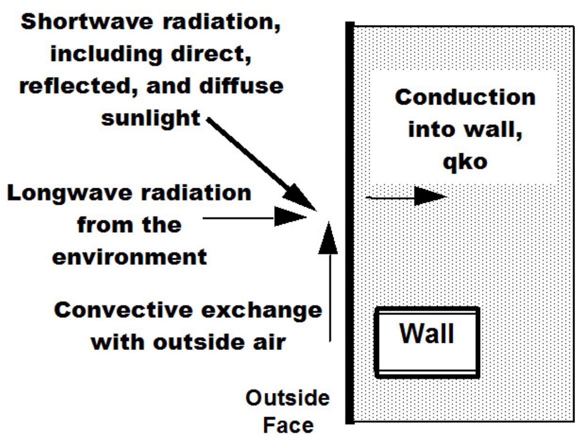


Figure V - 29 Outside heat balance volume control volume diagram

The heat balance on the outside face is:

$$q''_{\alpha sol} + q''_{LWR} + q''_{conv} - q''_{ko} = 0 \tag{9}$$

Where:

$q''_{\alpha sol}$	-	Absorbed direct and diffuse solar (short wavelength) radiation heat flux
q''_{LWR}	-	Net long wavelength (thermal) radiation flux exchange with the air and surroundings
q''_{conv}	-	Convective flux exchange with outside air
q''_{ko}	-	Conduction heat flux (q/A) into the wall

The inside heat balance control volume diagram is presented from the engineering reference in EnergyPlus in Figure V – 30 (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012).

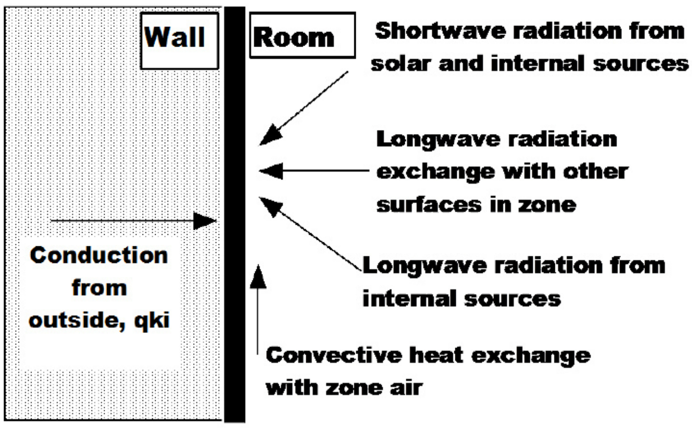


Figure V - 30 Inside heat balance volume control volume diagram

Considering the inside heat balance control volume diagram the heat balance on the inside face can be written as follows in Equation 10:

$$q''_{LWX} + q''_{SW} + q''_{LWS} + q''_{ki} + q''_{sol} + q''_{conv} = 0 \quad (10)$$

Where:

q''_{LWX}	-	Net longwave radiant exchange flux between zone surfaces
q''_{SW}	-	Net short wave radiation flux to surface from lights
q''_{LWS}	-	Longwave radiation flux from equipment in zone
q''_{ki}	-	Conduction flux through the wall
q''_{sol}	-	Transmitted solar radiation flux absorbed at surface
q''_{conv}	-	Convective heat flux to zone air

Air Heat Balance manager in EnergyPlus is formed from the following modules (US Department of Energy, University of Illinois and Ernest Orlando Lawrence Berkeley National Laboratory 2012):

- Convection from surfaces
- Convection from internal sources
- Infiltration/ventilation
- Air exchange
- Calculation of zone air temperature

EnergyPlus engine's interface with the EP Launch and IDF Editor are shown in Figure V - 31. The EnergyPlus simulation process window is presented in Figure V - 32. The processes, simulation time can be followed in the simulation window and later analyzed in textual file format.

Simulation processes and options, output variables, output meters, report data dictionary, expand objects, shadowing, reports summarizing input, environment, sizing options are all presented in the **Appendix E.**

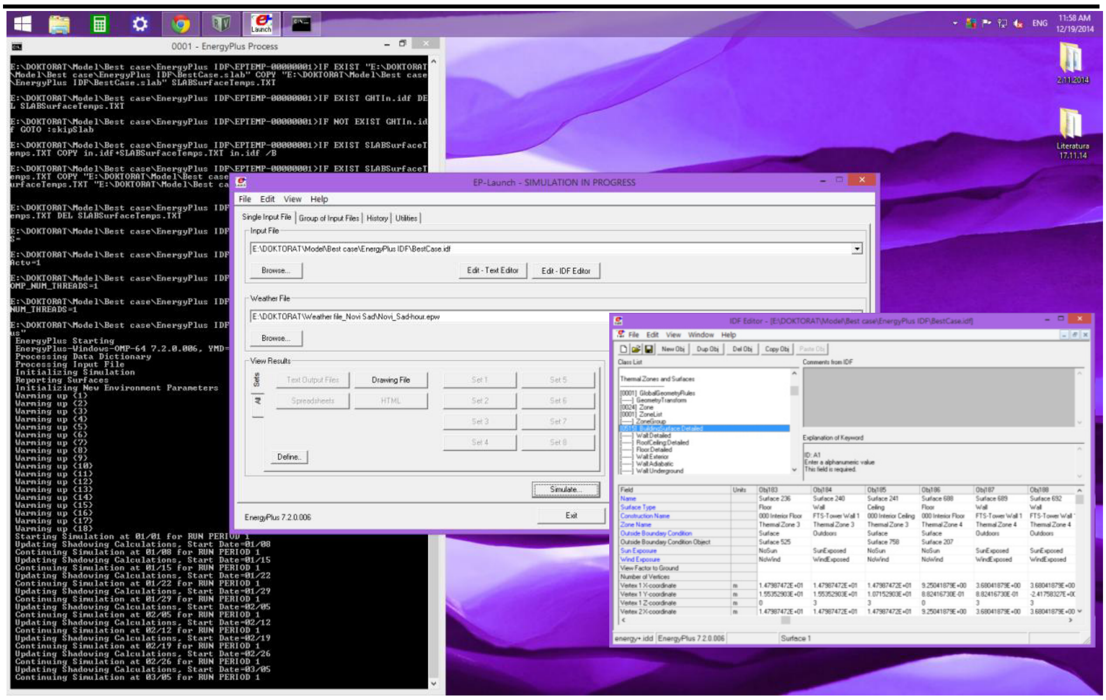


Figure V - 31 EnergyPlus engine interface, EP Launch and IDF Editor

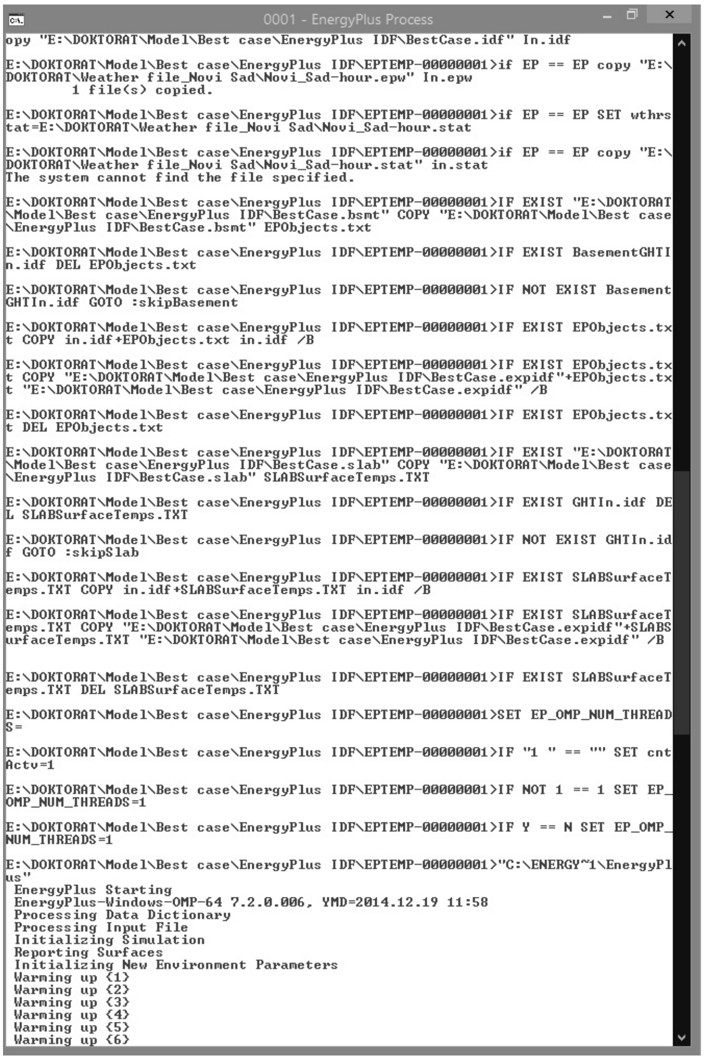


Figure V - 32 EnergyPlus simulation window

5.3. EnergyPlus simulation results

5.3.1. Energy simulation results

The dynamic energy simulation was performed for 10 Scenarios with the following constant parameters of:

- **Construction** – exterior walls, roof, ceiling, basement and interior partitions were constant for in all scenarios;
- **Internal loads** – occupants, electric lights and equipment;
- **Schedules** – occupancy, electric lights, equipment, heating and cooling thermostat.

The building construction of the external walls was designed in accordance with the minimal thermal insulation requirements of building envelope construction. It was important to maintain the existing exterior wall construction of 25cm fired clay brick. The improvement of the exterior walls thermal performance was accomplished by adding an insulation layer from expanded polystyrene and finishing from cement mortar in order to advance its performance, while keeping the investments in economic limits. The construction of the building model was elaborated previously in Chapter 4 with specified material parameter of layers.

Further consideration referred to the internal gains and schedules which were elaborated previously in this section. The internal gains and schedules of building operation were identical for all Scenarios since office activities and operation of mechanical systems are necessary to be in coordination. Occupancy intensities and activity need to define the mechanical systems operation mode in an office building in order to reduce the energy demands.

The variable parameter in the Scenarios was the exterior glazing type since windows can significantly increase or decrease the energy demands for heating and cooling. A particular analysis was performed in order to determine and apply preferable window properties for the climatic conditions of Novi Sad. In Scenarios from 1 to 10, ten window products (All Weather Windows 2012) (Pilkington 2014) with different parameters will be applied for the adapted WWR and WG. The windows were assigned with the following parameters of thermal transmittance, solar heat gain coefficient (SHGC) and visible transmittance (VT) as presented in Table V - 5.

Table V - 5 Scenarios with window properties

Scenario No.	Windows	Material properties	
W1	Window 1 Dual pane Pilkington Optifloat-clear	U-value SHGC Visible Trans.	1.70 W/(m^2K) 0.60 0.70
W2	Window 2 Dual pane Pilkington Optifloat-clear	U-value SHGC Visible Trans.	1.30 W/(m^2K) 0.50 0.73
W3	Window 3 Tri-pane Pilkington Planar + Optifloat + K Glass	U-value SHGC Visible Trans.	0.90 W/(m^2K) 0.34 0.57
W4	Window 4 Tri-pane Pilkington Planar + Optifloat + Optitherm	U-value SHGC Visible Trans.	0.70 W/(m^2K) 0.23 0.42
W5	Window 5 Dual pane Pilkington, Energy Advantage, Argon, Low-E, #3 Surface	U-value SHGC Visible Trans.	1.67 W/(m^2K) 0.75 0.77
W6	Window 6 Dual pane Guardian Clima-Guard 80/70	U-value SHGC Visible Trans.	1.53 W/(m^2K) 0.69 0.81
W7	Window 7 Tri-pane One pane with Sun-Stop coating and Argon	U-value SHGC Visible Trans.	1.05 W/(m^2K) 0.34 0.63
W8	Window 8 Tri-pane Two panes with Sun-Stop coating and Argon	U-value SHGC Visible Trans.	0.70 W/(m^2K) 0.310 0.54
W9	Window 9 Tri-pane Pilkington Planar + Optifloat + K Glass	U-value SHGC Visible Trans.	0.80 W/(m^2K) 0.22 0.39
W10	Window 10 Tri-pane Pilkington Planar + Optifloat + Optitherm	U-value SHGC Visible Trans.	0.70 W/(m^2K) 0.26 0.52

Table V - 6 Internal loads of lights and equipment

Month	Interior Lights Electricity [kWh]	Interior Equip. Electricity [kWh]
Jan	5617	7180
Feb	5067	6490
Mar	5548	7159
Apr	5537	7015
May	5392	7060
Jun	5537	7015
Jul	5773	7278
Aug	5392	7060
Sept	5537	7015
Oct	5617	7180
Nov	5313	6896
Dec	5773	7278
Sum	66104	84626
Min	5067	6490
Max	5773	7278

The determined energy demand of electric lights and equipment was set up according to the intensity and schedules of building occupancy. Energy simulations presented demands roughly between 5000 – 6000 kWh monthly for electric lighting and 6500 – 7300 kWh for electric equipment. Monthly, annual and peak demands are presented in Table V - 6. The total annual demand for electric lighting is 66 MWh/a which equals 19.27 kWh/m^2/a, and the total annual demand for electric equipment is higher 85 MWh/a which equals 24.67 kWh/m^2/a.

In conclusion, internal loads for electric lighting and equipment in case of FTS office-tower building which is occupied in average 9 hours on weekdays and 4 hours on Saturdays the highest rationally scheduled electricity demand per square meter of floor area requires 43.94 ~ 44 kWh/m^2/a annually. The monthly electricity loads are also shown in Figure V - 33.

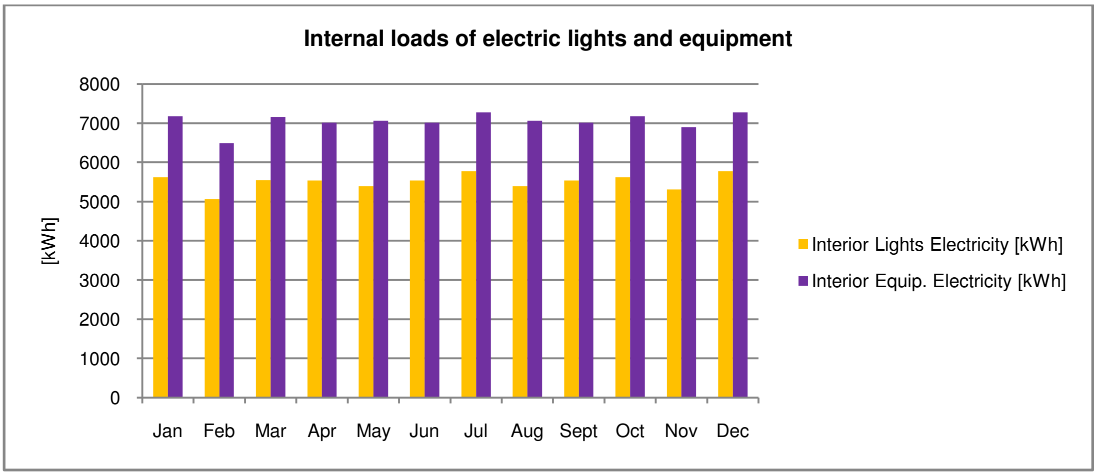


Figure V - 33 Internal loads of electric lights and equipment

The internal loads for electric lighting and equipment in case of the 10 simulated Scenarios are equal since the setup of lighting and equipment operation was setup according to the occupancy schedules. These internal loads will be adopted as constant loads in all scenarios with the internal energy gains produced by their operation. Therefore the influence of internal energy gains from lights and equipment on the comfort parameters will be elaborated in detail in the following Chapter 6 “Energy performance optimization in the function of comfort parameters”.

Simulations in this Chapter considered the following:

- Determination of heating and cooling energy demands in case of 10 Scenarios and
- Evaluation of glazing influence on the annual energy performance.

The selection of performable glazing lies in finding a correlation between the heating and cooling demand. In order to find a performable solution in a temperate climate the SHGC coefficient, U-value and VT were varied and tested for 10 window types in order to calculate the deviation among the heating and cooling demands.

The variable parameters in the Scenarios considered only the glazing properties from Table V - 5. Findings indicated the significance of the SHGC coefficient's influence on the annual heating and cooling demand. The energy performance results for all Scenarios are presented in Figures from V – 34 to V - 43 and compared in Figures from V – 44 to V - 47. In order to compare the energy demands of the Scenarios the limit on the graphs were set to 36000 kWh for all cases except in Scenario W5 and W6, where the upper limit was set to 40000 kWh, Figures V – 38 and V - 39.

Highest energy demand for heating was recorded in Scenario W1, **39243 kWh/a**, Figure V - 34, while Scenario W10 presented the lowest heating demand of **27773 kWh/a**, Figure V - 43, as shown in Table V - 7 and V - 8. When the SHGC coefficients were compared, lowest 0.22 and 0.26 values of Scenarios W9 and W10 presented lowest energy demands since the energy gains from the solar rays are low (22-26%) which resulted in less energy needs for cooling compared to scenarios with higher SHGC coefficients. The heating demand is lower due to constant internal heat gains specific for office environments which maintains in the building since 22-26% escapes through the glazing.

In order to evaluate the energy demand of the building and the importance of SHGC coefficients influence, annual cooling energy demand was analyzed respectively. The simulations for the cooling demand presented significantly higher values compared to the heating demands due to specifically high internal gains. Major internal gains are specific for office environments during occupied hours, since the electric equipment, people and electric lights emit heat in the indoor environment. This emitted heat could be reused by a recovery system attached to the outdoor air loop system in the indoor environment. For this reason adequate windows need to be selected in order to lower the external loads and reuse the internal energy gains from the office environment. Since the heating loads are maintained in the environment high cooling demand results are expected.

The highest energy demand for cooling was recorded in Scenario W5, **178597 kWh/a**, Figure V - 38, while Scenario W9 presented the lowest cooling demand, **96886 kWh/a**, Figure V - 42. The heating energy accumulation in the interior is influenced by the SHGC coefficient. Higher SHGC values transmit more solar energy into the interior as in Scenario W5 with 75% energy transmission. High SHGC value 0.756 as assigned for W5 windows manifested high solar gains in the interior, which resulted in approximately 90% higher cooling demands compared to the lowest result from W9 and 85% higher cooling demands compared to W10.

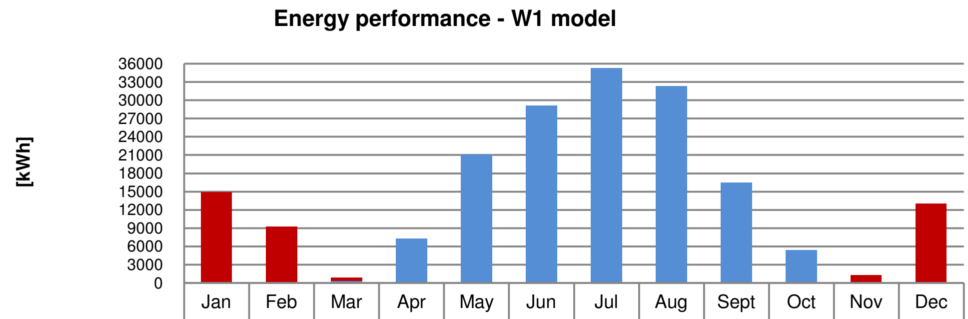
The cooling demand in all Scenarios presented significantly higher values compared to heating due to high internal gains and highly insulated building envelope. The primary criterion for selection was the low annual energy demand. When Scenarios with similar annual energy demands were compared, the criteria for selection was the following:

- Possibly lower U-value than defined in regulations;
- Low SHGC coefficient (equal or below 0.3);
- High VT value (above 0.5).

Scenarios W4, W8, W9 and W10 resulted in less deviation between heating and cooling demands compared to scenarios W5 and W6. Scenarios W5 and W6 are inadequate for the temperate climate of Novi Sad since the SHGC coefficients were the highest. Simulated heating demands were significantly low **34 MWh** in average, while the cooling demands resulted in significantly high values between **168 MWh** and **178 MWh**. The high SHGC coefficient and high VT value accumulates the internal and external energy gains in the interior spaces, which is negative in an office building which is constructed on a territory with temperate climatic conditions. These two scenarios would be preferable for colder climates. Scenarios W1, W2, W3, W7 and W8 resulted in similar heating demands between **35 MWh** and **39 MWh**, while the cooling demands varied between **117 MWh** and **147 MWh**.

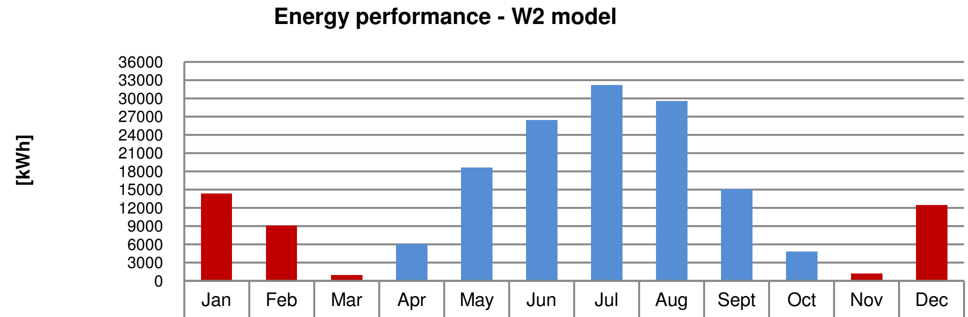
The selected Scenarios for final glazing application were among W4, W9 and W10 as shown in Figures V - 37, V - 42 and V - 43. In these Scenarios the total energy demands were similar within the limits of **28 MWh** to **38 MWh** for heating and **97 MWh** to **104 MWh** for cooling.

Finally the W10 Scenario was adopted due to the highest visible transmittance value 0.52 since in the simulations for the daylight dispersion analysis the applied glazing's VT value was above 0.5. Hence VT values in Scenarios W4 and W9 did not match the criteria for the WWR which was adopted in the previous investigation.



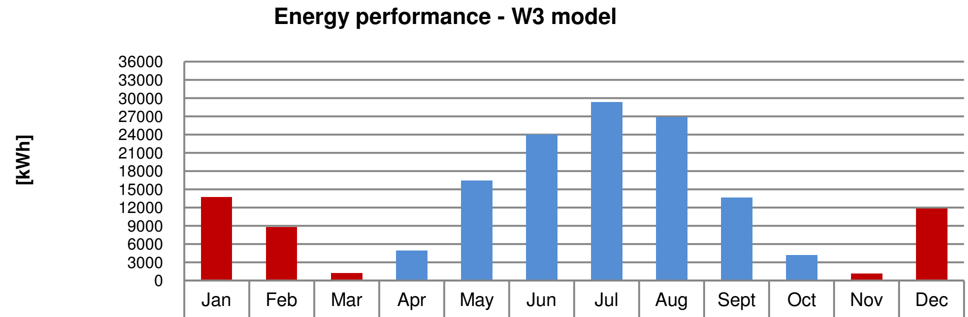
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W1 [kWh]	14905	9262	822	0	0	0	0	0	0	2	1233	13019
Cooling Energy W1 [kWh]	0	0	289	7296	21028	29139	35289	32321	16460	5393	0	0

Figure V - 34 Monthly energy performance for W1 Scenario



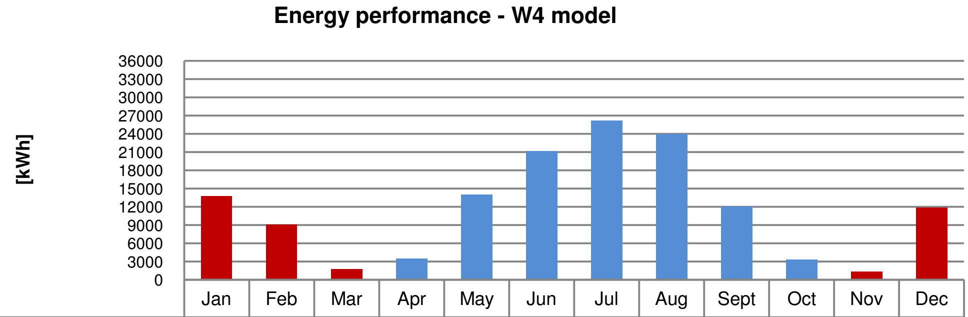
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W2 [kWh]	14349	9052	984	0	0	0	0	0	0	2	1190	12468
Cooling Energy W2 [kWh]	0	0	146	6073	18661	26459	32210	29602	15045	4782	0	0

Figure V - 35 Monthly energy performance for W2 Scenario



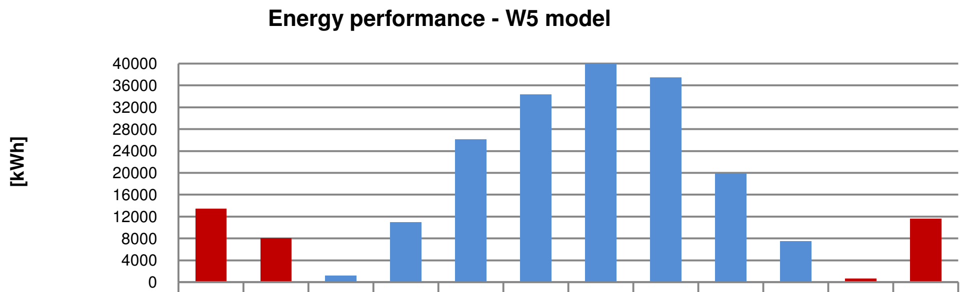
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W3 [kWh]	13737	8816	1218	0	0	0	0	0	0	3	1170	11873
Cooling Energy W3 [kWh]	0	0	59	4914	16440	24002	29355	26891	13662	4158	0	0

Figure V - 36 Monthly energy performance for W3 Scenario



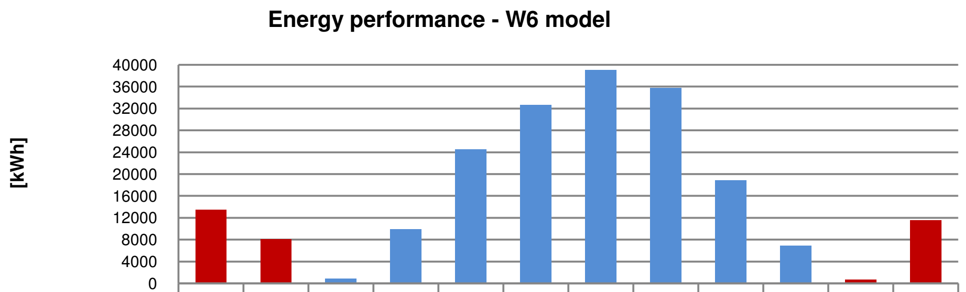
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W4 [kWh]	13801	9088	1758	0	0	0	0	0	0	6	1384	11920
Cooling Energy W4 [kWh]	0	0	8	3498	13993	21191	26209	24031	12077	3364	0	0

Figure V - 37 Monthly energy performance for W4 Scenario



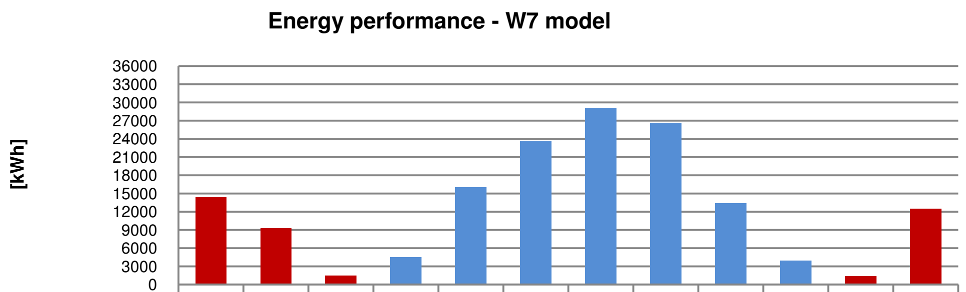
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W5 [kWh]	13482	8070	310	0	0	0	0	0	0	0	668	11621
Cooling Energy W5 [kWh]	0	2	1195	10960	26150	34407	40964	37440	19945	7484	50	0

Figure V - 38 Monthly energy performance for W5 Scenario



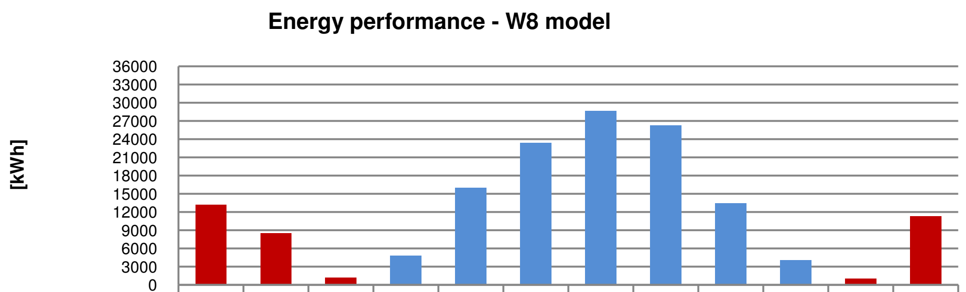
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W6 [kWh]	13477	8143	384	0	0	0	0	0	0	0	715	11618
Cooling Energy W6 [kWh]	0	1	922	9970	24580	32703	39079	35761	18927	6938	30	0

Figure V - 39 Monthly energy performance for W6 Scenario



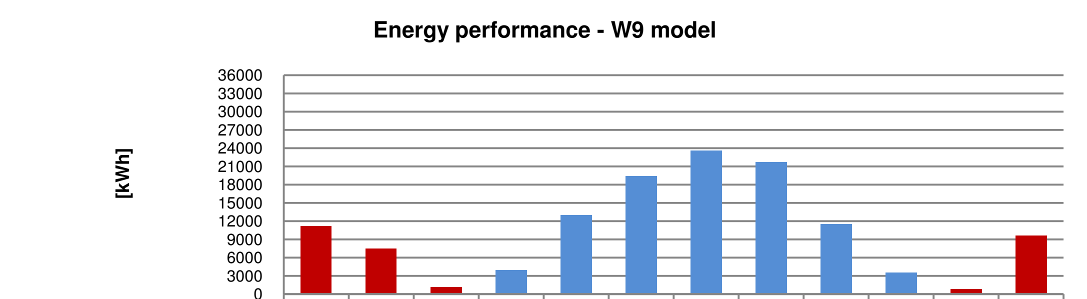
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W7 [kWh]	14387	9264	1434	0	0	0	0	0	0	5	1396	12478
Cooling Energy W7 [kWh]	0	0	37	4553	16083	23719	29105	26644	13371	3918	0	0

Figure V - 40 Monthly energy performance for W7 Scenario



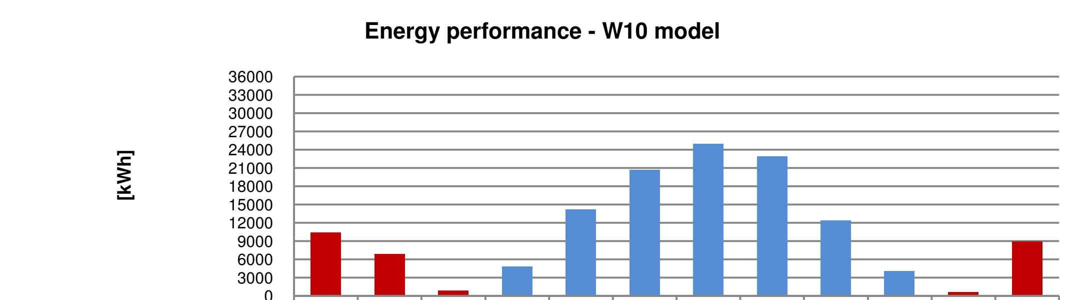
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W8 [kWh]	13180	8485	1167	0	0	0	0	0	0	2	1038	11331
Cooling Energy W8 [kWh]	0	0	58	4820	16037	23439	28661	26279	13457	4145	0	0

Figure V - 41 Monthly energy performance for W8 Scenario



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W9 [kWh]	11188	7510	1196	0	0	0	0	0	0	2	867	9657
Cooling Energy W9 [kWh]	0	0	14	3951	13033	19437	23645	21706	11542	3557	0	0

Figure V - 42 Monthly energy performance for W9 Scenario



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W10 [kWh]	10445	6924	834	0	0	0	0	0	0	1	631	8939
Cooling Energy W10 [kWh]	0	0	55	4881	14197	20685	24960	22917	12369	4127	0	0

Figure V - 43 Monthly energy performance for W10 Scenario

Figures V - 44 and V - 45 show the comparison of the simulated annual heating and cooling demand of all Scenarios. The heating energy demands are various, highly influenced by the characteristics of the windows. It was concluded that the SHGC coefficient had:

- Major influence considering external solar energy gains and
- Indoor energy maintenance from occupants, electric lights and equipment.

The thermal transmittance did not take a crucial part in the heating and cooling demand influence. As for example Scenario W7 and W8 had U-values of 1.056 W/(m^{2}K) and 0.704 W/(m^{2}K), but the results of the total annual energy demand was similar; 156 MWh in case of Scenario W7 and 152 MWh for Scenario W8. The SHGC values were the following; 0.33 for Scenario W7 and 0.31 for Scenario W8.

It can be concluded that the energy demands as previously stated are mostly affected by the SHGC coefficient since similar coefficients will have results with only slight deviation among each other. In case of office buildings with high internal gains the SHGC coefficient has to be considered of great importance in adequate window selection.

Table V - 7 Heating and cooling energy demand for Scenarios from W1 to W5

Month	Heating Energy W1 [kWh]	Cooling Energy W1 [kWh]	Heating Energy W2 [kWh]	Cooling Energy W2 [kWh]	Heating Energy W3 [kWh]	Cooling Energy W3 [kWh]	Heating Energy W4 [kWh]	Cooling Energy W4 [kWh]	Heating Energy W5 [kWh]	Cooling Energy W5 [kWh]
Jan	14905	0	14349	0	13737	0	13801	0	13482	0
Feb	9262	0	9052	0	8816	0	9088	0	8070	2
Mar	822	289	984	146	1218	59	1758	8	310	1195
Apr	0	7296	0	6073	0	4914	0	3498	0	10960
May	0	21028	0	18661	0	16440	0	13993	0	26150
Jun	0	29139	0	26459	0	24002	0	21191	0	34407
Jul	0	35289	0	32210	0	29355	0	26209	0	40964
Aug	0	32321	0	29602	0	26891	0	24031	0	37440
Sept	0	16460	0	15045	0	13662	0	12077	0	19945
Oct	2	5393	2	4782	3	4158	6	3364	0	7484
Nov	1233	0	1190	0	1170	0	1384	0	668	50
Dec	13019	0	12468	0	11873	0	11920	0	11621	0
Sum	39243	147213	38045	132978	36819	119481	37956	104372	34151	178597
Max	14905	35289	14349	32210	13737	29355	13801	26209	13482	40964

Table V - 8 Heating and cooling energy demand for Scenarios from W6 to W10

Month	Heating Energy W6 [kWh]	Cooling Energy W6 [kWh]	Heating Energy W7 [kWh]	Cooling Energy W7 [kWh]	Heating Energy W8 [kWh]	Cooling Energy W8 [kWh]	Heating Energy W9 [kWh]	Cooling Energy W9 [kWh]	Heating Energy W10 [kWh]	Cooling Energy W10 [kWh]
Jan	13477	0	14387	0	13180	0	11188	0	10445	0
Feb	8143	1	9264	0	8485	0	7510	0	6924	0
Mar	384	922	1434	37	1167	58	1196	14	834	55
Apr	0	9970	0	4553	0	4820	0	3951	0	4881
May	0	24580	0	16083	0	16037	0	13033	0	14197
Jun	0	32703	0	23719	0	23439	0	19437	0	20685
Jul	0	39079	0	29105	0	28661	0	23645	0	24960
Aug	0	35761	0	26644	0	26279	0	21706	0	22917
Sept	0	18927	0	13371	0	13457	0	11542	0	12369
Oct	0	6938	5	3918	2	4145	2	3557	1	4127
Nov	715	30	1396	0	1038	0	867	0	631	0
Dec	11618	0	12478	0	11331	0	9657	0	8939	0
Sum	34337	168912	38963	117430	35204	116897	30420	96886	27773	104191
Max	13477	39079	14387	29105	13180	28661	11188	23645	10445	24960

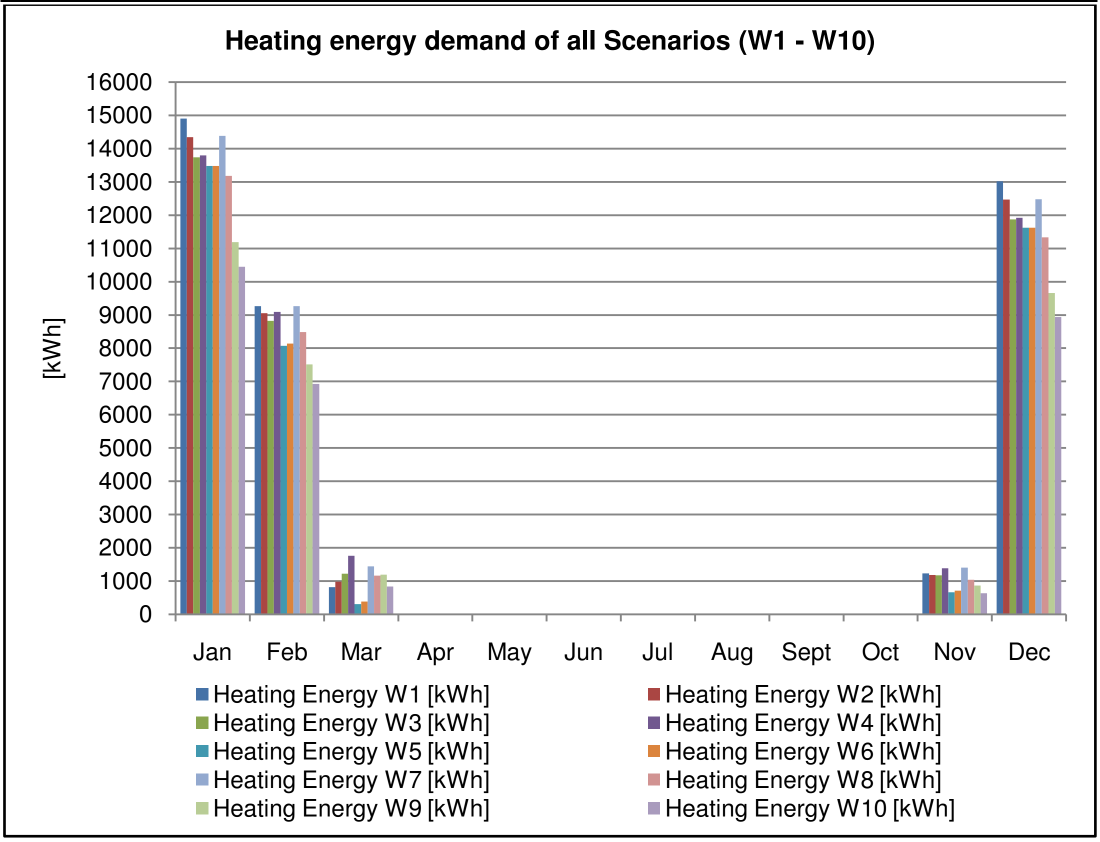


Figure V - 44 Heating energy demand of all Scenarios

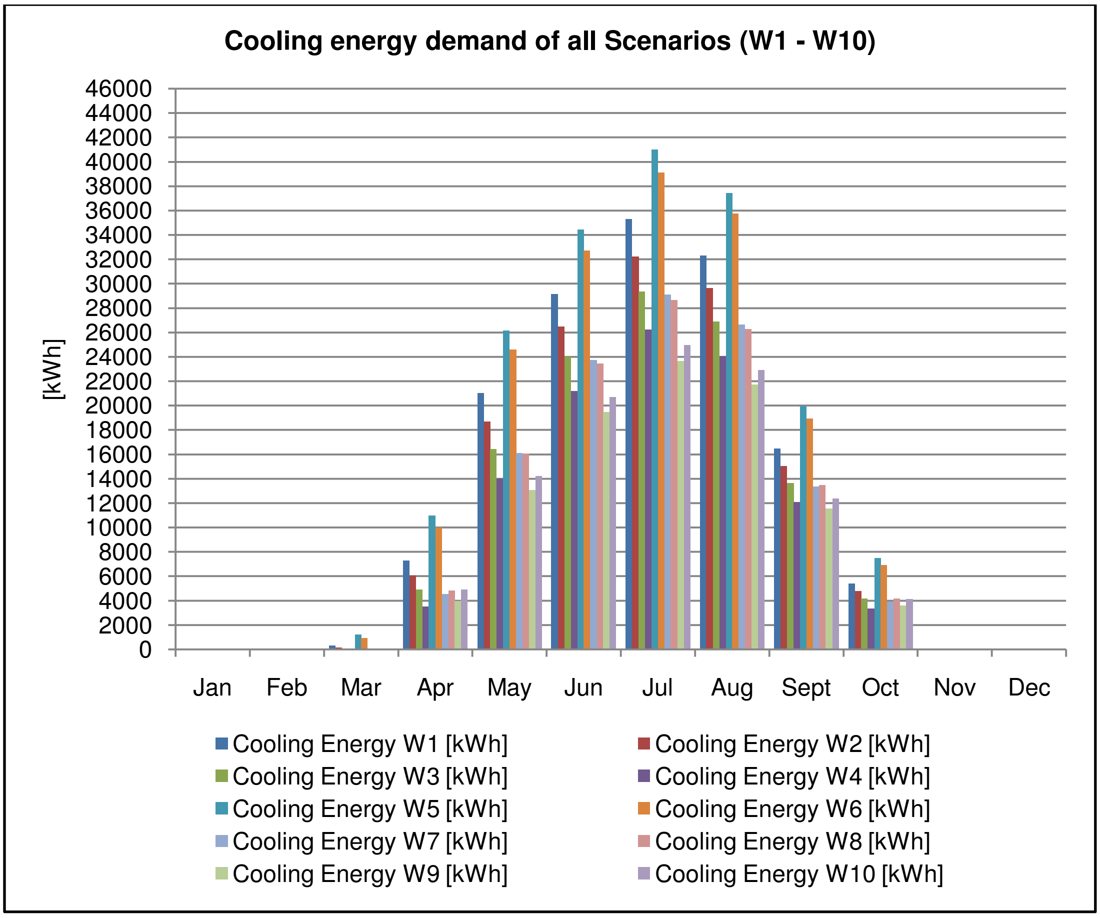


Figure V - 45 Cooling energy demand of all Scenarios

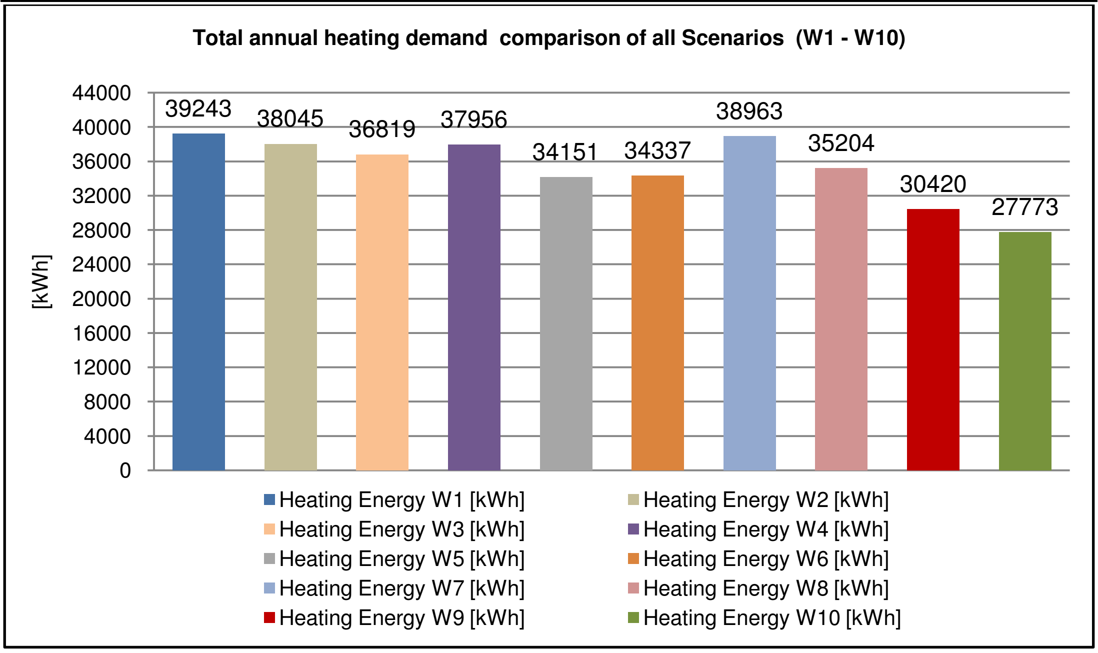


Figure V - 46 Total annual heating demand comparison of all Scenarios

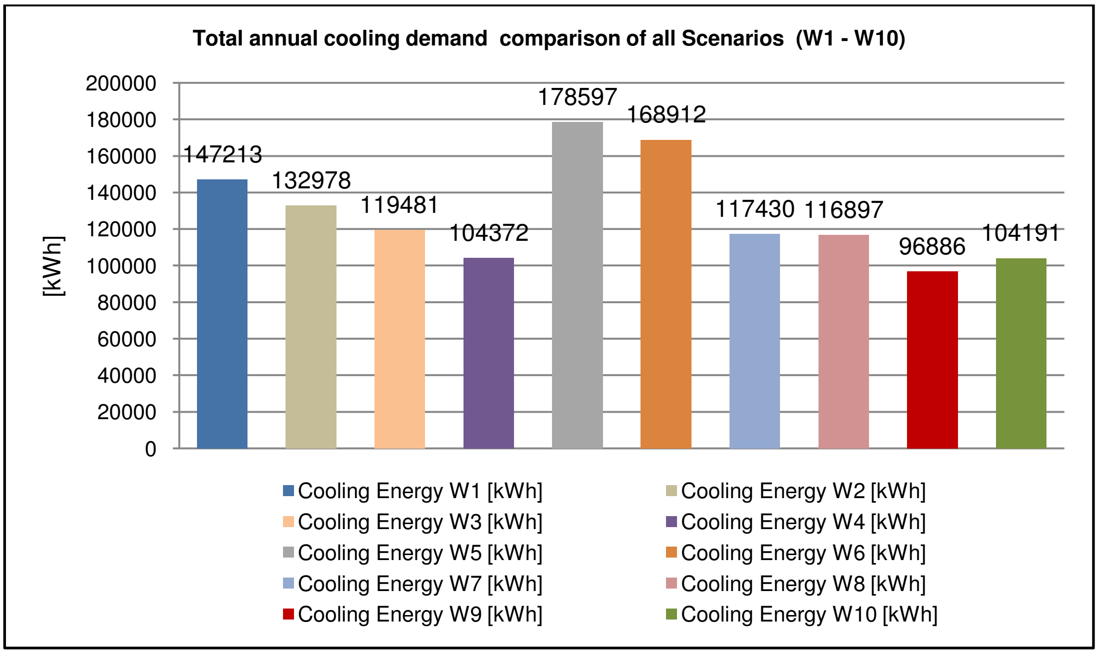


Figure V - 47 Total annual cooling demand comparison of all Scenarios

5.4. Best Case Scenario from the energy performance aspect

5.4.1. Best Case Scenario overview

For the Best Case Scenario from the energy performance aspect as elaborated previously the W10 Scenario was adopted on the basis of defined criteria (U-value, SHGC and VT). Windows applied in this Scenario would be efficient for the climatic conditions on the territory of Novi Sad with the following properties shown in Table V - 9. This Scenario was adopted since it matched the criteria which included the following definitions:

- Possibly lower U-value than defined in regulations,
- Low SHGC coefficient due to high internal gains (equal or below 0.3),
- High VT value in case of qualitative illumination (above 0.5).

Table V - 9 Window properties for the Best Case Scenario

Scenario	Window	Properties		
W10	Tri-pane Window Pilkington Planar + Optifloat + Optitherm	U-value	0.7 W/(m²K)	**According to the regulations**
		SHGC	0.26	**Low**
		VT	0.52	**High**

Scenario W10 presented results where the deviation between annual heating and cooling demand was acceptable. Due to high internal gains in winter season the heat generated by occupants, equipment and lights can be reused, resulting in space heating reduction.

The optional adopted construction according to the regulations of thermal requirements for exterior walls and roof terrace are shown in Table V - 10. Detailed material properties were elaborated in the previous Chapter 4.

Table V - 10 Adopted construction for the Best Case Scenario

No.	Exterior wall	Roof terrace
1	Stucco Portland cement mortar	Lightweight concrete tiles
2	Expanded polystyrene molded beads (140mm)	Air gap
3	Fired clay brick	Styrodur C – molded beads (180mm)
4	Stucco Portland cement mortar	Waterproof membrane (3 layers)
5		Heavyweight concrete
6		Air gap
7		Gypsum board
U – value [W/(m^2K)]	0.22	0.18

5.4.2. Energy performance calculation according to European Standard EN 15251

According to the European Standards EN 15251 Annex B - Basis for the criteria for indoor air quality and ventilation rates; B.1 Recommended design ventilation rates in non-residential buildings (EN 15251 2007). The total ventilation rate for a room is calculated from the following Equation 11:

$$Q_{tot} = n \cdot q_p + A \cdot q_B \tag{11}$$

Where:

Q_{tot} - Total ventilation rate of the room, [m³/h]

n - Design value for the number of the persons in the room, [-]

q_p - Ventilation rate for occupancy per person, [m³/h/pers.]

A - Room floor area, [m^2]

q_B - Ventilation rate for emissions from building, [m³/h/m^2]

Ventilation rates can be adjusted according to the ventilation efficiency if the performance of air distribution differs from complete mixing, and can be reliably proven (EN 13779 2007) (EN 15251 2007). The people dependant air ventilation amount and area dependant air ventilation amount per m^2 was calculated for category II of recommended ventilation rates for non-residential buildings with default occupant density using data from EN 15251 "Examples of recommended ventilation rates for non-residential buildings with default occupant density for three categories of pollution from building itself". In the calculations for single offices 0.7 l/s (2.52 m^3/h) per m^2 was adopted in case of low polluted building (q_B) and 0.7 l/s (2.52 m^3/h) per m^2 was adopted in case of occupancy (q_p). Table V - 11 presents the annual energy amount for people dependant air ventilation amount where the calculated result is **25517 kWh** if the ventilation is turned on for 8 hours daily. Significant energy requirement above 4 MWh was recorded for the three coldest months of the year; November, December and January.

Table V - 11 People dependant air ventilation amount

Mon.	No. of people	Parameters							Results		
		A [m²]	V [m³/h]	ρ [kg/m³]	c [kJ/(kg˚C)]	t_k [˚C]	t_b [˚C]	Δt [˚C]	Q_f [kJ/h]	Q_f [kJ/s,kW]	Q [kWh] - 8h daily
Jan	160	1200	4032	1.27	1.005	0.4	21	-20.6	106013	29.4	4712
Feb	160	1200	4032	1.26	1.005	2.3	21	-18.7	95477	26.5	4243
Mar	160	1200	4032	1.24	1.005	7.3	21	-13.7	68838	19.1	3059
Apr	160	1200	4032	1.21	1.005	12.7	21	-8.3	40696	11.3	1809
May	160	1200	4032	1.19	1.005	18.0	22	-4.0	19288	5.4	857
Jun	160	1200	4032	1.18	1.005	20.8	23	-2.2	10519	2.9	468
Jul	160	1200	4032	1.17	1.005	22.4	23	-0.6	2845	0.8	126
Aug	160	1200	4032	1.17	1.005	22.2	23	-0.8	3793	1.1	42
Sep	160	1200	4032	1.20	1.005	16.9	21	-4.1	19937	5.5	886
Oct	160	1200	4032	1.21	1.005	12.6	21	-8.4	41186	11.4	1830
Nov	160	1200	4032	1.24	1.005	7.1	21	-13.9	69843	19.4	3104
Dec	160	1200	4032	1.26	1.005	1.7	21	-19.3	98540	27.4	4380
										Annual Sum	**25517**

Table V - 12 presents the area dependant air ventilation amount where the calculated result is **19138 kWh** if the ventilation is turned on for 8 hours daily. Significant energy requirement above 3 MWh was recorded for the three coldest months of the year; November, December and January.

Table V - 12 Area dependant air ventilation amount

Mon.	No. of people	Parameters							Results		
		A [m²]	V [m³/h]	ρ [kg/m³]	c [kJ/(kg˚C)]	t_k [˚C]	t_b [˚C]	Δt [˚C]	Q_f [kJ/h]	Q_f [kJ/s,kW]	Q [kWh] - 8h daily
Jan	160	1200	3024	1.27	1.005	0.4	21	-20.6	79509	22.1	3534
Feb	160	1200	3024	1.26	1.005	2.3	21	-18.7	71608	19.9	3183
Mar	160	1200	3024	1.24	1.005	7.3	21	-13.7	51629	14.3	2295
Apr	160	1200	3024	1.21	1.005	12.7	21	-8.3	30522	8.5	1357
May	160	1200	3024	1.19	1.005	18.0	22	-4.0	14466	4.0	643
Jun	160	1200	3024	1.18	1.005	20.8	23	-2.2	7890	2.2	351
Jul	160	1200	3024	1.17	1.005	22.4	23	-0.6	2133	0.6	95
Aug	160	1200	3024	1.17	1.005	22.2	23	-0.8	2845	0.8	32
Sep	160	1200	3024	1.20	1.005	16.9	21	-4.1	14952	4.2	665
Oct	160	1200	3024	1.21	1.005	12.6	21	-8.4	30890	8.6	1373
Nov	160	1200	3024	1.24	1.005	7.1	21	-13.9	52382	14.6	2328
Dec	160	1200	3024	1.26	1.005	1.7	21	-19.3	73905	20.5	3285
										Annual Sum	**19138**

The annual energy demand for air ventilation amount according to the European Standards, EN 15251, in non-residential buildings is **44655 kWh/a** where the energy demand per m^2 of floor area equals **37.2 kWh/m^2/a**. Following the total energy demand for heating and cooling according to the adopted Scenario W10 is **131964 kWh/a** where the energy demand per m^2 of floor area equals **38.47 kWh/m^2/a**.

Finally, the total heating and cooling energy demand for the **Best Case Scenario** (W10) resulted in **176619 kWh/a**, where the energy demand per m^2 of floor area equals **51.49 kWh/m^2/a**.

5.4.3. Comparison of EnergyPlus simulation results and monitored data with discussion

Comparison of annual energy demands between the monitored reference FTS office-tower building and the Best Case Scenario are presented in Table V - 13. In case of the reference building the heating energy amount along with the electricity consumption for cooling, lights and equipment was taken from the annual energy expenses for the year 2012. Since the building is equipped with district heating system, the monthly expenses were issued separately from other expenses.

Considering the monthly electricity expenses the cooling, lighting and equipment energy consumption cannot be determined since the monthly expenses are issued in total. Another problem occurs considering the determination of relational values among these three loads, since the following data are unknown:

- Precise occupancy schedules and intensity,
- Cooling system operation (operated manually),
- Cooling intensity (operated manually),
- Lighting schedules and intensity (operated manually),
- Electric equipment (operated manually)

In Table V - 13 the annual energy performance between the reference FTS office-tower building and the adopted Best Case Scenario is compared. The annual heating energy consumption in case of the reference building per m^2 of single floor area is 99 kWh/a, with unsatisfied indoor environmental standards. Compared to the Best Case Scenario the heating energy demand per m^2 of single floor area is reduced 5 times, equals 19 kWh/a, while indoor environmental standards are completely satisfied. The comparison of the reference building and Best Case Scenario could not be determined precisely since numerous data were not available, as listed previously, or could not be measured. The annual heating energy demand for the Best Case Scenario compared to the reference office building expenses from 2012 can be reduced by 80%.

Considering the reference building's cooling energy demand the comparison could not be established because neither the cooling system's electricity consumption nor air-conditioning system performance is known. The energy expenses for lighting and equipment are added to the electricity demand of the cooling system, therefore the sum is issued together.

Table V - 13 Energy performance comparison and indoor environment standard definition

Reference FTS office-tower (2012)			**Best Case Scenario**			
Month	**Heating energy [kWh]**	**Cooling, lighting and equipment electricity [kWh]**	**Heating energy [kWh]**	**Cooling energy [kWh]**	**Energy demand for lighting and equipment (100% usage) [kWh]**	
Jan	115993	19158	10445	0	5617	7180
Feb	63473	14544	6924	0	5067	6490
Mar	42323	21141	834	55	5548	7159
Apr	1415	15870	0	4881	5537	7015
May	0	16411	0	14197	5392	7060
Jun	0	19203	0	20685	5537	7015
Jul	0	20164	0	24960	5773	7278
Aug	0	18402	0	22917	5392	7060
Sep	0	17014	0	12369	5537	7015
Oct	9551	18883	1	4127	5617	7180
Nov	45003	18922	631	0	5313	6896
Dec	61030	20111	8939	0	5773	7278
Sum [kWh/a]	**338788**	**219823**	**27773**	**104191**	Electric lighting (according to dimming mode) **(32%) 21153** Equipment **(100%) 84626**	
			EN 15251 Air ventilation energy: + 37325 (for heating) + 7330 (for cooling)			
Annual [kWh/m^2/a]	**99**	**64**	**19**	**32**	**31**	

Table V - 14 presents the comparison of energy expenses from 2011 and 2013 with the results from the simulation. As recorded the heating energy was higher in both cases compared to 2012. The heating energy demand according to the Best Case Scenario is 85% less compared to 2011 expenses and 83% compared to 2013. Considering the state of indoor environment the reference office-tower had unsatisfactory results according to the comfort parameters from the monitoring. The Best Case Scenario had satisfied indoor environmental standards since the comfort parameters were set up according to the thermal satisfaction of occupants. In the following Chapter 6 using the Fanger comfort model, PMV and PPD indexes will be calculated in order to evaluate thermal comfort sensation and determine the comfort category in the building according to EN 15251.

Table V - 14 Energy performance comparison and indoor environment standard definition

Month	Reference FTS office-tower (2011)		Reference FTS office-tower (2013)	
	Heating energy [kWh]	Cooling, lighting and equipment electricity [kWh]	Heating energy [kWh]	Cooling, lighting and equipment electricity [kWh]
Jan	82306	19099	81610	19214
Feb	95210	18376	76527	17478
Mar	70106	18595	55891	18519
Apr	31934	16918	52467	16918
May	/	16486	/	14375
Jun	/	17519	/	16706
Jul	/	17947	/	17078
Aug	/	16707	/	16652
Sep	/	18541	/	14113
Oct	18580	18009	21980	17245
Nov	63268	19124	30005	15282
Dec	80788	20398	60304	20230
Sum [kWh/a]	**442192**	**217719**	**378784**	**203810**
Annual [kWh/m^2/a]	**129**	**64**	**110**	**59**
Best Case Scenario [kWh/m^2/a]	**19**	**63**	**19**	**63**
Energy demand reduction	**85 %**	**Identical**	**83 %**	**Slight deviation**

In order to reduce the energy demand for heating and cooling even further a heat exchanger could be added to the supply outdoor air system. Depending from the heat exchanger's efficiency demands can be reduced, especially in the cooling season. Chapter 7 will elaborate the HVAC system selection and its application.

Chapter 6

Energy performance optimization in the function of comfort parameters

6.1. Indoor environmental quality in buildings

6.1.1. Introduction

The indoor environmental quality is the complex of thermal, visual, acoustic, vibration and ergonomic comfort, and indoor air quality which strongly influences indoor well-being and productivity in working environment (Wargocki, et al. 2006).

The evaluation of the indoor environmental quality plays an important role, completing the evaluation of the building energy quality. The Energy Performance Building Directive concerning the energy certification of buildings, clearly underlines the importance of assessing the expected or achieved indoor environmental quality level corresponding to a given energy performance (Directive 2010/31/EU of the European Parliament and the Council of 19 May 2010 on the energy performance of buildings (recast) 2010) (EN 15217 Standard 2008) (EN 15603 Standard 2008). Furthermore, energy consumption may have significant variations depending on the actual operating condition as (Corgnatti and Silva 2011):

- Operating strategies and schedules of the HVAC system;
- Comfort expectations of occupants;
- Strategies adopted by the occupants for the control of the indoor climate;
- Type of activities.

Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment. There are large variations, both physiologically and psychologically, from person to person, which makes it difficult to satisfy everybody in a space. The environmental conditions required for comfort are not the same for everyone according to ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy (ASHRAE Standard 55 2013).

EN ISO 7730 Ergonomics of the thermal environment, defines thermal comfort as the condition of mind which expresses satisfaction with the thermal environment. Thermal comfort is a subjective way to define if the surrounding climate is comfortable or not and a perfect environment can be summarized as (EN ISO 7730 2005):

- The occupant feels thermally neutral and does not wish the environment to be colder or warmer;
- The occupant is not exposed to any local cooling or heating at any place on their body.

Six factors are influencing thermal comfort conditions which are the following:

- Metabolic rate;
- Clothing insulation;
- Air temperature;
- Radiant temperature;
- Air velocity;
- Relative humidity.

Variables 2-6 may be non-uniform over an occupant's body and this non-uniformity may be an important consideration in determining thermal comfort (ASHRAE Standard 55 2013).

When people are dissatisfied with their thermal environment, not only is it a potential health hazard, it also impacts on their ability to function effectively and their satisfaction at work (Designing Buildings Ltd. 2014). Criteria for the thermal environment shall be based on the thermal comfort indices PMV-PPD (predicted mean vote - predicted percentage of dissatisfied) with assumed typical levels of activity and thermal insulation for clothing (winter and summer) as described in detail in EN ISO 7730. Based on the selected criteria (comfort category) a corresponding temperature interval is established (EN 15251 2007).

Unfortunately it is impossible to create a thermal indoor climate where everybody is satisfied, since everyone's perception to temperature is different and therefore have different conceptions of what it means to by thermally satisfied; based on practical data it is generally recognized that for a perfect building scenario it is not possible to have less than 5% of occupants dissatisfied. The human thermal environment cannot be expressed in degrees. Nor can it be satisfactorily defined by acceptable temperature ranges. It is a personal experience dependent on a great number of criteria and can be different from one person to another within the same space. For example, a person walking up stairs in a cold environment whilst wearing a coat might feel too hot, whilst someone sat still in a shirt in the same environment might feel too cold (Designing Buildings Ltd. 2014).

For design of ventilation systems and calculation of heating and cooling loads the required ventilation rate shall be specified in the design documents (EN 15251

2007). In the previous Chapter 5 the energy demand for heating and cooling included the determination of the total ventilation rate by calculating people and area dependant ventilation amounts.

6.1.2. Factors influencing thermal comfort

Thermal comfort results from a combination of environmental factors and personal factors (Designing Buildings Ltd. 2014):

Environmental factors:

- **Air temperature (AT);** the temperature of the air that a person is in contact with, measured by the dry bulb temperature;
- **Radiant temperature (RT);** the temperature of a person's surroundings (including surfaces, heat generating equipment, the Sun and the sky). This is generally expressed as **mean radiant temperature (MRT)**, a weighted average of the temperature of the surfaces surrounding a person, which can be approximated by globe thermometer, and any strong mono-directional radiation such as radiation from the sun;
- **Relative humidity (RH);** the ratio between the actual amount of water vapor in the air and the maximum amount of water vapor that the air can hold at that air temperature, expressed as a percentage. Humans are sensitive to humidity because the human body uses evaporative cooling, enabled by perspiration, as the primary mechanism to rid itself of waste heat. Perspiration evaporates from the skin more slowly under humid conditions than under arid conditions. Since humans perceive a low rate of heat transfer from the body to be equivalent to a higher air temperature, the body experiences greater distress of waste heat burden at high humidity than at lower humidity, given equal temperatures;
- **Air velocity (AV);** the velocity of the air that a person is in contact with (measured in m/s). The faster the air is moving, the greater the exchange of heat between the person and the air (for example, draughts generally make people feel colder).

Personal factors:

- **Clothing (CLO);** clothes insulate a person from exchanging heat with the surrounding air and surfaces as well as affecting the loss of heat through the evaporation of sweat. Clothing can be directly controlled by a person whereas environmental factors may be beyond their control;
- **Metabolic heat (MET);** the heat we produce through physical activity. A stationary person will tend to feel cooler than a person that is exercising. Metabolic rate is the rate of transformation of chemical energy into heat and mechanical work by metabolic activities of an individual, per unit of skin surface are (expressed in units of met) equal to 58.2 W/m^2, which is the energy produced per unit skin surface are of an average person seated at rest (ASHRAE Standard 55 2013);
- Well being generally and sickness, such as the common cold or flu which affect our ability to maintain body temperature, 37°C at the core.

Ten elements would have to be taken in consideration when addressing thermal comfort in buildings. The following factors are shown in Table VI - 1 below from the ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy (ASHRAE Standard 55 2013).

Table VI - 1 Factors Affecting Thermal Comfort

General environmental factors	Localized factors
Dry bulb temperature	Vertical air temperature differences
Mean radiant temperature	Radiant temperature asymmetry
Relative humidity	Floor Temperature
Air velocity	Drafts
Personal factors	
Metabolic rate	Clothing

According to the REHVA guidebook an executive summary has been made of the requirement related to indoor environmental quality, as seen in Table VI - 2 (Corgnatti and Silva 2011).

Table VI - 2 Executive summary of requirements related to each topic, matched with what designers have to analyze and demonstrate

Topic	Requirement	To verify
Indoor air quality and indoor pollutant source control	Pollutant levels monitoring	▪ Indoor pollutant level concentration, compared with benchmark ▪ Required air changes per hour ▪ Humidity level during occupancy (monitoring) ▪ All design strategies related to this topic
	Adequate air change rates	
	Limiting and/or cracking air pollution	
	Minimizing microbiological contamination risk	
	Humidity control	
	Designing strategies of smokers management	
	Designing natural ventilation strategies	
Thermal comfort	Summer overheating	▪ Indoor dry bulb temperature ▪ Effective temperature ▪ Operative temperature ▪ Mean radiant temperature ▪ PVM ▪ PPD
	Winter indoor surface temperature	
	Summer indoor surface temperature	
	Indoor temperature	
Visual comfort	Daylight	▪ Building orientation ▪ Shading device control ▪ Daylight factor ▪ Illuminance level ▪ Light fixture (with or without dimming control) ▪ Glare rating
	View	
	Direct solar radiation penetration	
	Lighting uniformity	
	Windows awnings	
	Fluorescent lamp use	
Acoustic comfort	Acoustic performance of building envelope	▪ Sound insulation between rooms ▪ Impact sound insulation ▪ Reverberation time ▪ Indoor ambient noise levels ▪ Speech intelligibility
	Acoustic performance of indoor spaces	

A person's body temperature in a comfortable and uncomfortable state is shown in Figure VI - 1 (Creech 2013).

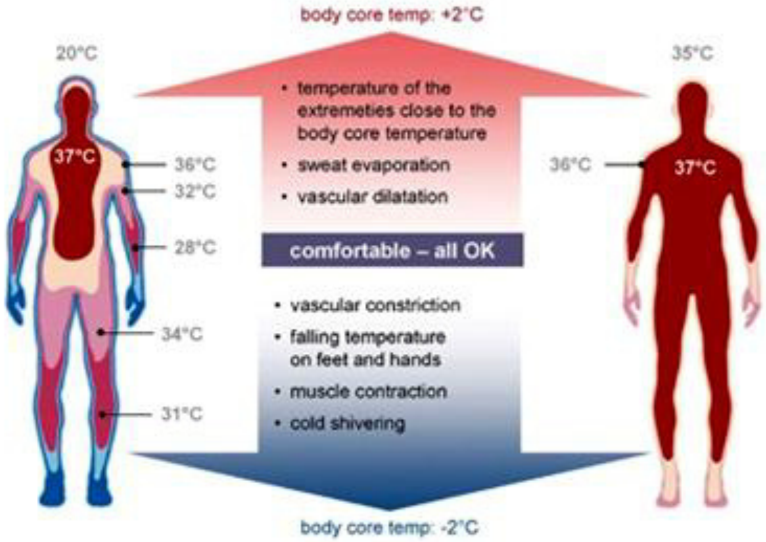


Figure VI - 1 Body temperature in comfortable state (right) and uncomfortable state (left)

Body temperature regulation in the human organism is a complex topic. The control center in the brain responds when the temperature of the body rises or falls. This complex process is simplified in Figure VI - 2 (Cummings 2007).

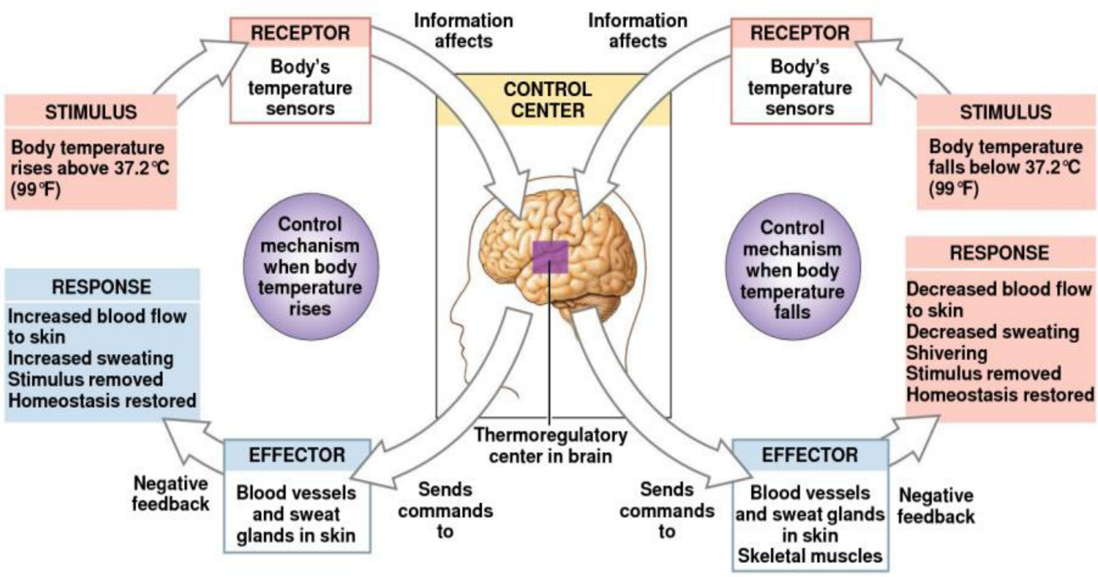


Figure VI - 2 Thermoregulation in the human body

Figure VI - 3 shows body surface temperature differences in case of sedentary activity in an office environment (ThermoAnalytics 2014). Simulations show highest temperatures on the hands and head of the occupant, while clothing isolates partially the metabolic heat radiation.

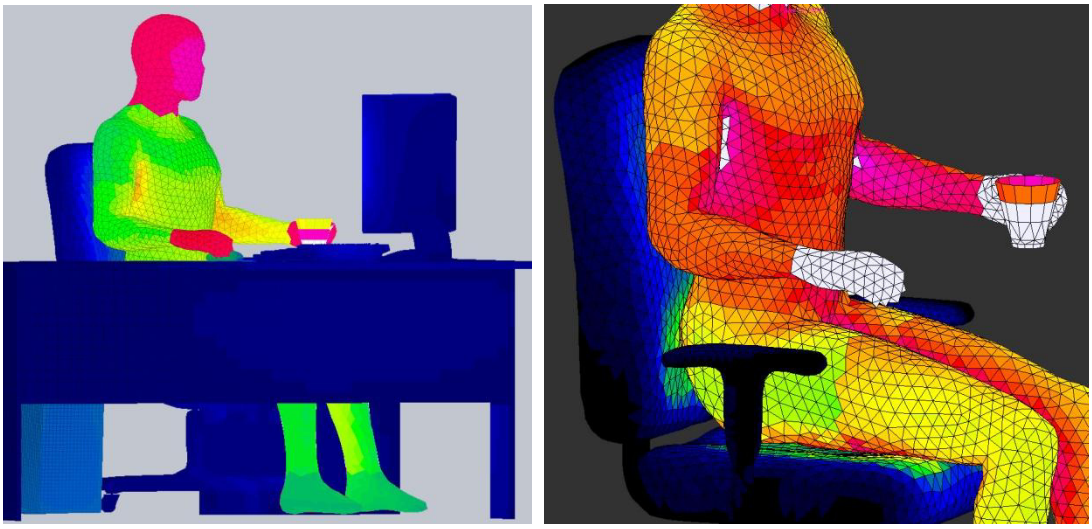


Figure VI - 3 Body surface temperature differences in case of sedentary activity

6.1.3. Controlling thermal comfort

Thermal comfort can be controlled or adjusted by a number of different measures: (Designing Buildings Ltd. 2014)

- Environmental monitoring and control (automated or user-controlled systems, active systems such as heating and cooling and passive systems such as shading). NB User-controlled systems require that users are properly trained.
- Adapting or changing clothing. Businesses can allow people to wear different clothing depending on conditions. They can also provide things like cloak rooms or lockers so that people can change clothes or take off and put down coats. The golden rule is layering, generally 3 layers, and use zips and buttons to regulate temperature.
- Allowing flexible working hours or changing start and finish times.
- Adjusting tasks. For example, allowing breaks or reducing the length of time people are exposed to particular conditions.
- Providing information telling people what sort of conditions to expect so that they can dress and behave appropriately.
- Providing or allowing personal equipment such as desk fans.
- Separating people from sources of discomfort. For example putting heat generating equipment such as ICT equipment in separate rooms, insulating pipes, preventing draughts and so on. NB draughts can be caused by high local surface temperature differences even in a space where there is no air infiltration – for example a cold down-draught near a window.
- Providing protective clothing (PPE Personal Protective Equipment). This should be a last resort option.

6.2. Thermal comfort theory – PMV and PPD model

6.2.1. Comfort theory – comfort zone

In order to determine the thermal comfort quality in a workplace it is important to know within what limits should we maintain temperature, humidity air velocity and air quality to achieve reasonable results. The answers can be obtained from the Predicted Mean Vote index (PMV) which predicts the mean value of the subjective ratings of a group of people in a given environment. The Predicted Mean Vote (PMV) model stands among the most recognized thermal comfort models. It was developed using principles of heat balance and experimental data collected in a controlled climate chamber under steady state conditions (Fanger 1970). Predicted mean vote is an index that predicts the mean value of the thermal sensation votes (self-reported perceptions) of a large group of person on a sensation scale expressed from -3 to +3 corresponding to the categories "cold," "cool," "slightly cool," "neutral," "slight warm," "warm," and "hot." The 7 point ASHRAE scale of thermal comfort sensation is presented in Table VI - 3 below.

Table VI - 3 ASHRAE scale of thermal comfort sensation

Scale	Sensation
3	Hot
2	Warm
1	Slightly warm
0	Neutral
- 1	Slightly cool
- 2	Cool
- 3	Cold

The comfort zone is defined in terms of a range of operative temperatures that provides acceptable thermal environmental conditions or in terms of the combinations of air temperature and mean radiant temperature that people find thermally acceptable. (ASHRAE Standard 55 2013)

Calculation of the operative temperature based on air- and mean radiant temperature in most practical cases where the relative air speed is small (< 0.2 m/s) or where the difference between mean radiant and air temperature is small (< 4 °C) the operative temperature can be calculated with sufficient approximation as the mean value of air and mean radiant temperature. For higher precision and other environments the following Equation 12 may be used: (ASHRAE Standard 55 2013)

$$t_{op} = A\, t_a + (1 - A)\, t_r \tag{12}$$

Where:

t_{op}	-	Operative temperature
t_a	-	Air temperature
t_r	-	Mean radiant temperature
A	-	Shown in Table VI - 4 below as function of the relative air speed v_r

Table VI - 4 A and v_r values

v_r	< 0.2 m/s	0.2 to 0.6 m/s	0.6 to 1.0 m/s
A	0.5	0.6	0.7

According to the ASHRAE Standard 55 and data based on ISO 7730 the graphical method for typical office environment may be applied to spaces where the occupants have activity levels that result in metabolic rates between 1.0 met and 1.3 met and where clothing is worn that provides between 0.5 clo and 1.0 clo of thermal insulation. Most office spaces fall within these limitations. The range of operative temperatures presented in Figure VI - 4, are for 80% occupant acceptability. This is based on a 10% dissatisfaction criteria for general (whole body) thermal comfort based on the PMV-PPD index, plus an additional average 10% dissatisfaction that may occur from local thermal discomfort (ASHRAE Standard 55 2013) (EN ISO 7730 2005).

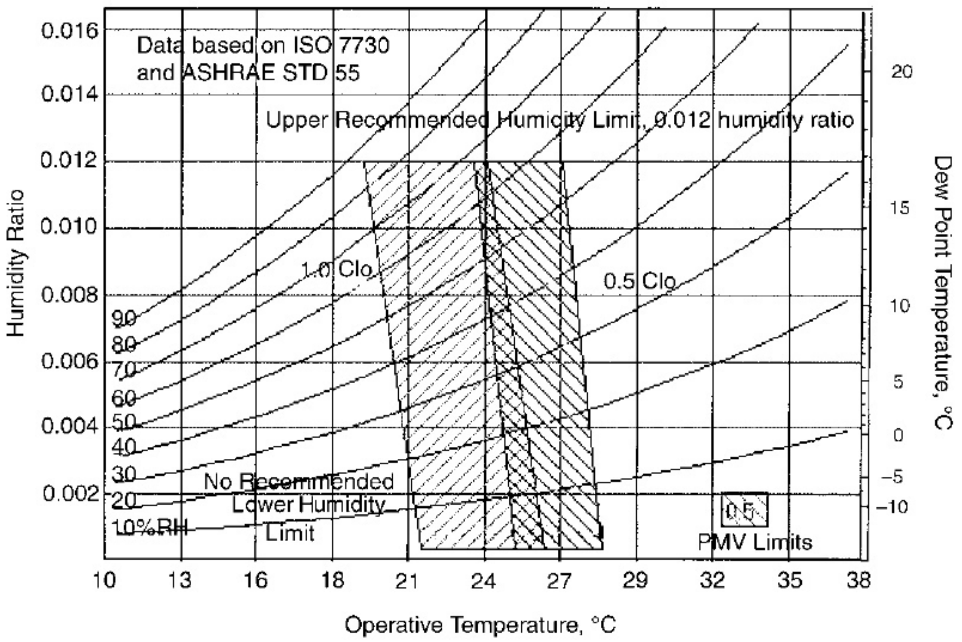


Figure VI - 4 Acceptable range of operative temperature and humidity for spaces that meet the specified criteria

6.2.1.1. Psychrometric chart

A psychrometric chart is a graphical representation of the psychrometric processes of air. Psychrometric processes include physical and thermodynamic properties such as dry bulb temperature, wet bulb temperature, humidity, enthalpy, and air density. Psychrometric charts show temperature vs. humidity, and can be used to express human thermal comfort, design strategies, and energy requirements for those strategies (Autodesk 2014).

An example is presented in Figure VI - 5 according to ASHRAE Standard 55 of how plotted data on a psychrometric chart can be studied, and related to passive design. In this chart, the dark blue boxes represent the comfort zone, and the other colors represent design strategies that have been enabled to study how they can potentially expand the comfort zone. This psychrometric chart was generated using Climate consultant. (Autodesk 2014) (Milne 2013)

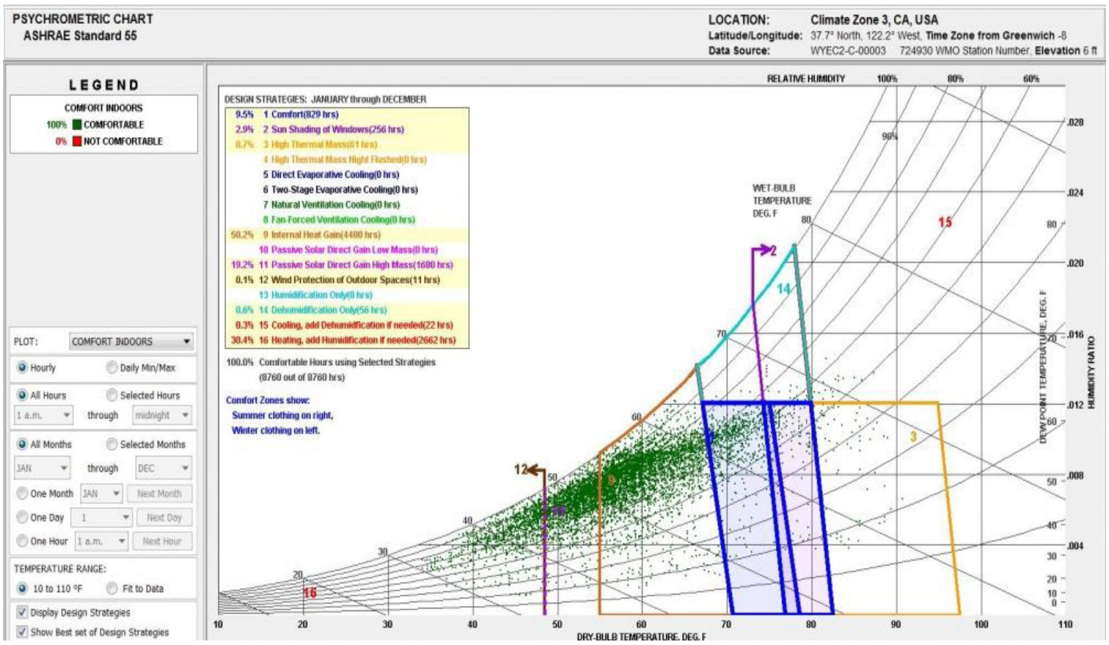


Figure VI - 5 Psychrometric chart from CC

The anatomy of the psychrometric chart is gathers numerous information, vertical lines represent dry-bulb temperature, diagonal lines indicate wet-bulb temperature, curved lines represent relative humidity lines and air temperature is presented increasingly from left to right on the horizontal axis, Figure VI - 6.

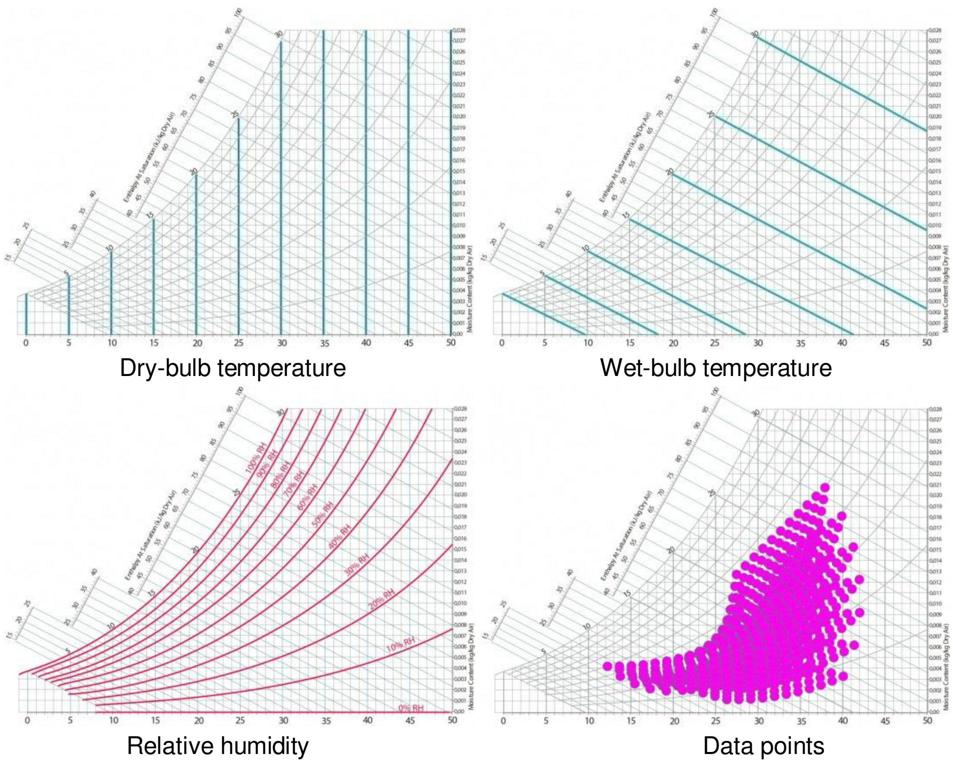


Figure VI - 6 Psychrometric chart anatomy

In order to read the data from a psychrometric chart and analyze if the data points are in the comfort zone minimum two parameters are necessary. Further parameters can be read directly from the chart as presented in Figure VI - 7.

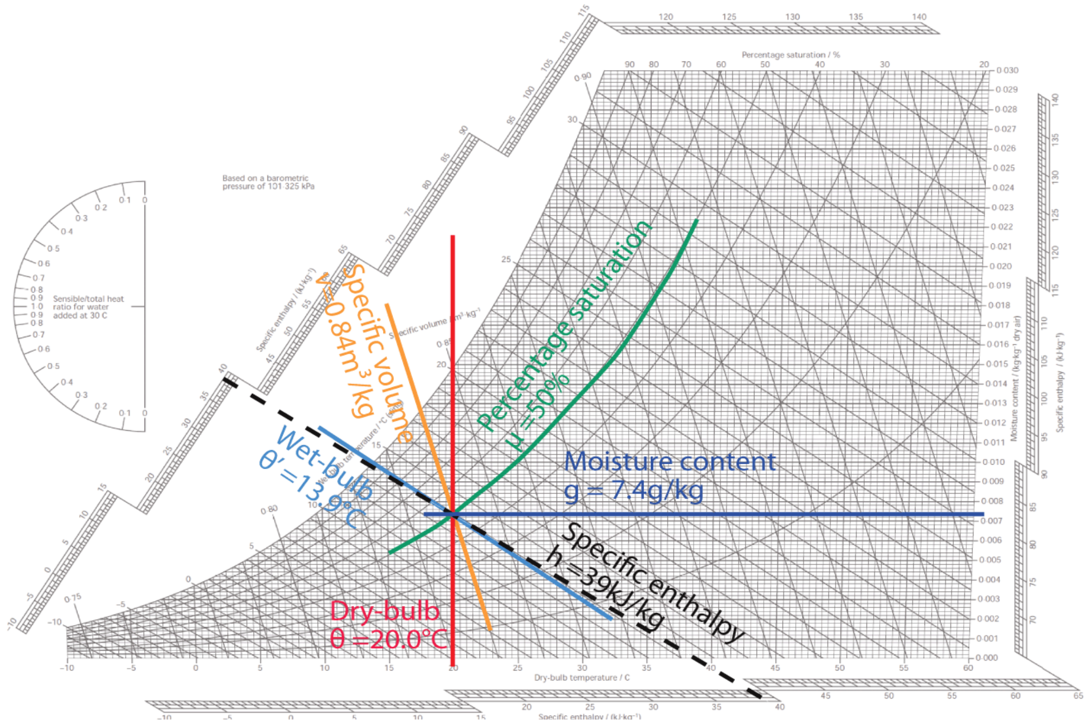


Figure VI - 7 Psychometric chart parameters (Dwyer 2014)

Figure VI - 8 below presents the boundaries of the comfort zone and boundaries if passive measures or a mechanical system is applied.

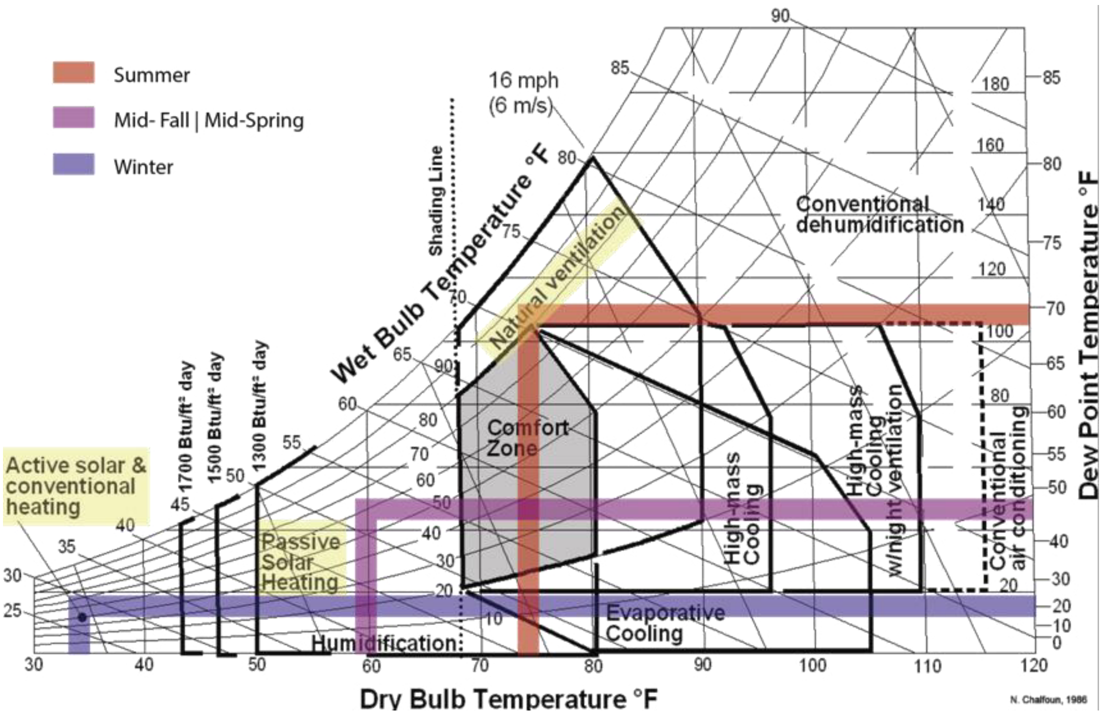


Figure VI - 8 Comfort zone boundaries (Baird Sampson Neuert Architects Inc 2012)

ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy) is a standard that provides minimum requirements for acceptable thermal indoor environments. It establishes the ranges of indoor environmental conditions that are acceptable to achieve thermal comfort for occupants. The purpose of the standard is to specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space (ASHRAE Standard 55 2013). Thermal comfort calculations according to ANSI/ASHRAE Standard 55 can be freely performed with the CBE Thermal Comfort Tool for ASHRAE 55 (Hoyt, et al. 2013). Figure VI - 9 presents the thermal comfort tool for calculation with the PMV method and adaptive method respectively.

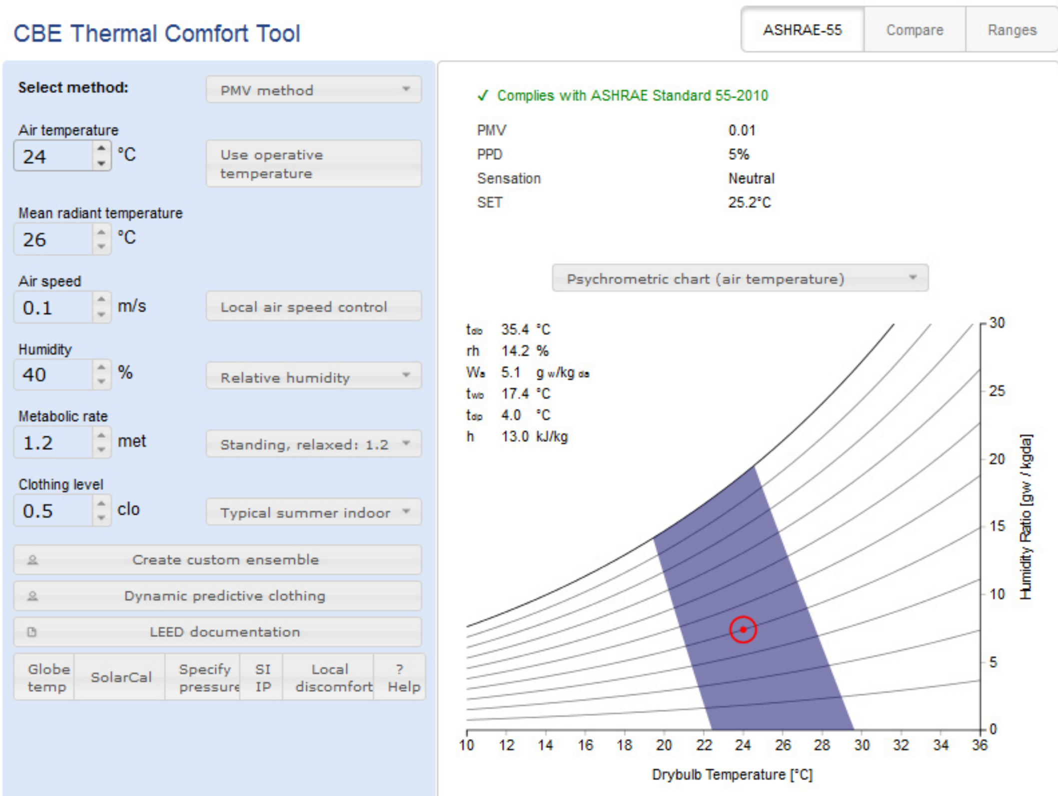


Figure VI - 9 CBE Thermal Comfort Tool

6.2.3. Fanger equations

P.Ole Fanger's equations are used to calculate the Predicted Mean Vote (PMV) of a large group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation. Although predicting the thermal sensation of a population is a significant and important step in determining which conditions are comfortable, it is more useful to consider whether or not people will be satisfied. Fanger developed another equation to relate the PMV to the Predicted Percentage of Dissatisfied (PPD). This relation was based on studies that surveyed subjects in a chamber where the indoor conditions were controlled (Fanger 1970).

The PMV-index can be determined when activity (metabolic rate) and clothing (thermal resistance) are estimated, and the following environmental parameters are measured: air temperature, mean radiant temperature, relative air velocity and partial water vapor pressure. The PMV-index is based on heat balance of the human body. Human body is in heat balance when internal heat production in the body is equal to the loss of heat to the thermal environment. In the PMV-index the physiological response of the thermoregulatory system has been related statistically to thermal sensation votes collected from more than 1300 subjects (Sala, Gallo and Sayigh 1998). ASHRAE Standard 55-2010 uses the PMV model to set the requirements for indoor thermal conditions. It requires that at least 80% of the occupants be satisfied (ASHRAE Standard 55 2013).

The PMV is given by Equations 13, 14 and 15:

$$PMV = \left[0.303e^{(-0.036)} + 0.028\right] \cdot [(M-W) - 3.05 \cdot 10^{-3} \cdot (5733 - 6.99 \cdot (M-W) - p_a) - 0.42 \cdot [(M-W) - 58.15] - 1.7 \cdot 10^{-5} \cdot M \cdot (5867 - p_a) - 0.0014 \cdot M \cdot (34 - t_a) - 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl}+273)^4 - (t_r+273)^4] - f_{cl}h_c \cdot (t_{cl} - t_a)] \tag{13}$$

Where:

$$t_{cl} = 35.7 - 0.028 \cdot (M-W) - I_{cl}\{3.96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl}+273)^4 - (t_r+273)^4] + f_{cl}h_c \cdot (t_{cl} - t_a)\}$$
$$t_{cl} = 2.38 \cdot (t_{cl} - t_a)^{0.25}\ for\ 2.38 \cdot (t_{cl} - t_a)^{0.25} > 12.1 \cdot \sqrt{v_{ar}}$$
$$t_{cl} = 12.1 \cdot \sqrt{v_{ar}}\ for\ 2.38 \cdot (t_{cl} - t_a)^{0.25} > 12.1 \cdot \sqrt{v_{ar}} \tag{14}$$

$$f_{cl} = 1.00 + 1.290 \cdot I_{cl}\ for\ \ I_{cl} < 0.078 m^2 ℃/W$$
$$f_{cl} = 1.05 + 0.645 \cdot I_{cl}\ for\ \ I_{cl} < 0.078 m^2 ℃/W \tag{15}$$

Where:

M	-	Metabolic rate, of body surface area [W/m^2]
W	-	External work, equal to zero for most activities [W/m^2]
I_{cl}	-	Thermal resistance of clothing [(m^2 * °C)/W]
f_{cl}	-	Ratio of man's surface area while clothed, to man's surface are while nude
t_a	-	Air temperature [°C]
t_r	-	Mean radiant temperature [°C]
v_{ar}	-	Relative air velocity (relative to human body) [m/s]
p_a	-	Partial water vapor pressure [Pa]
h_c	-	Convective heat transfer coefficient [W/ (m^2 * °C)]
t_{cl}	-	Surface temperature of clothing [°C]

Furthermore it is recommended to use the PMV-index when six main parameters are inside the following intervals:

M = 46 to 232 W/m^2 (0.8 to 4 met);
I_{cl} = 0 to 0.310 (m^2 * °C)/W (0 to 2 clo);
t_a = 10 to 30 °C;
t_r = 10 to 40°C;
v_{ar} = 0 to 10 m/s;
p_a = 0 to 2700 Pa; Inside this range it is furthermore recommended that the relative humidity be kept inside 30-70%

The PMV-index predicts the mean value of the thermal votes of a large group of people exposed to the same environment. But individual votes are scattered around this mean value and it is useful to predict the number of people likely to feel uncomfortably war or cool (ASHRAE Standard 55 2013).

The PPD-index establishes a quantitative prediction of the number of thermally dissatisfied people. The PPD predicts the percentage of a large group of people likely to feel too warm or cool, i.e. voting hot (+3), warm (+2), cool (-2) or cold (-3) on the 7 point thermal sensation scale. The PPD-index predicts the number of thermally dissatisfied persons (ASHRAE Standard 55 2013). When the PMV value has been determined, the PPD can be determined from the Equation 16:

$$PPD = 100 - 95 \cdot e^{(-0.03353 \cdot PMV^4 - 0.2179 \cdot PMV^2)} \qquad (16)$$

The PMV curve is shown in Figure VI - 10 below (ASHRAE Standard 55 2013). It is simetrical and has a minimum value of 5%, therefore there is no indoor condition which satisfies more than 95% of occupants.

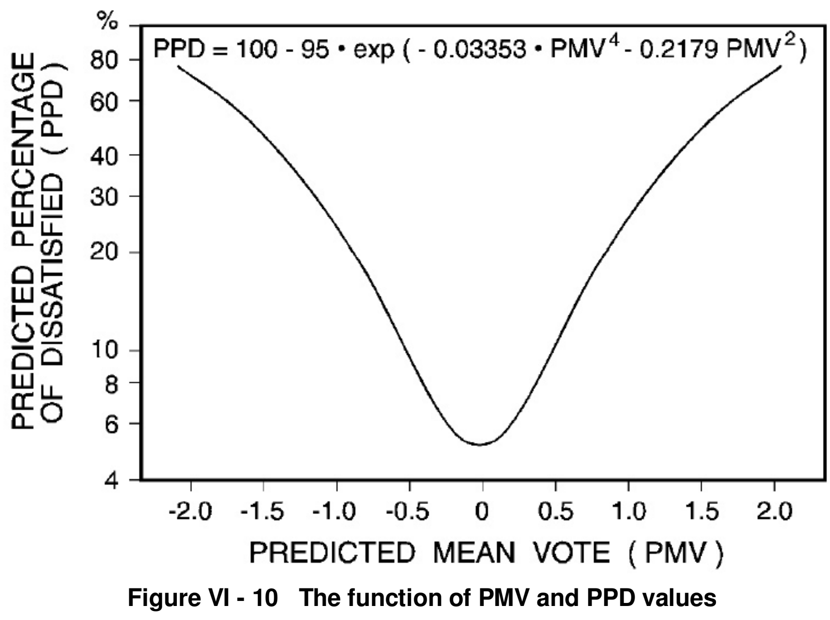


Figure VI - 10 The function of PMV and PPD values

6.4. Comfort parameter simulation and results

6.4.1. Comfort parameters

Human comfort zone refers to the combinations of air temperature, mean radiant temperature and humidity that are predicted to be an acceptable thermal environment at particular values of air speed, metabolic rate and clothing insulation (ASHRAE Standard 55 2013). In order to determine the PMV/PPD values the focus was on the following parameters:

- Air temperature (t [ºC]);
- Mean radiant temperature (t_r [ºC]);
- Relative air velocity (v [m/s]);
- Relative humidity (RH [%]);
- Metabolic rate (M [met]);
- Thermal resistance of clothing (I_{clo} [clo]).

The simulated comfort parameters according to which the optimization was performed considered the following environmental factors:

- Mean air temperature;
- Mean radiant temperature;
- Relative humidity;
- Operative temperature.

To reduce the number of combinations the following assumptions have been made: the relative air velocity is assumed low, 0.10 m/s, the metabolic rate is fixed for sedentary activity, 1.2 met and the thermal resistance of clothing was adjusted and fixed according to the season.

6.4.2. Results and comparison with discussion

6.4.2.1. Results for ground level from comfort parameter simulation

The simulated comfort parameters for the ground level East oriented double office are shown in Figures from VI - 11 to VI - 17. Analyzing the air temperature oscillation graph, Figure VI - 11, it can be concluded that the building envelope's performance is efficient since the temperature oscillation has short intervals. The analysis has been divided into two seasons; winter and summer, which complies with the annual thermostat settings for heating and cooling days. During winter season when heating is turned off daily for a period of 16 hours, indoor air temperature falls maximum 4°C. The air temperature oscillation for this period has been enlarged in order to examine the parameter more precisely. As seen in Figure VI - 12 for the winter period the weekends are indicated with vertical arrows. The brackets indicate the oscillation values in certain periods when the heating is turned off and the building is not occupied (estimated occupation in 8h during weekdays). According to the clothing parameter the comfort zone is defined according to the EN 15251 standard. If clothing is approximately 1.0 the indoor air temperature range for comfort is between 20-24°C in case of II category, which is marked in Figure VI - 12. Considering summer period, Figure VI -13, the situation is different compared to the winter season due to significant internal heat gains which are specific for office buildings. The temperature range is between 23-26°C according to the same category. **Internal heat gains in office buildings are constant throughout the year and lead to significant deviation between heating and cooling demand. A highly thermally insulated building will always require a significant amount of cooling while heating can be reduced drastically.**

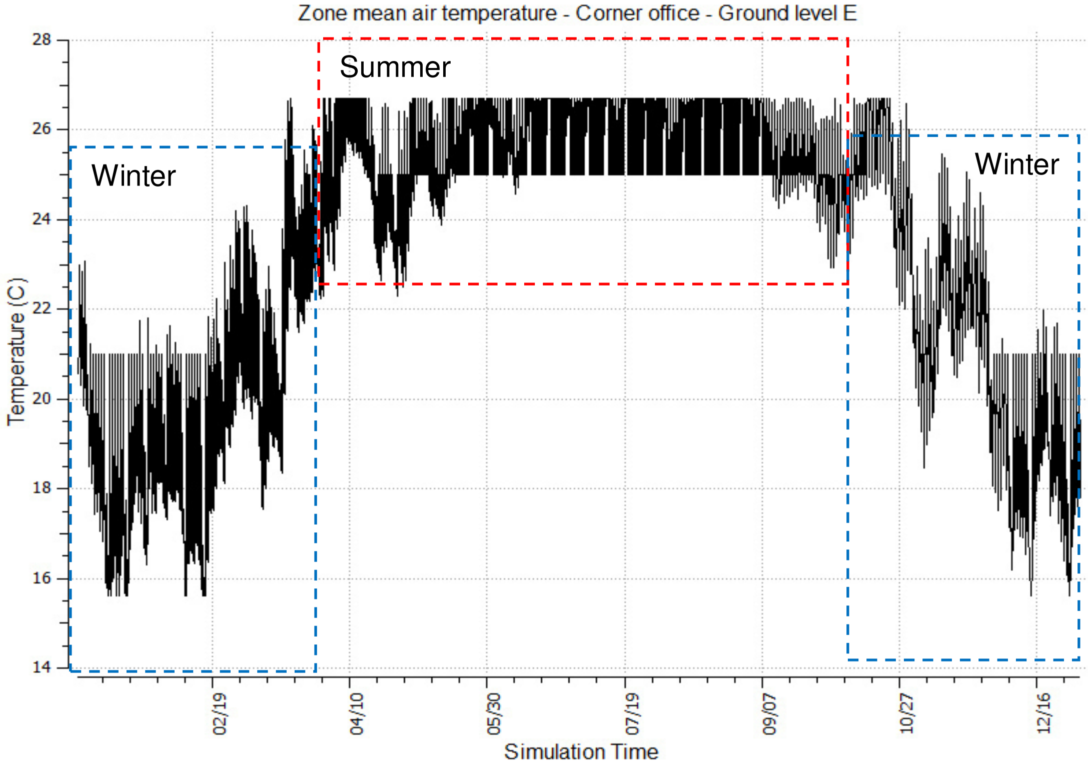


Figure VI - 11 Annual mean air temperature oscillation – Ground level

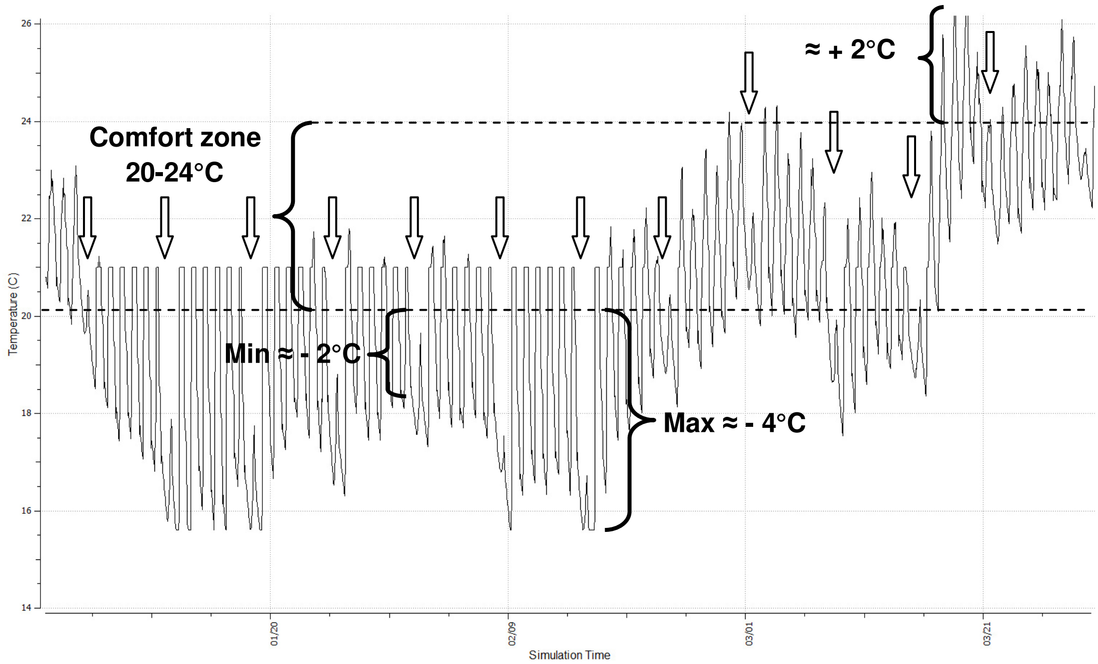


Figure VI - 12 Air temperature oscillation in winter period – Ground level

Results indicate that the thermal properties of the optional building envelope are satisfactory and the envelope efficiency is preferable. Existing office buildings in temperate climate conditions should apply envelopes where exterior walls are well insulated nevertheless exterior glazing should have low SHGC coefficient so internal heat gains can be released.

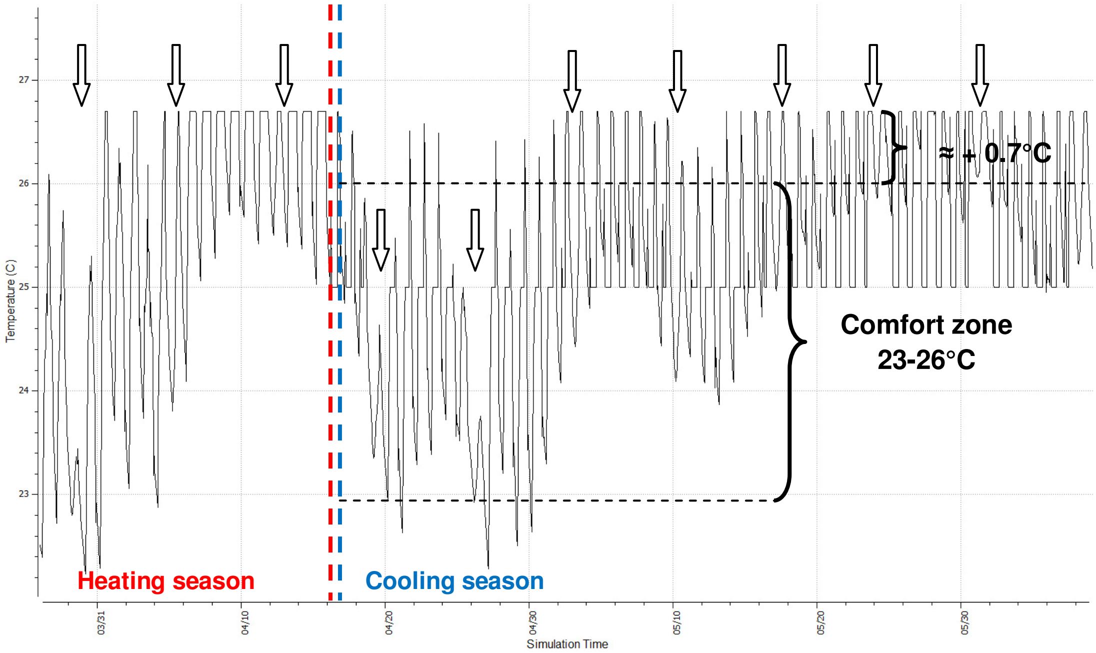


Figure VI - 13 Air temperature oscillation in summer period – Ground level

The mean radiant temperature graph can be seen in Figure VI - 14. It presented slight oscillations during the winter and the summer period which is positive for occupant comfort maintenance. Radiant temperature oscillations in the winter period were maximum 3°C during occupied hours which is preferable for indoor microclimatic conditions.

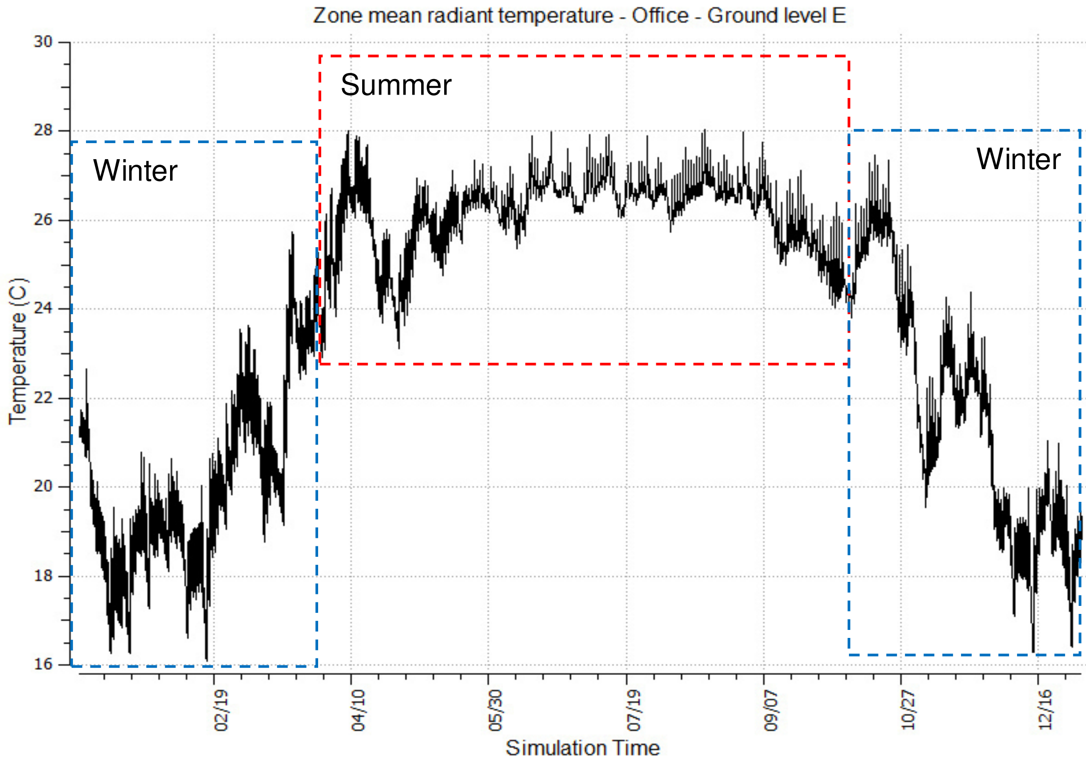


Figure VI - 14 Annual mean radiant temperature oscillation – Ground level

Operative temperature can be defined as the average of the mean radiant and ambient air temperatures, weighted by their respective heat transfer coefficients (ASHRAE Standard 55 2013). The operative temperature is significant in thermal comfort topic. Results from the simulation are presented in Figure VI - 15, where the oscillation trajectories are maximum 5°C in winter and 2.5°C in the summer season during occupied hours.

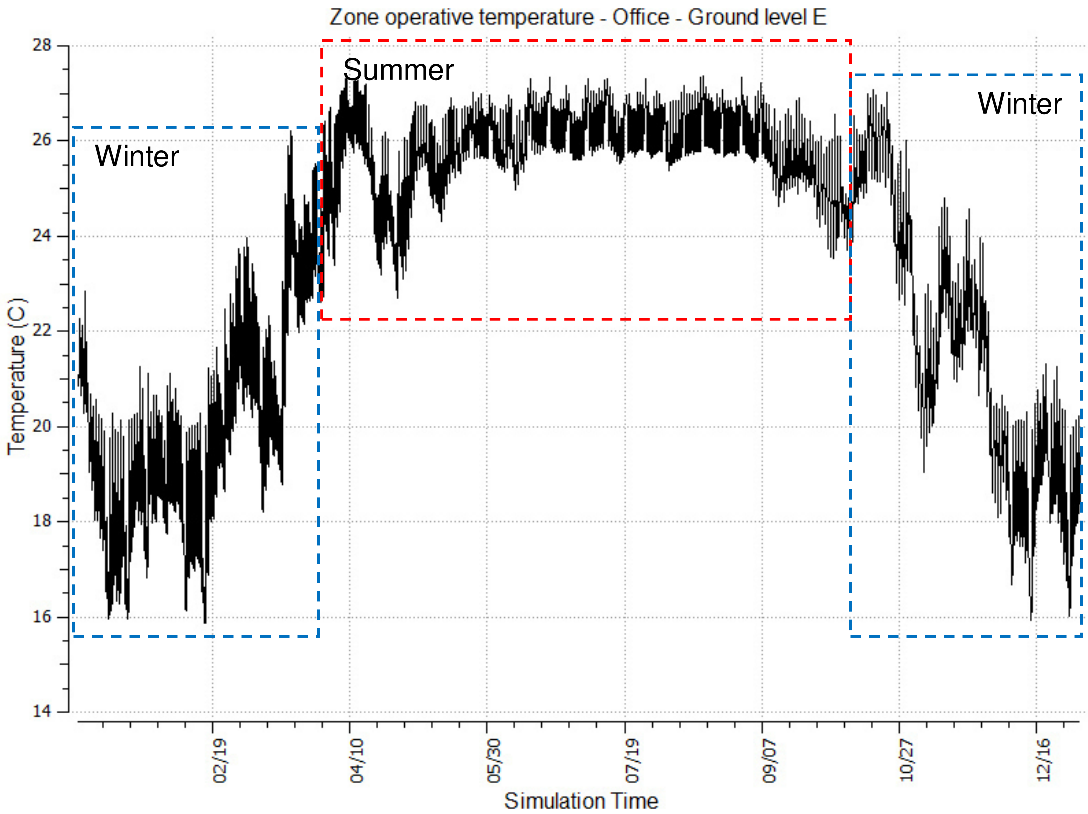


Figure VI - 15 Annual operative temperature oscillation – Ground level

The importance of relative humidity as it relates to your indoor comfort is important when incoming air is heated. During cold winter months the outdoor to indoor relative humidity levels can drop dramatically if indoor environment is under humidified.

The humidification of indoor air is usually not needed since humidity has only a small effect on thermal sensation and perceived air quality in the rooms of sedentary occupancy, however, long term high humidity indoors will cause microbial growth, and very low humidity (<15-20%) causes dryness and irritation of eyes and air ways. Requirements for humidity influence the design of dehumidifying (cooling load) and humidifying systems and will influence energy consumption (EN 15251 2007).

The recommended criteria for dimensioning of humidification and dehumidification by EN 15251 are shown in Table VI - 5 as design values under design conditions. Besides it is recommended to limit the absolute humidity to 12g/kg (EN 15251 2007).

Table VI - 5 Example of recommended design criteria for the humidity in occupied spaces if humidification or dehumidification systems are installed

Type of building/space	Category	Design relative humidity for dehumidification [%]	Design relative humidity for humidification [%]
Spaces where humidity criteria are set by human occupancy	I	50	30
	II	60	25
	III	70	20
	IV	> 70	< 20

Analyzing the relative humidity oscillation graph, Figure VI - 16, if expecting II PPD category as the Best Case Scenario it can be concluded that the values are preferable during occupied hours since values are between 25 and 60%. No humidification system will be required.

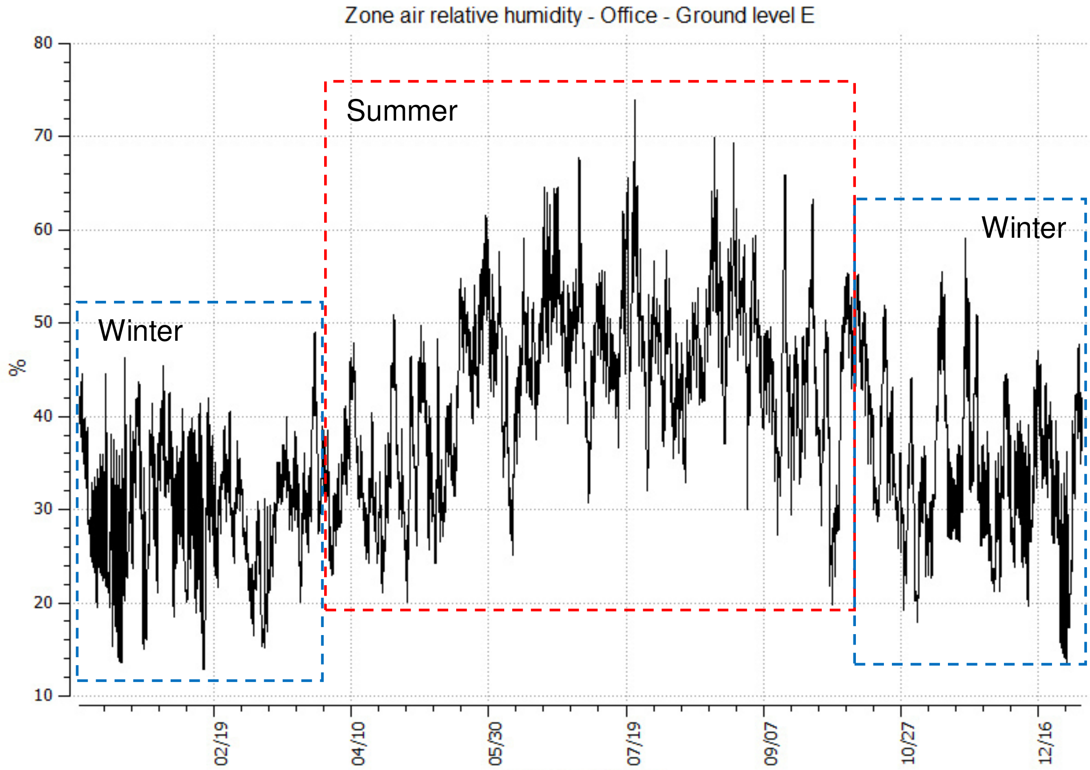


Figure VI - 16 Annual relative humidity oscillation – Ground level

As seen in Figures VI - 17 and VI - 18 the brackets indicate oscillation values during the winter and summer period. Considering the relative humidity of outside air which is heated or cooled when entering the building the humidity ratio can change drastically. The simulated results presented preferable relative humidity values throughout the year.

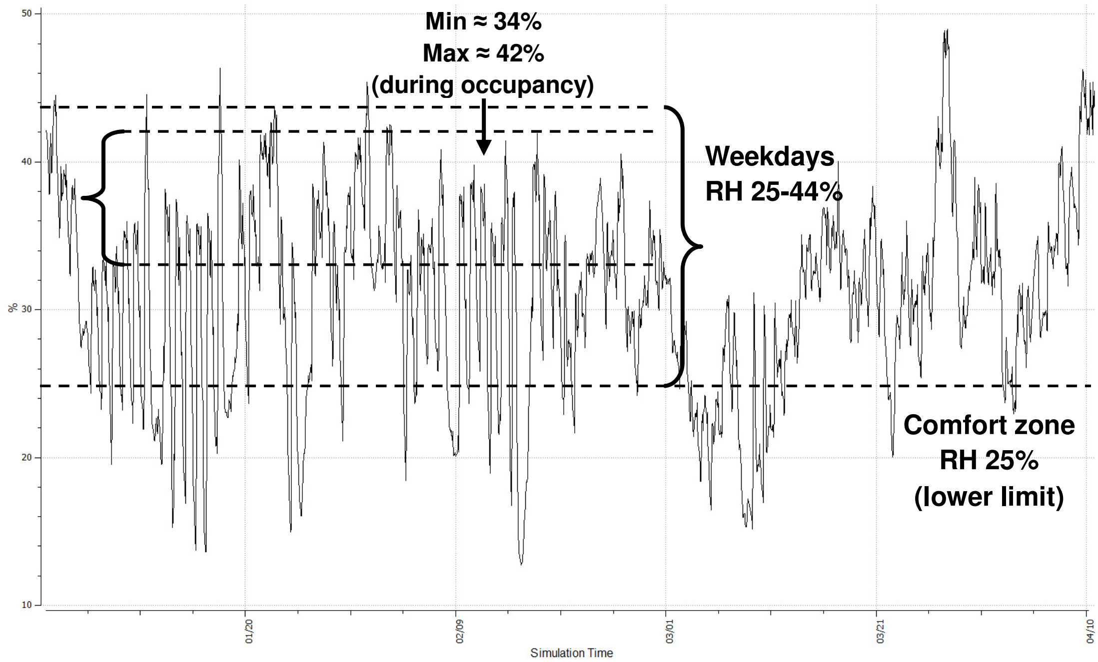


Figure VI - 17 Winter relative humidity oscillation – Ground level

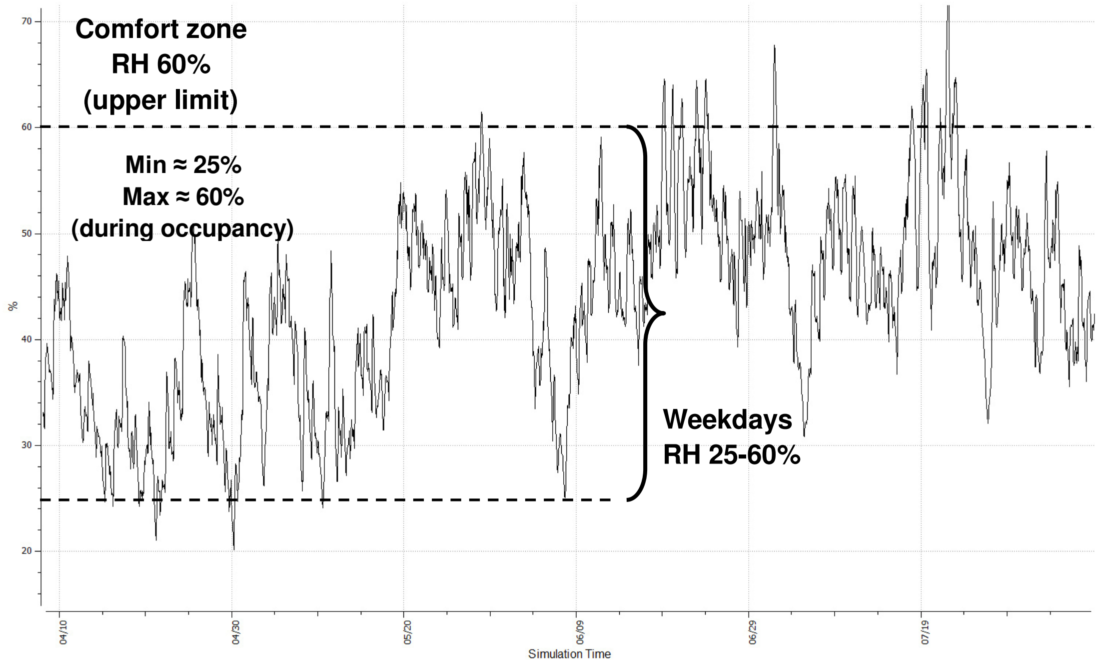


Figure VI - 18 Summer relative humidity oscillation – Ground level

6.4.2.1. Results for 5th level from comfort parameter simulation

The simulated comfort parameters for the 5th level South oriented office are shown in Figures from VI - 19 to VI - 26. Analyzing the air temperature oscillation graph, Figure VI - 19, it can be concluded that the building envelope's performance is efficient since the temperature oscillation has short intervals. Compared to the ground level office which has twice the volume of the 5th level single office the air temperature oscillation presented results with less deviation from the comfort zone.

The analysis was divided into two seasons as previously; winter and summer, which complies with the annual thermostat settings for heating and cooling days. During winter season when heating is turned off daily for a period of 16 hours, indoor air temperature falls maximum 4°C. The air temperature oscillation for this period has been enlarged in order to examine the parameter more precisely. As seen in Figure VI - 20 the brackets indicate the oscillation values in certain periods when the heating is turned off and the building is not occupied (estimated occupation in 8h during weekdays). Considering the summer period, Figure VI - 21 results the situation is different compared to the winter season due to significant internal heat gain which is specific in office buildings.

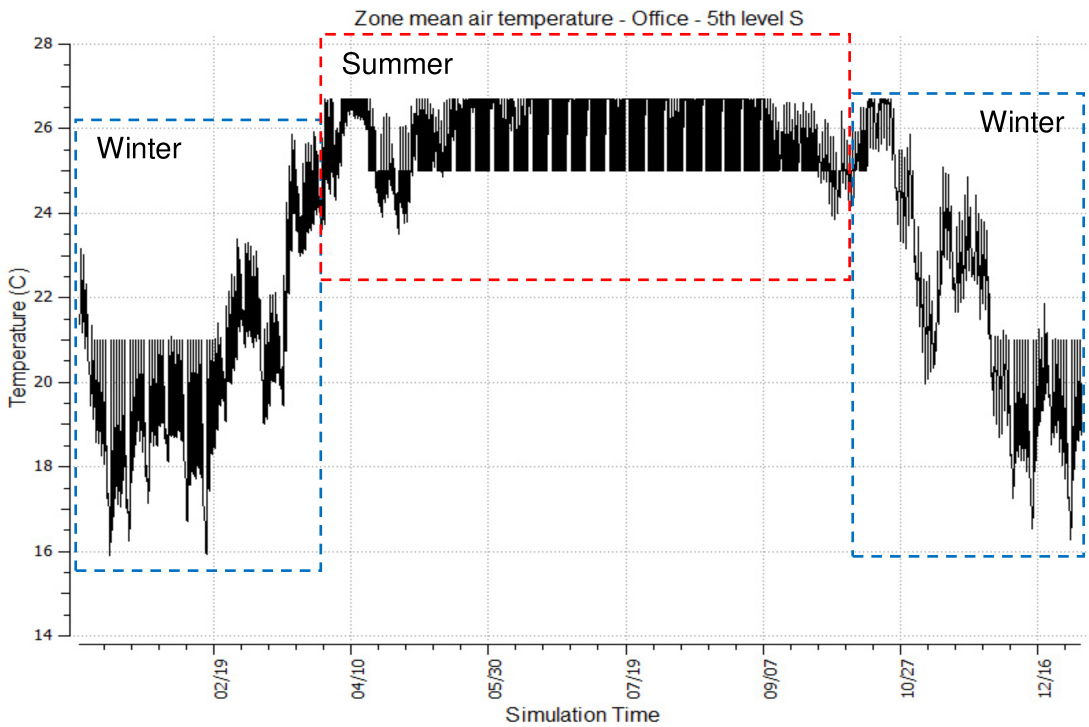


Figure VI - 19 Annual mean air temperature oscillation – 5th level

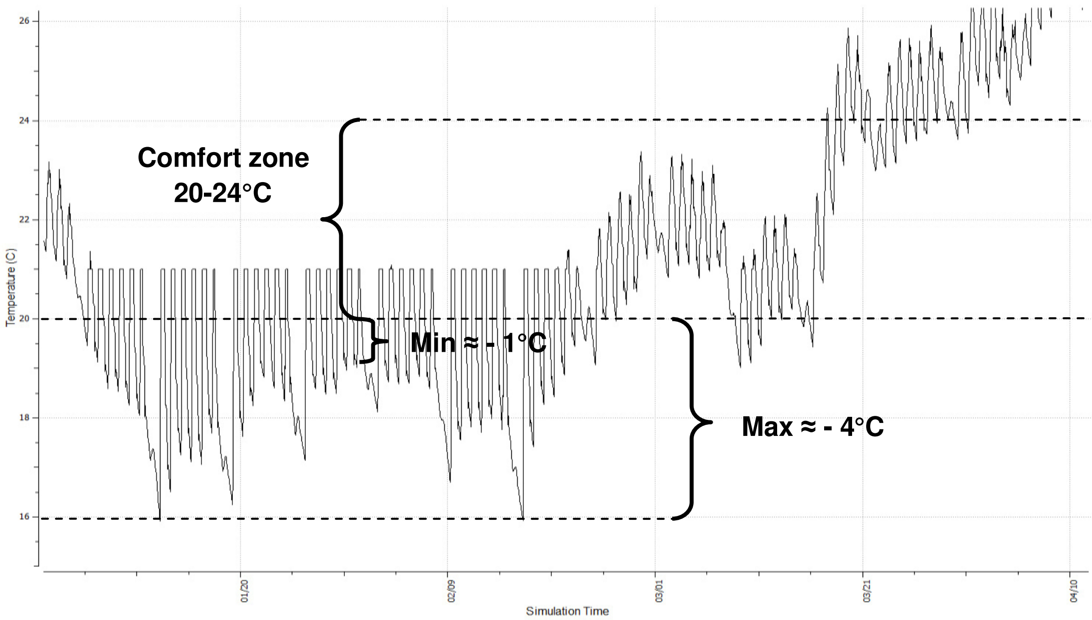


Figure VI - 20 Air temperature oscillation in winter period – 5th level

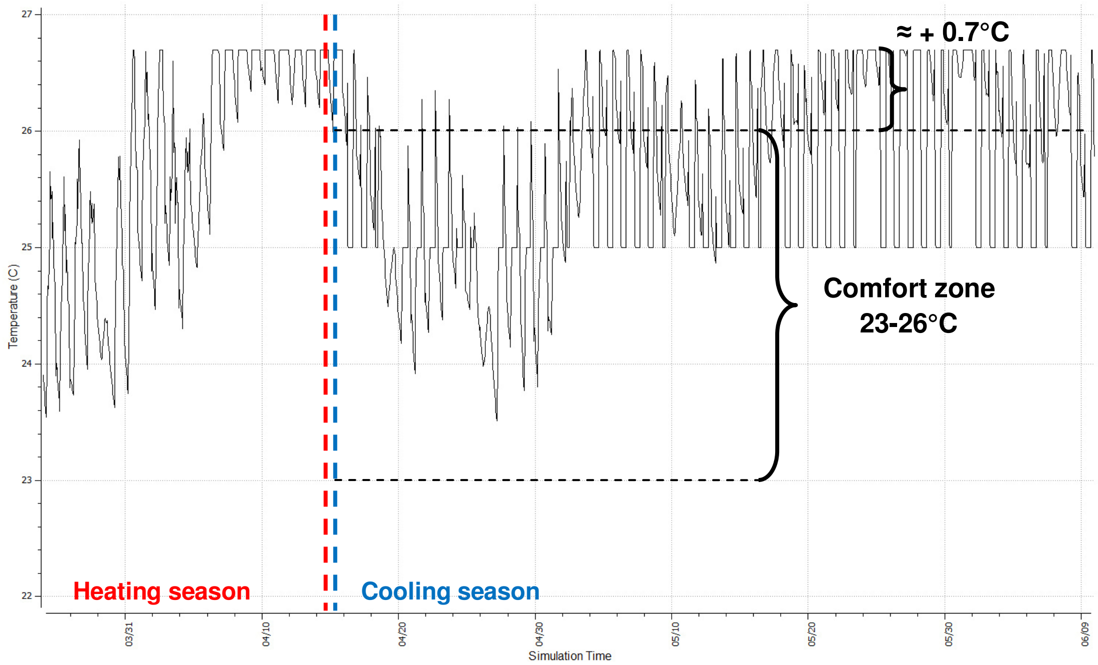


Figure VI - 21 Air temperature oscillation in summer period – 5th level

The mean radiant temperature graph can be seen in Figure VI - 22. It presented slight oscillations during the winter and the summer period which is positive for occupant comfort maintenance. Radiant temperature oscillations in the winter period were maximum 3°C which is preferable for indoor microclimatic conditions.

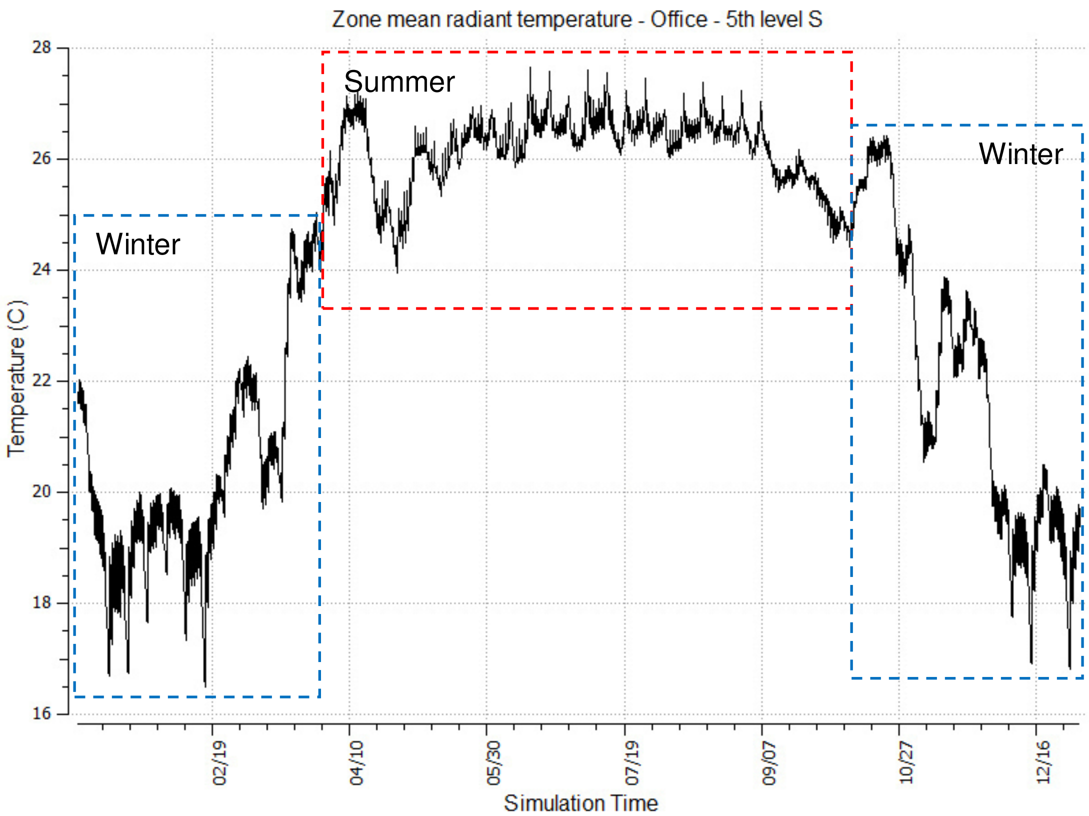


Figure VI - 22 Annual mean radiant temperature oscillation – 5th level

Operative temperature results from the simulation are presented in Figure VI - 23, where the oscillation trajectories are maximum 5°C in winter and 2°C during occupied hours in the summer period.

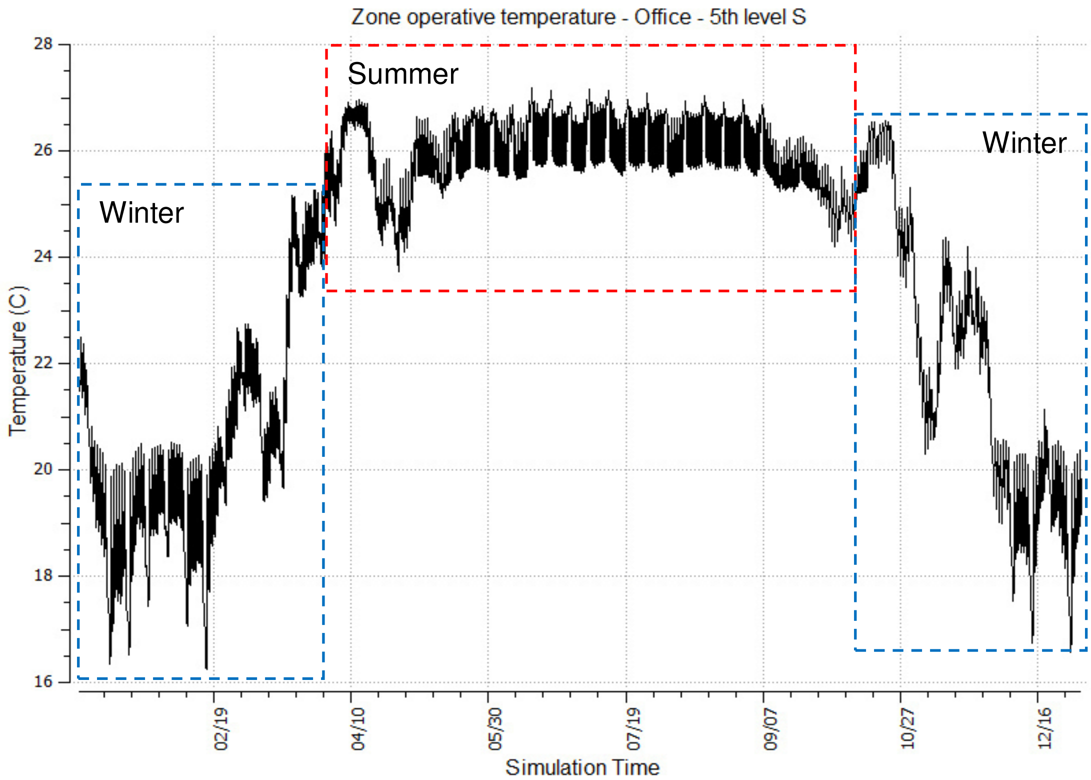


Figure VI - 23 Annual operative temperature oscillation – 5th level

Analyzing the relative humidity oscillation graph, Figure VI - 24, if expecting II PPD category as the Best Case Scenario it can be concluded that the values are preferable during occupied hours since values are between 25 and 60%. No humidification system will be required.

As seen in Figures VI - 25 and VI - 26 the brackets indicate oscillation values during the winter and summer period. Considering the relative humidity of outside air which is heated or cooled when entering the building the humidity ratio can change drastically. The simulated results presented preferable relative humidity values throughout the year.

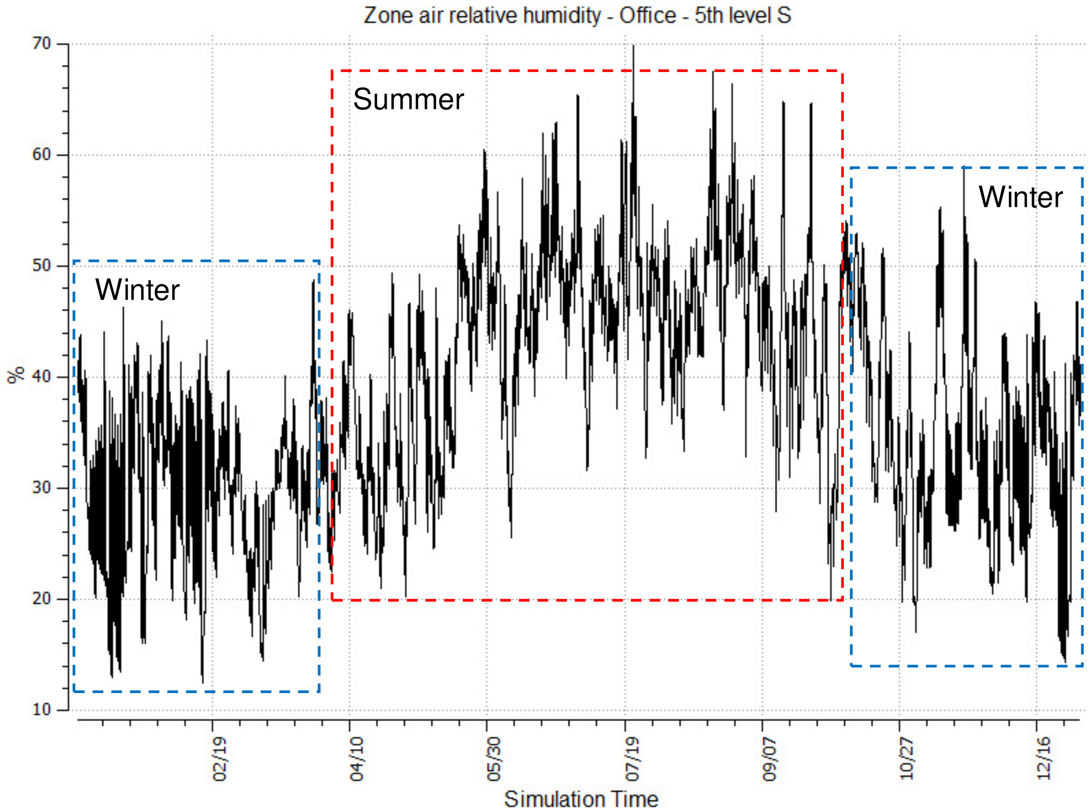


Figure VI - 24 Annual relative humidity oscillation – 5th level

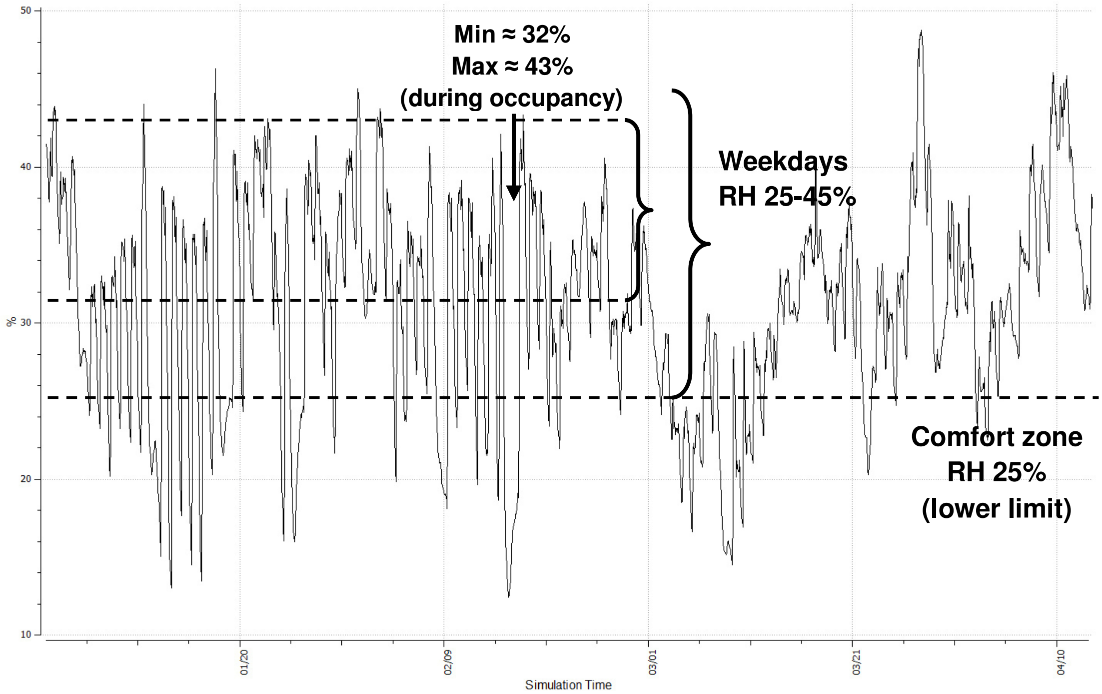


Figure VI - 25 Winter relative humidity oscillation – 5th level

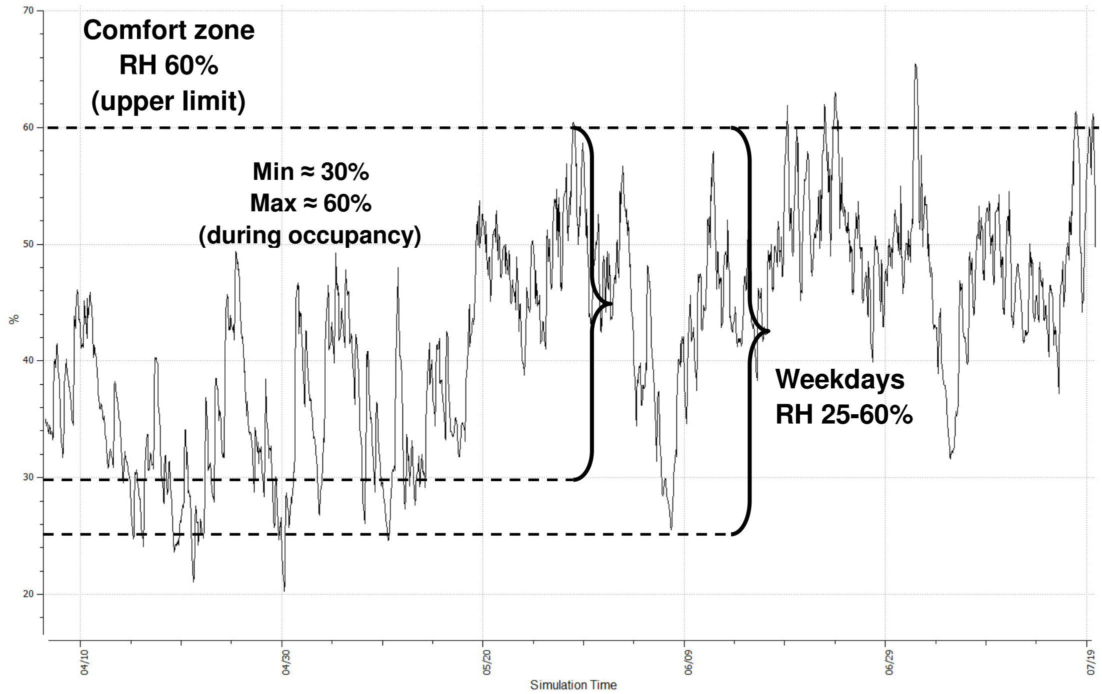


Figure VI - 26 Summer relative humidity oscillation – 5th level

6.4.2.1. Results for 9th level from comfort parameter simulation

The simulated comfort parameters for the 9th level West oriented office are shown in Figures from VI - 27 to VI - 34. Analyzing the air temperature oscillation graph, Figure VI - 27, it can be concluded that the building envelope's performance and roof construction are efficient since the temperature oscillation has relatively short intervals with the maximum of 5.4°C during occupied hours.

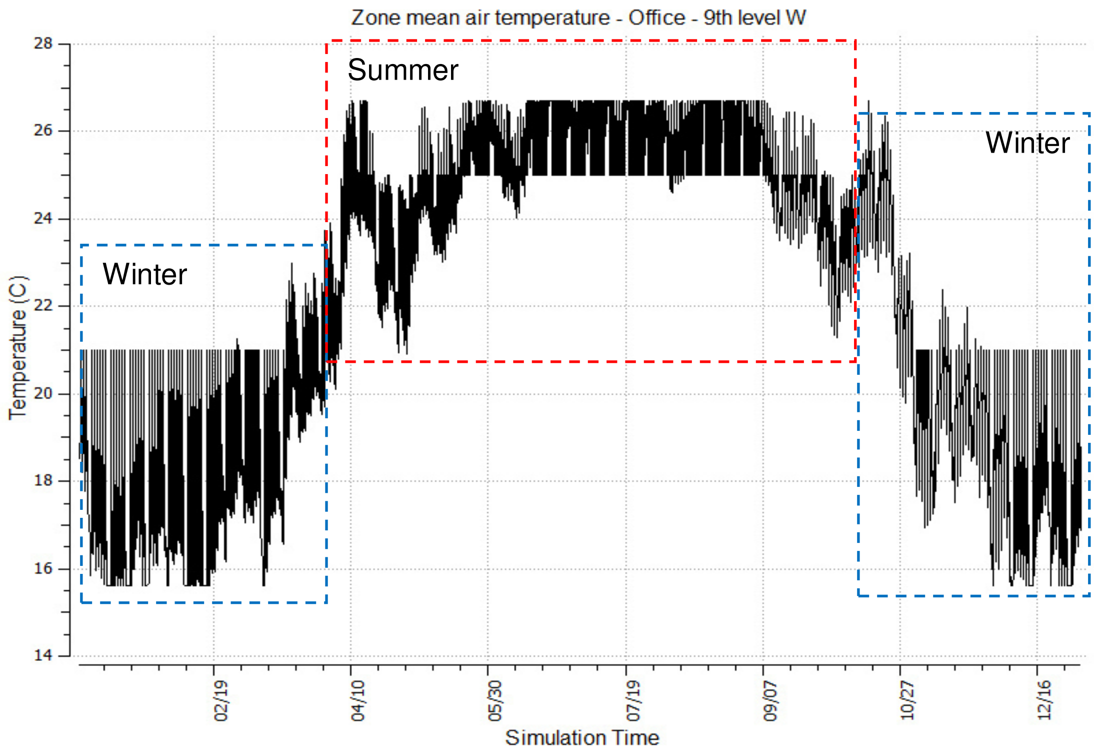


Figure VI - 27 Annual mean air temperature oscillation – 9th level

The analysis was divided into two seasons as previously; winter and summer, which complies with the annual thermostat settings for heating and cooling days. During winter season when heating is turned off daily for a period of 16 hours, indoor air temperature falls maximum 4.4°C. The air temperature oscillation for this period has been enlarged in order to examine the parameter more precisely. As seen in Figure VI - 28 the brackets indicate the oscillation values in certain periods when the heating is turned off and the building is not occupied. Considering the summer period, Figure VI - 29 results the situation is different compared to the winter season due to significant internal heat gain which is specific in office buildings.

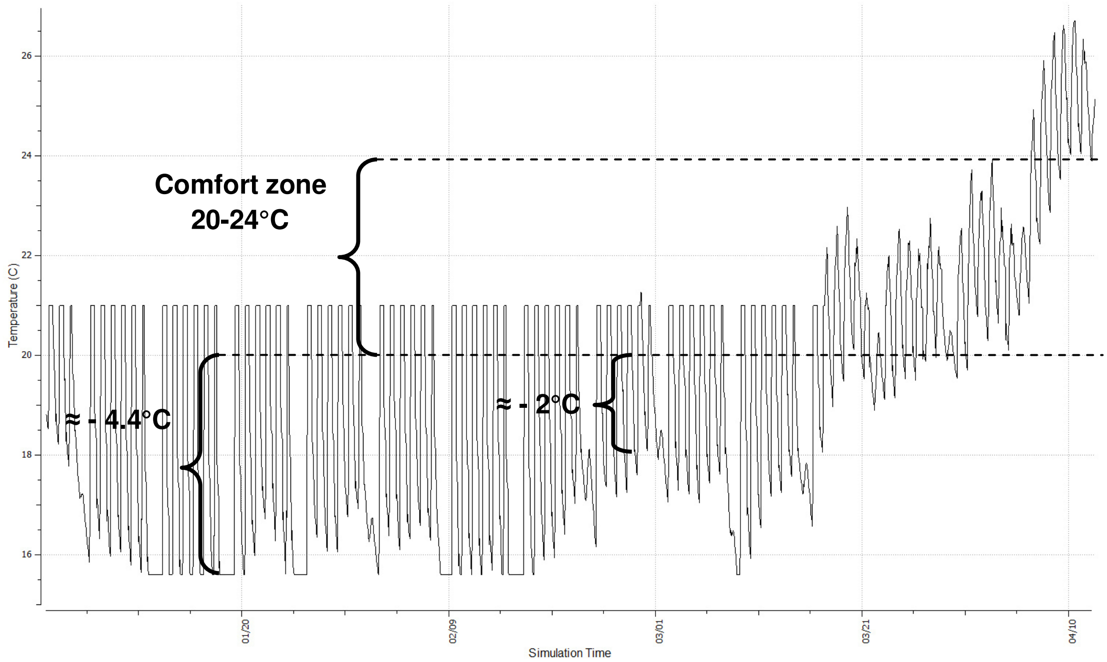


Figure VI - 28 Air temperature oscillation in winter period – 9th level

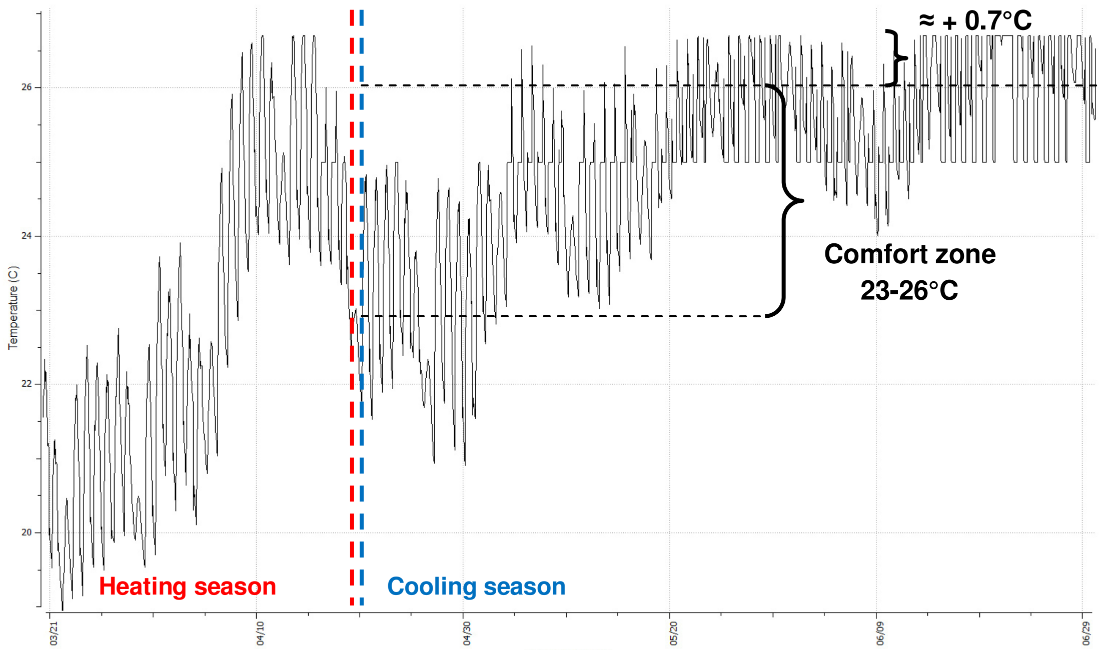


Figure VI - 29 Air temperature oscillation in summer period – 9th level

The mean radiant temperature graph can be seen in Figure VI - 30. It presented slight oscillations during the winter and the summer period which is positive for occupant comfort maintenance. Radiant temperature oscillations in the winter period were maximum 3°C during occupied hours which is preferable for indoor microclimatic conditions.

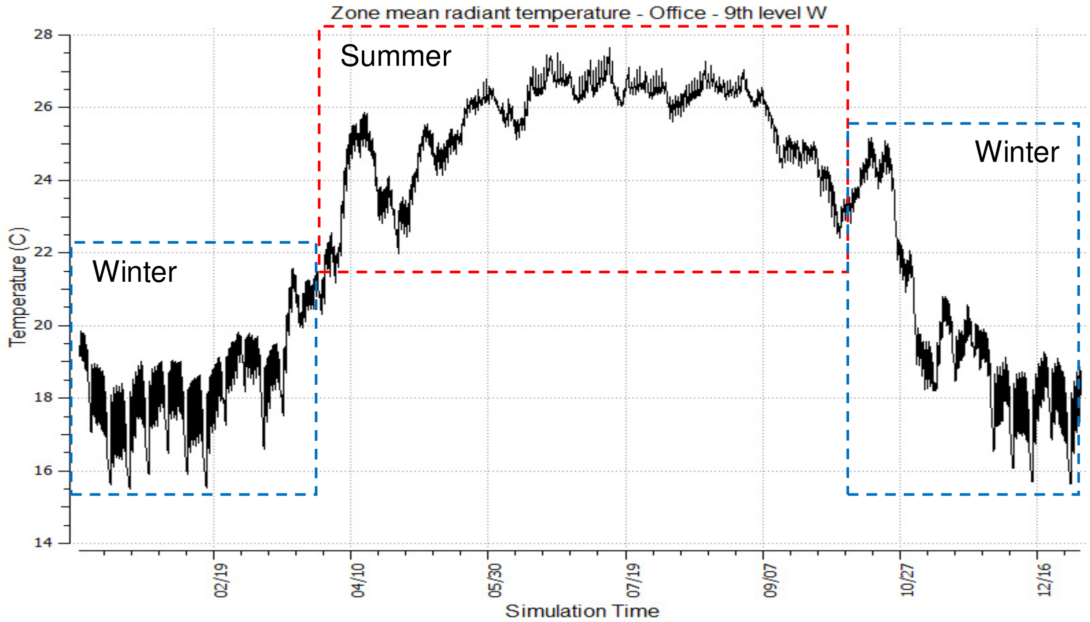


Figure VI - 30 Annual mean radiant temperature oscillation – 9th level

Operative temperature results from the simulation are presented in Figure VI - 31, where the oscillation trajectories are maximum 5°C in winter and 2°C during occupied hours in the summer period.

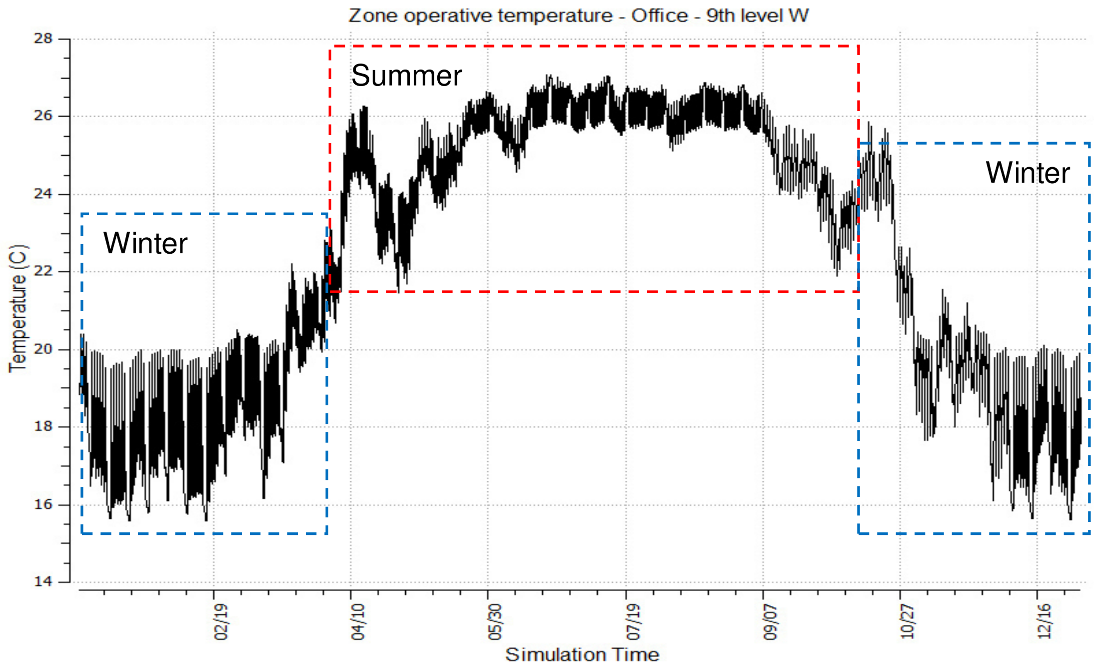


Figure VI - 31 Annual operative temperature oscillation – 9th level

Analyzing the relative humidity oscillation graph, Figure VI - 32, if expecting II PPD category as the Best Case Scenario it can be concluded that the values are preferable during occupied hours since values are between 25 and 60%. No humidification system will be required.

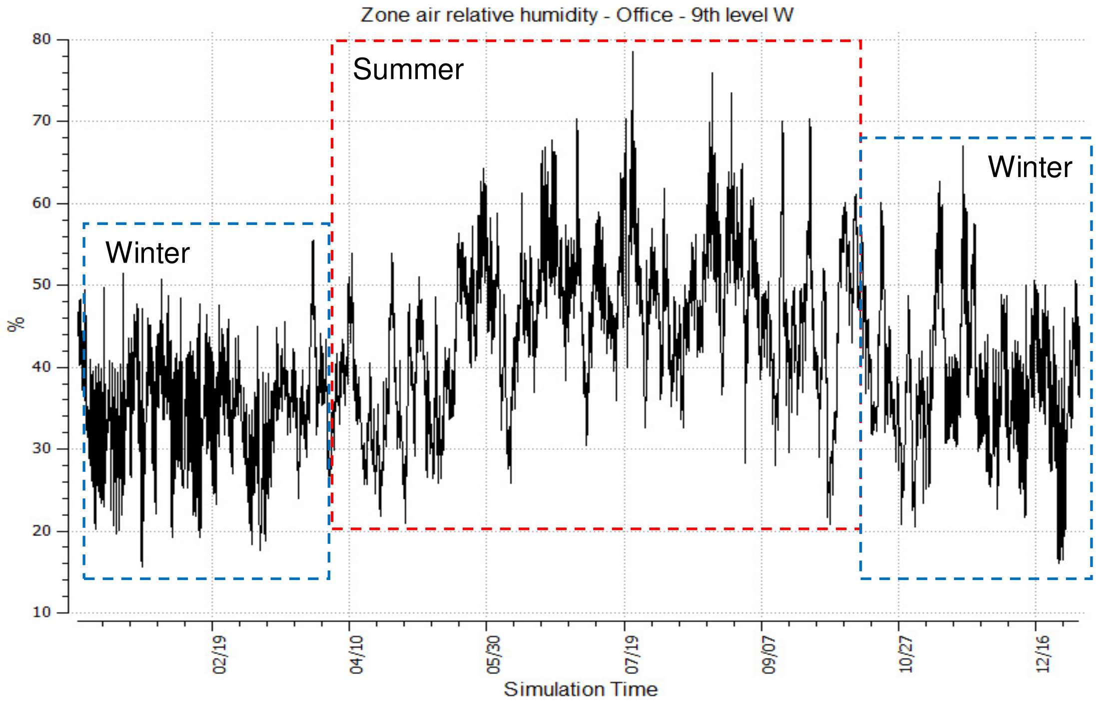


Figure VI - 32 Annual relative humidity oscillation – 9th level

As seen in Figures VI - 33 and VI - 34 the brackets indicate oscillation values during the winter and summer period. Considering the relative humidity of outside air which is heated or cooled when entering the building the humidity ratio can change drastically. The simulated results presented preferable relative humidity values throughout the year.

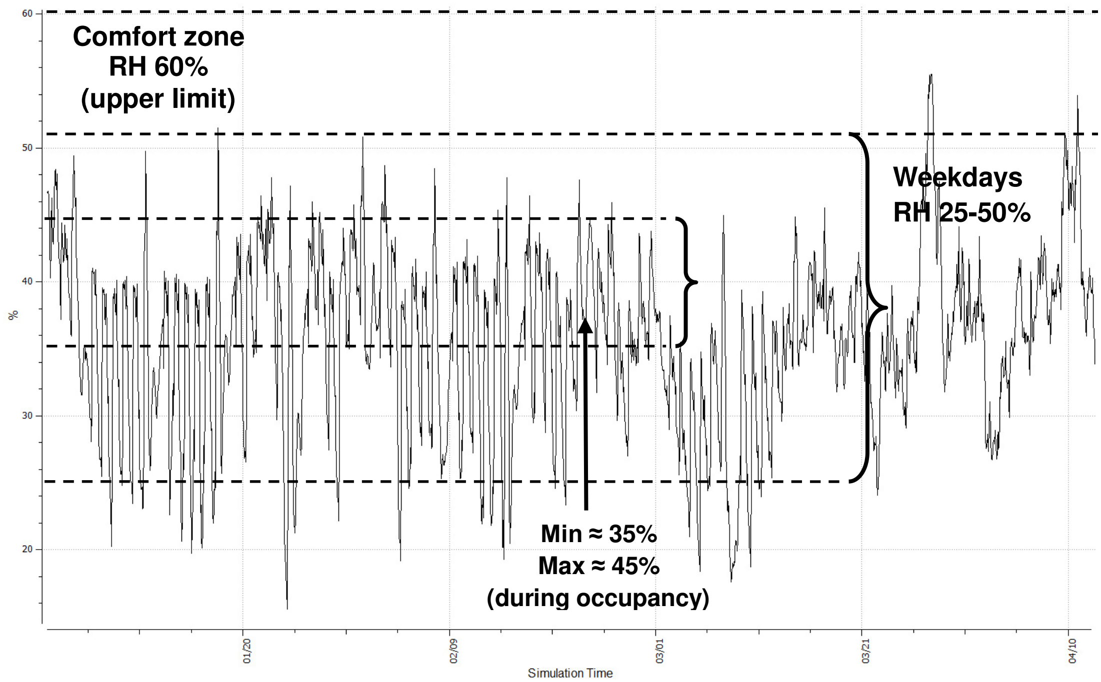


Figure VI - 33 Winter relative humidity oscillation – 9th level

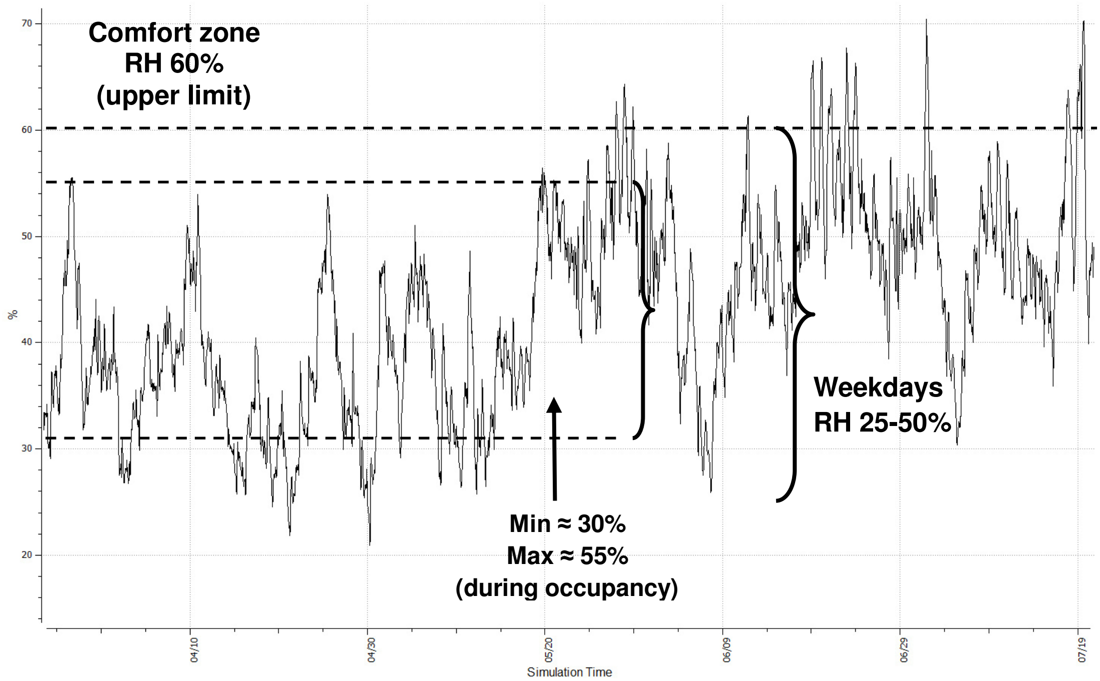


Figure VI - 34 Summer relative humidity oscillation – 9th level

6.5. Comfort model results with discussion

6.5.1. PMV and PPD results with discussion

PMV and PPD values were calculated according to Fanger's comfort equations, as shown previously, for the Best Case energy performance scenario. The EnergyPlus comfort parameter simulation output was setup for an annual period with hourly time steps which resulted in 8760 values per single parameter. Since three parameters (MAT, MRT, RH) were included in the comfort equations the number of output data was 26280 per single office coordinates. PMV and PPD-indexes were calculated for three offices situated on the ground level, 5th level and 9th level.

The total number of determined PMV and PPD-indexes was 78840. Due to multiple output data the selection of PMV and PPD-indexes which are marked on the PMV curve for comfort category determination were reduced to single weekdays per month. Comfort categories were determined during occupied hours. Tabular output data with PMV and PPD-indexes is presented in **Appendix F** including hourly comfort category values.

Assuming different criteria for the PMV and PPD (EN ISO 7730 2005) different categories of the indoor environment are established. Recommended PPD ranges are shown in Table VI - 6.

Table VI - 6 Examples of recommended PMV and PPD categories for design of mechanical heated and cooled buildings (EN ISO 7730 2005)

Category	Thermal state of the body as a whole	
	PPD [%]	PMV
I	< 6	-0.2 < PMV < +0.2
II	< 10	-0.5 < PMV < +0.5
III	< 15	-0.7 < PMV < +0.7
IV	> 15	PMV < -0.7 or +0.7 < PMV

Figures VI – 35 and VI – 36 show the PMV and PPD function during autumn-winter and in spring-summer period in case of the ground level office in intervals from 8h to 18h. From the PMV curve it can be concluded that the **PPD values are below 10%** which presents high indoor environmental quality. The percentage of dissatisfied occupants is mostly in the 1st comfort category (< 6% PPD), followed by the 2nd category (6% < PPD < 10%), while less than 1% is on the border of the 3rd category (10% < PPD). Figure VI - 35 presents 132 PMV and PPD indexes selected on an annual basis (single workday per month) where only 2 PPD values can be found in the third category, both values are present in the morning hours between 8 and 9h at the beginning of the workday. Figure VI – 36 showed all indexes in the first two categories.

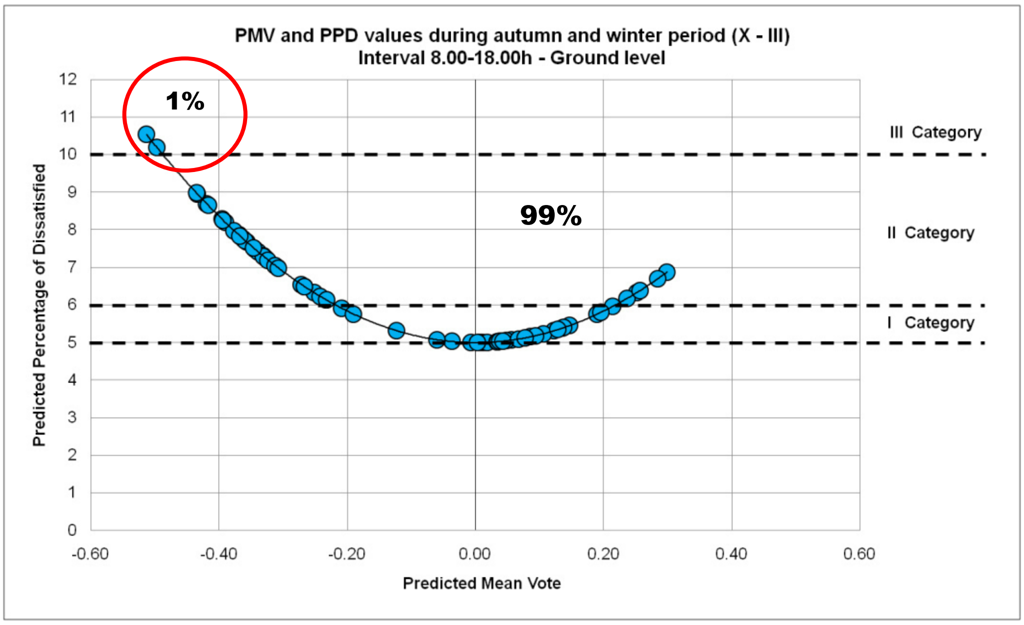


Figure VI - 35 PMV and PPD values for the ground level office – autumn/winter

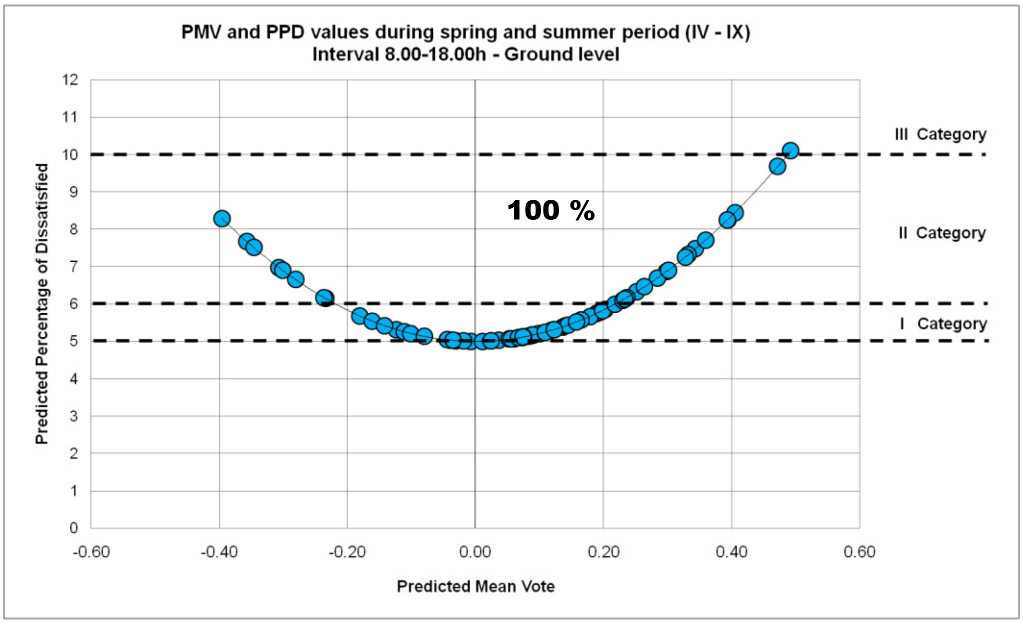


Figure VI - 36 PMV and PPD values for the ground level office – spring/summer

Figures VI – 37 and VI – 38 present the PMV and PPD values in case of the 5th level office for identical periods and intervals as previously. From the functions it can be concluded that the **PPD values are below 10%** in autumn-winter period which presents high indoor environmental quality. The spring-summer period has shown preferable PPD values, since **100% of satisfied occupants are in the first two comfort categories.**

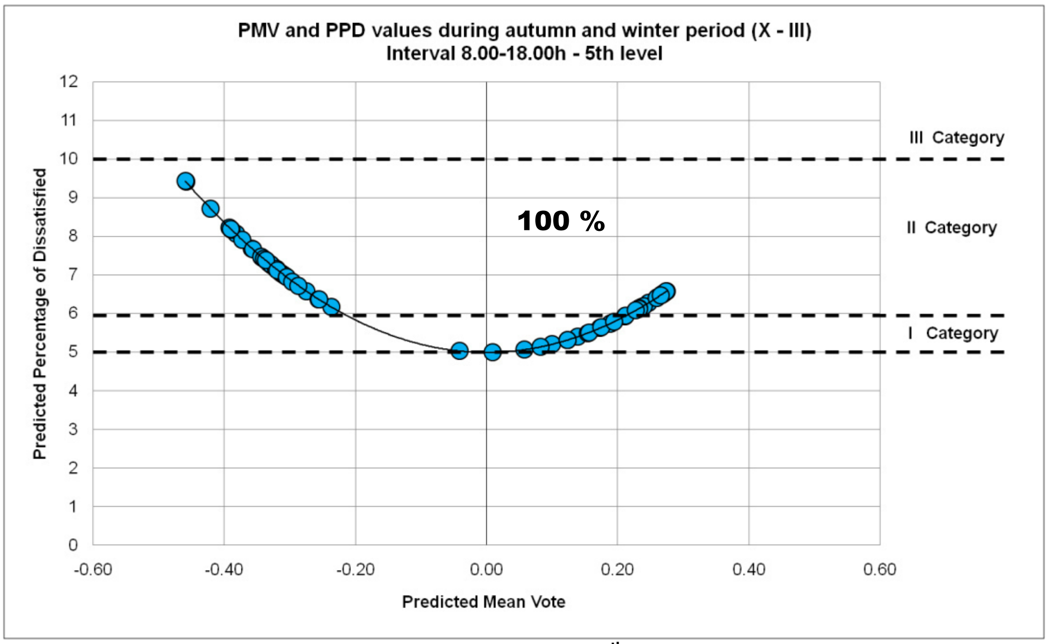


Figure VI - 37 PMV and PPD values for the 5th level office – autumn/winter

During the spring and summer period as seen in Figure VI – 38 from the 132 PMV and PPD indexes 6 indexes can be found in the third category which is approximated to 5% of the total. PPD values above 10% were observed in the morning hours between 8 and 10h and in the afternoon at the end of the workday 17-18h. Only a slight deviation exists when the PPD values rise above 10% which are usually neglected, or in certain cases could be controlled by the HVAC system. The HVAC system is scheduled according to the occupancy intensity and occupied hours on workdays. The HVAC system's intensity is lowered from 17h due to occupancy descent.

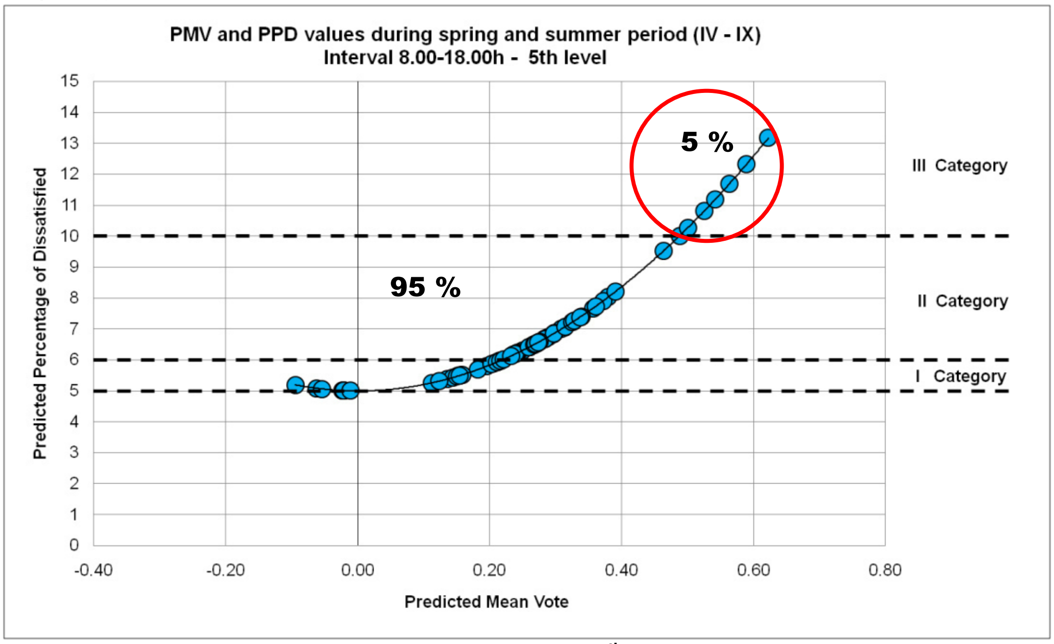


Figure VI - 38 PMV and PPD values for the 5th level office – spring/summer

Figures VI – 39 and VI – 40 present the PMV and PPD values in case of the 9th level office for identical periods and intervals as previously mentioned. From the functions it can be concluded that the **PPD values are mostly in the interval between 6% and 10%** (2nd comfort category) in autumn-winter period which presents high indoor environmental quality. The spring-summer period has shown preferable PPD values, since where the majority of dissatisfied occupants are in the 2nd comfort category. Only a slight deviation exists when the PPD values rise above 10% (max. 14%) which are usually neglected, or in certain cases could be controlled by the HVAC system. During autumn and winter period as seen in Figure VI – 39 from the 132 PMV and PPD indexes 10 indexes can be found in the third category which is approximated to 8% of the total, while in the spring - summer period 3% of occupants demonstrated the 3rd comfort category. PPD values above 10% were observed in the morning hours between 8 and 10h and in the afternoon at the end of the workday 17-18h (as previously in the case of the 5th level office). The HVAC system is scheduled according to the occupancy intensity and occupied hours on workdays for the whole building. The HVAC system's intensity is lowered from 17h due to occupancy descent.

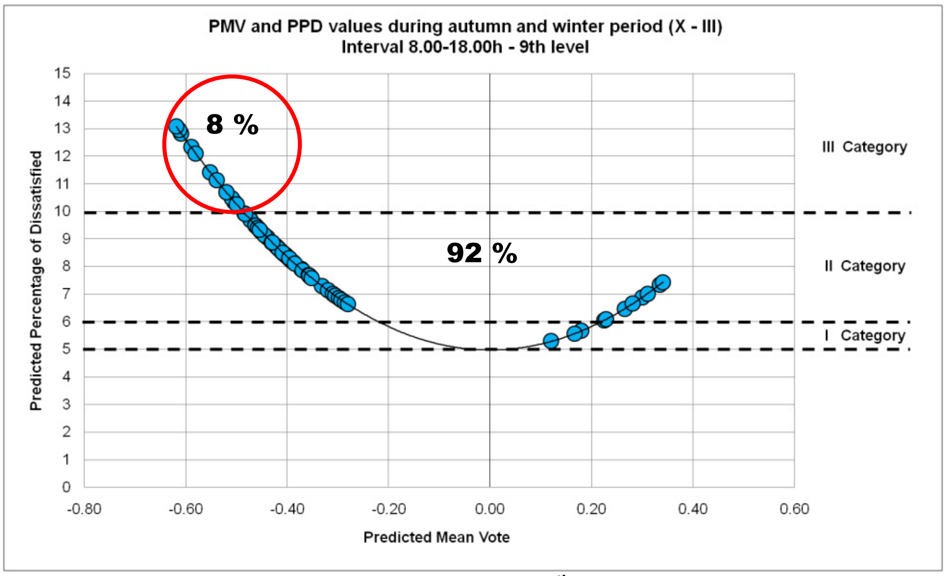


Figure VI - 39 PMV and PPD values for the 9th level office – autumn/winter

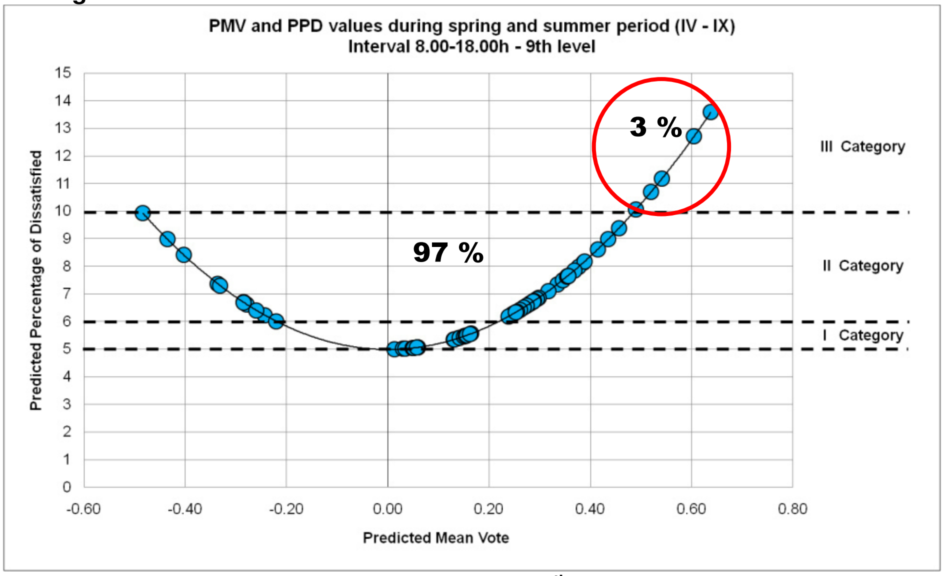


Figure VI - 40 PMV and PPD values for the 9th level office – spring/summer

Chapter 7

Optimal solution "Best Case Scenario"

7.1. Optimal construction overview

7.1.1. Building envelope

Building envelope improvement was elaborated previously in Chapter 4 "Building envelope performance" according to the EU and Serbian thermal insulation requirements. The building envelope construction was improved in order to reduce the heat transfer coefficient, U-value. The U-value of the existing office building's exterior walls is 2.32 W/(m^{2}K) since the walls are constructed from 25 cm fired clay brick, without insulation layer. The modified exterior wall construction compared to the existing is presented in Table VII - 1, where the new U-value equals 0.22 W/(m^{2}K).

Table VII - 1 Optional exterior wall construction with material properties

No.	Modified exterior wall	Material properties
1	Stucco Portland cement mortar	d = 20 mm λ = 0.6918 W/(mK) ρ = 1858 kg/m^3 Q = 837 J/kgK
2	Expanded polystyrene molded beads	d = 140 mm λ = 0.0352 W/(mK) ρ = 24 kg/m^3 Q = 1210 J/kgK
3	Fired clay brick	d = 250 mm λ = 0.675 W/(mK) ρ = 1601.84 kg/m^3 Q = 790 J/kgK
4	Stucco Portland cement mortar	d = 10 mm λ = 0.6918 W/(mK) ρ = 1858 kg/m^3 Q = 837 J/kgK
U = 0.22 W/(m^{2}K)		

The existing and modified construction of the roof terrace is presented in Table VII - 2 with optional solutions that meet the thermal insulation regulations in Serbia.

Table VII - 2 Optional roof terrace layers with properties

No.	Layers and construction	Specification
1	Lightweight concrete tiles	d = 40 mm λ = 0.530 W/(mK) ρ = 1280 kg/m^3 Q = 840 J/kgK
2	Air gap	R = 0.15 m^{2}K/W
3	Styrodur C – molded beads	d = 180 mm λ = 0.040 W/(mK) ρ = 33 kg/m^3 Q = 1450 J/kgK
4	Waterproof membrane (3 layers)	d = 0.009 mm (x3) λ = 0.160 W/(mK) ρ = 1121.29 kg/m^3 Q = 1460 J/kgK
5	Heavyweight concrete	d = 200 mm λ = 1.95 W/(mK) ρ = 2240 kg/m^3 Q = 900 J/kgK
6	Stucco Portland cement	d = 10 mm λ = 0.692 W/(mK) ρ = 1858 kg/m^3 Q = 837 J/kgK
7	Air gap	R = 0.15 m^{2}K/W
8	Gypsum board	d = 19 mm λ = 0.160 W/(mK) ρ = 800 kg/m^3 Q = 1090 J/kgK
U = 0.18 W/(m^{2}K)		

The basement was also insulated with styrodur C – molded beads, 100mm thickness, as the roof terrace resulting in thermal transmittance according to the standards. The U-value was 0.19 W/(m^{2}K).

7.1.2. Glazing

The Best Case WWR and WG were selected from the multi-criteria analysis in Chapter 3 “CAD building model, WWG/WG analysis and illumination simulation”. The Best Case Scenario for WWR and WG for all orientations are shown in Table VII - 3.

Table VII - 3 Best Case Scenario for WWR and WG

Orient.	WWR [%]	Applied WWR	WG	Dimensions [mxm]
E	30	WWR 30% / 30` rot.	Vertical Rectangular	Single Window 0.60 x 2.20
S	25	WWR 25% / 30` rot.	Vertical Rectangular	Single Window 0.60 x 1.86
W	30	WWR 30% / 30` rot.	Vertical Rectangular	Single Window 0.60 x 2.20
N	20	WWR 20% / 30` rot. (corridor, WC)	Vertical Rectangular	Single Window 0.60 x 1.49

From Chapter 5 “Energy Performance simulation” the Best Case Scenario was determined for glazing scenario W10 which was finally adopted (among the 10 scenarios) due to the visible transmittance value (0.52) and low building energy demand while the daylight dispersion analysis applied a VT value above 0.5. Properties of the optional glazing are presented in Table VII - 4.

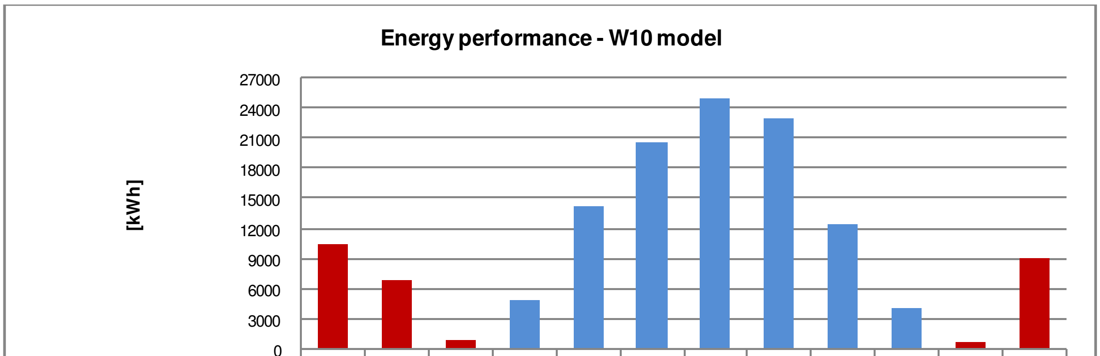
Table VII - 4 Optional glazing

Scenario	Windows	Material properties	
W10	Window 10 Tri-pane Pilkington Planar + Optifloat + Optitherm	U-value SHGC Visible Trans.	0.70 W/(m^{2}K) 0.26 0.52

The heating energy demands of the 10 Scenarios were various, highly influenced by the characteristics of the windows. It was concluded that the SHGC coefficient had:

- Major influence considering external solar energy gains and
- Indoor energy maintenance from occupants, electric lights and equipment.

The thermal transmittance did not take a crucial part in the heating and cooling demand influence. As for example Scenario W7 and W8 had U-values of 1.056 W/(m^{2}K) and 0.704 W/(m^{2}K), but the results of the total annual energy demand was similar; 156 MWh in case of Scenario W7 and 152 MWh for Scenario W8. The SHGC values were the following; 0.33 for Scenario W7 and 0.31 for Scenario W8. The energy performance of Scenario W10 is presented in Figure VII - 1.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Heating Energy W10 [kWh]	10445	6924	834	0	0	0	0	0	0	1	631	8939
Cooling Energy W10 [kWh]	0	0	55	4881	14197	20685	24960	22917	12369	4127	0	0

Figure VII - 1 Energy performance of Scenario W10 with monthly heating and cooling demands

It can be concluded that the energy demands as previously stated are mostly affected by the SHGC coefficient since similar coefficients will have results with only slight deviation among each other. In case of office buildings with high internal gains the SHGC coefficient has to be considered of great importance in adequate window selection.

7.2. Optimal occupancy and building operation schedules

In order to reduce the building energy demand and rationally use energy in the function of occupant comfort maintenance building operation has to be coordinated by occupant intensity. Proper compliance of these two factors is significant since the HVAC operation schedules have to be conditioned according to occupant schedules. Office buildings usually have regular operational schedules, which makes the energy model more accurate. Occupancy intensity can also be modeled with high probability since it is adjusted to the workday. Chapter 5 “Energy performance simulation” elaborated the schedules of occupancy, lighting and electric equipment, and thermostat schedules. All schedules were assigned according to the occupancy intensity schedule in order to rationally and efficiently use energy, which can be found in Chapter 5. The occupancy schedule is repeated in Figure VII - 2 below.

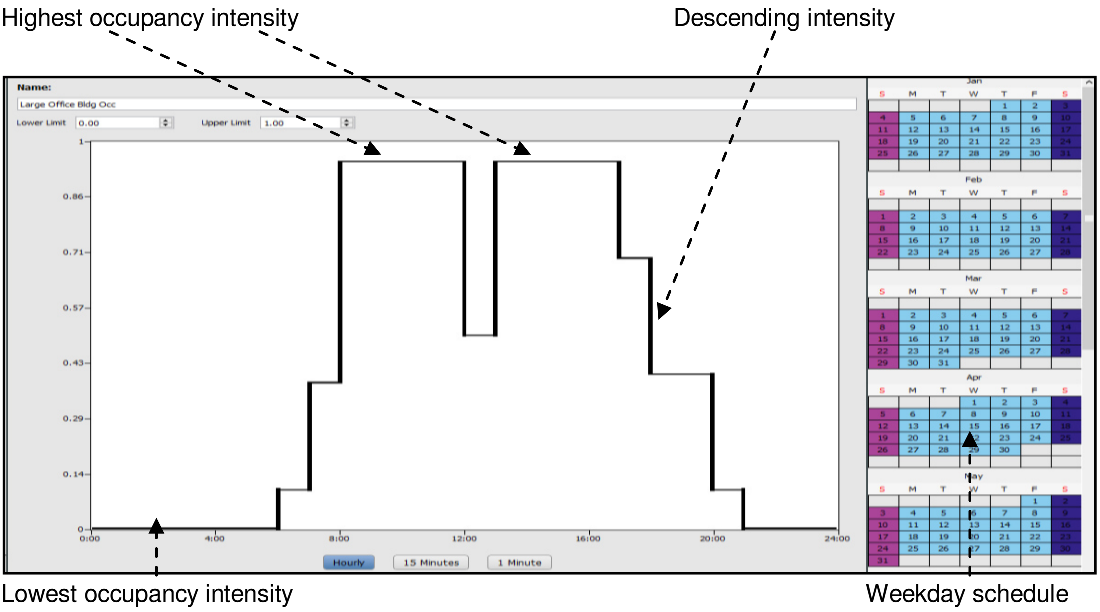


Figure VII - 2 Weekday priority - occupancy intensity

7.3. Best Case HVAC system solution

7.3.1. New buildings

The Best Case HVAC system solution was determined in previous researches by investigating the performance of different HVAC system types on a virtual office building for temperate climate conditions. The investigations were published in the international scientific journal of Thermal Science in 2014 (Harmati, Folić and Magyar (no. 1) 2014). Results are presented briefly below.

Analyzed literature referred to energy performance assessment methods in the early design stages since energy simulation was not integrated into the decision-making process. (Schlueter and Thesseling 2009) Numerous proposals have been applied in order to reduce the annual heating and cooling energy demand, as for example double skin facades which represent an additional skin on the outside wall of the building. (Ignjatovic 2014) Thermal mass impact on the energy demand has also been analyzed in the function of occupant comfort to investigate the reduction of the energy requirements from the mechanical systems. (Andjelkovic 2012)

The motivation of the investigation was to find respectable answers for improvement of the current heating and cooling supply systems of inefficient office buildings in Serbia. Findings could be extended further for different building types and climatic conditions. The investigation included the analysis of a medium multi-zone office building's annual energy performance for the location and climate data of central Belgrade, which has very similar climate conditions compared to Novi Sad. The HVAC system's and HR unit's performance was evaluated in order to conduct the most preferable heating and cooling solution (Best Case Scenario) for temperate climate conditions (Harmati, Folić and Magyar (no. 1) 2014).

The heating and cooling energy demand was determined for preferable microclimatic conditions for a 300 m^2 single level office building with an energy efficient envelope. Since indoor occupant comfort has to be maintained; the temperature, lighting comfort, humidity and air velocity were set in the simulation control for sedentary work environment. Intervals of occupancy and HVAC operation were implemented in the multi-zone model. Four HVAC systems were modeled and compared under the same conditions, referring to the climate data, internal loads, occupant schedules and energy efficient envelope with exterior wall U-value of 0.25 W/(m^2K) and glazing U-value 1.0 W/(m^2K). The HVAC system's and HR unit's performance was simulated in order to conduct the most preferable heating and cooling solution for the boundary conditions of indoor comfort parameters (Harmati, Folić and Magyar (no. 1) 2014).

7.3.1.1. HVAC systems

The investigation involved the calculation of the building energy performance of four HVAC system types tested on a medium office building model. Four multi-zone models with identical envelope, internal loads and occupancy schedules were modeled with the application of the following HVAC systems:

a. **System 1:** Heat pump – air to air (Multi-zone model 1)
b. **System 2:** Gas and electricity (Multi-zone model 2)
c. **System 3:** Electrical (Multi-zone model 3)
d. **System 4:** Fan coil – Rooftop unit with chiller and boiler (Multi-zone model 4)

The investigation methodology was the following:

a. **Modeling** – designing a multi-zone building model with an energy efficient envelope, internal loads, occupancy schedules and HVAC system

b. **Simulation** – hourly time step calculation in EnergyPlus simulation engine, utilizing system thermodynamics and heat balance method, which operates with surface and air mass balance modules
c. **Comparative analysis and evaluation** of the results.

Results outline major criteria for improvement from a synthesized, comparative and evaluative angle. The investigation concerns the following steps:

a. Designing a virtual single level multi-zone office building model according to the guidelines and functional disposition of office work spaces
b. Implementation of climate and location data, envelope construction, internal loads and HVAC systems
c. Run multiple simulations for an annual period
d. Comparatively analyze and evaluate the annual energy performance of four multi-zone thermal models with different HVAC systems and assess the HVAC systems energy demand
e. Assessment of the HR unit’s efficiency

The annual heating and cooling demand and HVAC energy performance are explored through the following steps:

1. Development of a **simulation base multi-zone 3D model** with assigned internal loads
2. Export the multi-zone 3D model to Open Studio in order to implement an energy efficient envelope, assign material properties, thermal zone properties and typical interior loads for offices
3. Implement each HVAC system in a separate but identical multi-zone model
4. Run multiple simulations in EnergyPlus on annual basis using the climate data from Meteonorm 7 and calculate zone heating and cooling demands
5. Implement for each HVAC system a HR unit connected to the air loop outdoor air system
6. Evaluate the energy performance of the building and evaluate the HR unit’s efficiency

Four HVAC systems have been modelled according to the system type and supply fuel. The systems consist of the following supply and demand equipments assigned to each multi-zone model, as shown in Table VII - 5. The schemes of the four HVAC systems are show in **Appendix G**. For detailed setup of the HVAC systems’mechanical elements, professional sources were used (ASHRAE Systems and Equipment 2012) (Nilson, et al. 1997).

Table VII - 5 HVAC system equipments

Equip.	**SYSTEM 1** **Heat pump (air to air)**	**SYSTEM 2** **Gas and electricity**
Supply equipment	1. Coil cooling DX single speed 2. Coil heating DX single speed 3. Coil heating electric 4. Variable speed fan 5. Setpoint manager single zone reheat	1. Coil cooling DX single speed (heat pump) 2. Coil heating (gas boiler) 3. Variable speed fan 4. Setpoint manager single zone reheat
Demand equipment	**Zone 1** Air terminal single duct VAV with electric reheat **Zone 2** Air terminal single duct VAV with electric reheat **Zone 3** Air terminal single duct VAV with electric reheat **Zone 4** Air terminal single duct VAV with electric reheat	**Zone 1** Air terminal with gas reheat **Zone 2** Air terminal with gas reheat **Zone 3** Air terminal with gas reheat **Zone 4** Air terminalwith gas reheat
Equip.	**SYSTEM 3** **Electrical**	**SYSTEM 4** **Fan coil**
Supply equipment	1. Coil cooling DX single speed 2. Coil heating electric 3. Variable speed fan 4. Setpoint manager single zone reheat	1. Coil cooling water - Pump varable speed, electic chiller 2. Coil heating water - Pump varable speed, gas boiler 3. Variable speed fan 4. Setpoint manager single zone reheat
Demand equipment	**Zone 1** Air terminal single duct parallel PIU reheat **Zone 2** Air terminal single duct parallel PIU reheat **Zone 3** Air terminal single duct parallel PIU reheat **Zone 4** Air terminal single duct parallel PIU reheat	**Zone 1** Air terminal single duct VAV with reheat **Zone 2** Air terminal single duct VAV with reheat **Zone 3** Air terminal single duct VAV with reheat **Zone 4** Air terminal single duct VAV with reheat

7.3.1.2. Energy performance results and discussion

7.3.1.2.1. Primary simulation – without the HR unit

The simulation was performed for a period of one year, 8760 hours with hourly timesteps. The primary simulations were run without the HR unit and the obtained results are shown below in Figures from VII - 3, to VII - 10 as a proportional representation and annual sum of building energy demand. Numerical results are shown in Tables from VII - 9, to VII - 12. The absolute values of monthly energy demands are shown from a proportional aspect for an annual period, in order to compare the energy demands of interior loads, fans, heating and cooling. In all four cases the highest annual energy demand was recorded for heating.

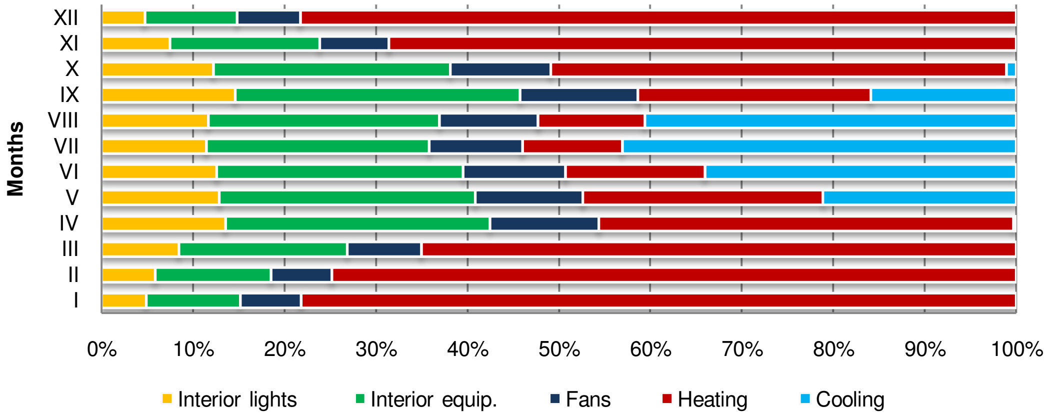


Figure VII - 3 Monthly energy performance proportion – System 1 – Heat pump (air to air)

For each multi-zone model the absolute value of interior lighting and equipment was set to constant intensity during working hours for every month, yet the proportional monthly energy demand presented a significant deviation. For system 1 (heat pump – air to air), Figure VII – 3, in the summer period the constant loads (interior lights and equipment) were approximated to 40% of total monthly consumption, while the winter period presented close to 20%. The highest heating energy requirement was recorded for January, February and December, nearly 78% of total monthly demands. In contrary, the peak demand for cooling was slightly above 40% in July.

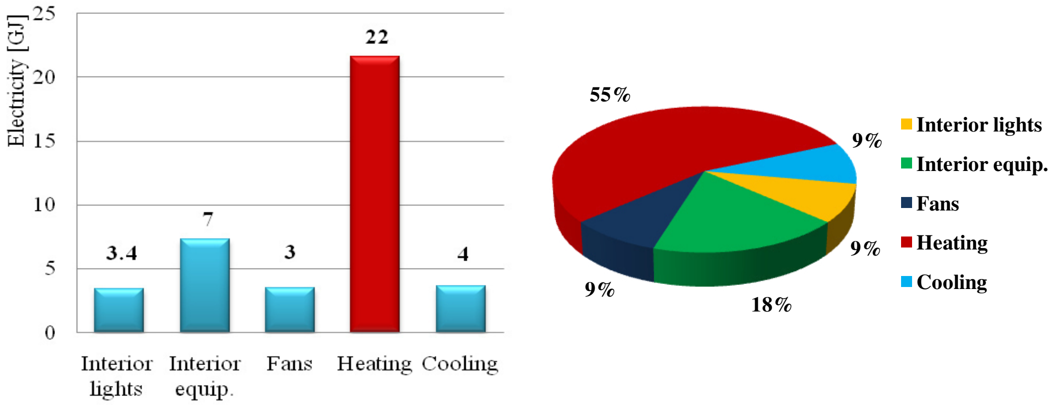


Figure VII - 4 Annual energy demand – System 1 - Heat pump (air to air)

The obtained heating load for the heat pump shows an annual energy demand of 22 GJ from total 39.4 GJ, which is 55% from total annual demand, Figure VII - 4 and Table VII - 6 shows the annual demand and peak values for the heat pump – air to air without the HR unit. Nevertheless, the heating energy demand can be reasonably lowered, with the attachment of the HR unit to the outside air loop system, which will be elaborated in the following section.

Table VII - 6 Building Energy Performance – Heat pump (air to air)

	Int. light: elec. [MJ]	Int. eq.: elec. [MJ]	Fans: elec. [MJ]	Heating: elec. [MJ]	Cooling: elec. [MJ]
Annual sum	3,385	7,276	3,454	**21,597**	3,639
Min. of months	259	558	247	279	-
Max. of months	292	623	428	4,843	1,102

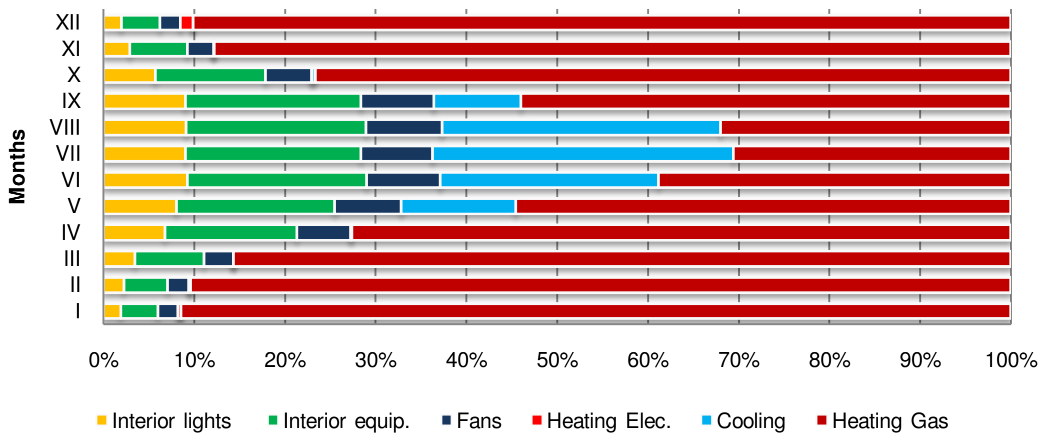


Figure VII - 5 Monthly energy performance proportion – System 2 – Gas and electricity

The absolute value of interior lighting and equipment for system 2 (gas-electricity), Figure VII - 5, presents only 2% of the energy requirement in the winter period, while in the summer period it rises to nearly 9%. The heating energy demand presented drastic values in the winter period with a peak demand of 92%. The peak value for cooling in the summer period reached close to 32%.

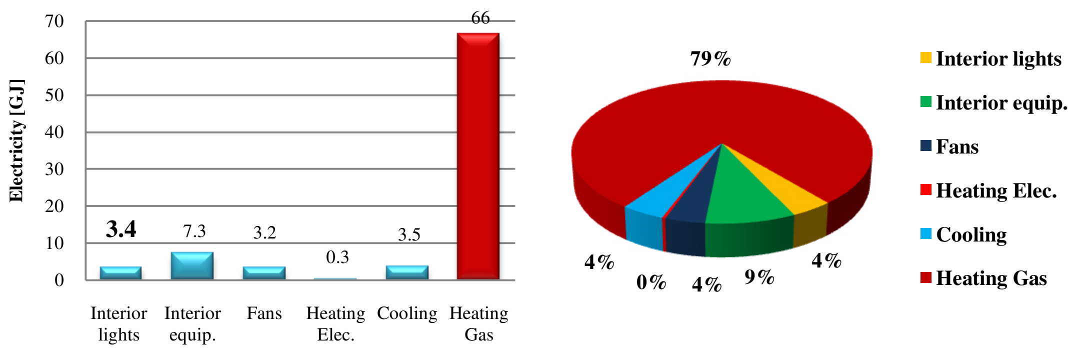


Figure VII - 6 Annual energy demand – System 2 – Gas and electricity

The heating load for system 2 supplied with gas and electricity requires the highest amount of energy among the four compared systems. The heating load is three times higher in comparison with the heat pump. The obtained heating load for system 2 (gas-electricity) shows an annual energy demand of 66 GJ from total 83.7 GJ, which is 79% from the total annual demand, Figure VII - 6 Table VII - 7 shows the annual demand and peak values for system 2 without the HR unit.

Table VII - 7 Building Energy Performance – Gas and electricity

	Int. light: elec. [MJ]	Int. eq.: elec. [MJ]	Fans: elec. [MJ]	Heating: elec. [MJ]	Cooling: elec. [MJ]
Annual sum	3,385	7,276	3,235	**66,264**	3,515
Min. of months	259	558	247	983	39
Max. of months	292	623	335	13,768	1,070

The monthly energy performance for system 3 (electrical) is presented below in Figures VII - 7 and VII - 8.

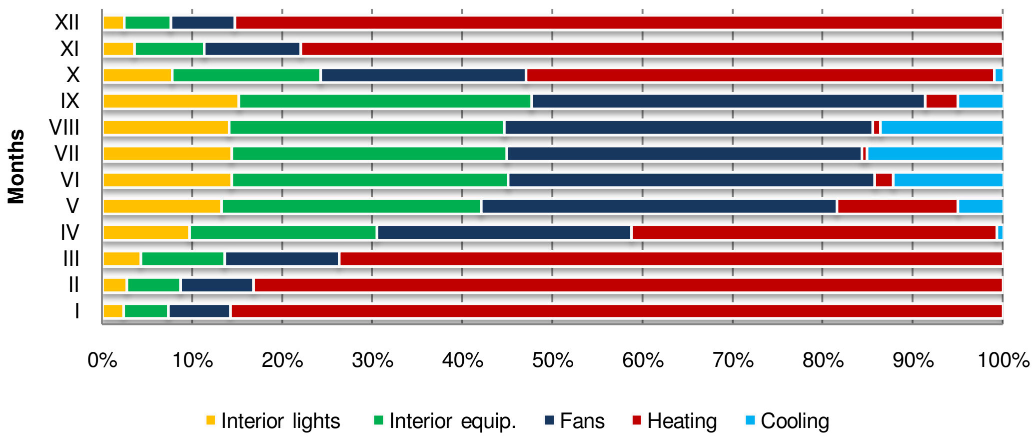


Figure VII - 7 Monthly energy performance proportion – System 3 – Electrical

The absolute values of internal loads for system 3 (electrical), Figure VII - 7, show 2% of the energy requirement in the winter period, while in the summer period it rises nearly to 14%. The heating energy demand has shown a peak demand of 85% in January. The peak value for cooling in the summer period reached close to 15%, while the fans require from May until September close to 40% of total monthly energy.

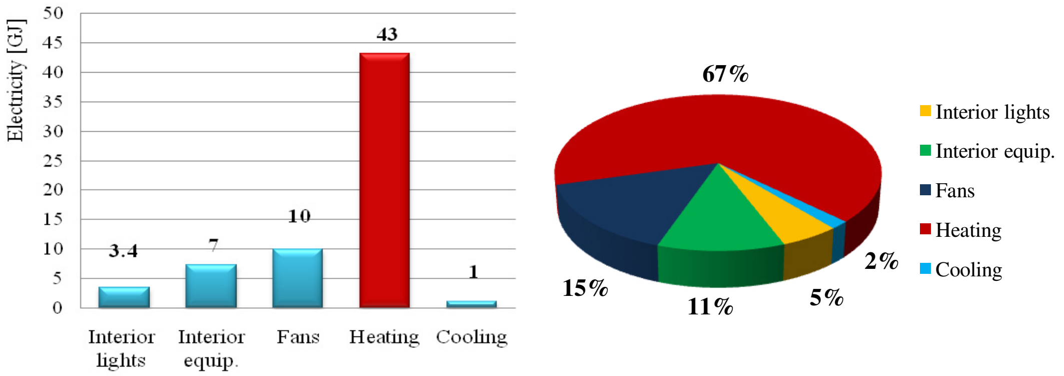


Figure VII - 8 Annual energy demand – System 3 – Electrical

The obtained heating load for system 3 (electrical) presented an annual energy demand of 43 GJ from total 64.4 GJ, which is 67% from the total annual demand, Figure VII - 8 and Table VII - 8 shows the annual demand and peak values for system 3 without the HR unit.

Table VII - 8 Building Energy Performance – Electricity – Electrical system

	Int. light: elec. [MJ]	Int. eq.: elec. [MJ]	Fans: elec. [MJ]	Heating: elec. [MJ]	Cooling: elec. [MJ]
Annual sum	3,385	7,276	9,880	**43,158**	1,076
Min. of months	259	558	766	11	-
Max. of months	292	623	859	10,572	308

The monthly energy performance for system 4 (fan coil) is presented below in Figure VII – 9.

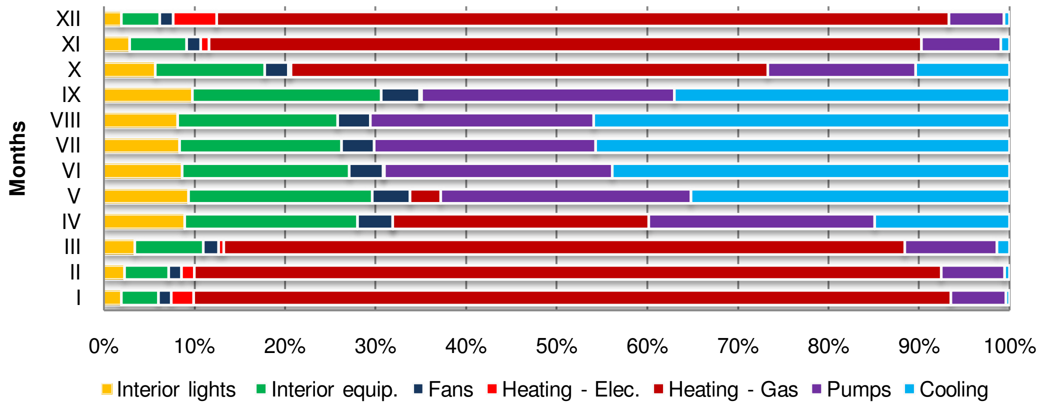


Figure VII - 9 Monthly energy performance proportion – System 4 – Fan coil

The absolute value of internal loads for system 4 (fan coil) presented 6% of the energy requirement in the winter period, while in the summer period it rises nearly to 30%. The heating energy demand has shown a peak demand of 83% in January. The peak value for cooling in the summer period reached close to 46%, while the fans require close to 24% of the total monthly energy.

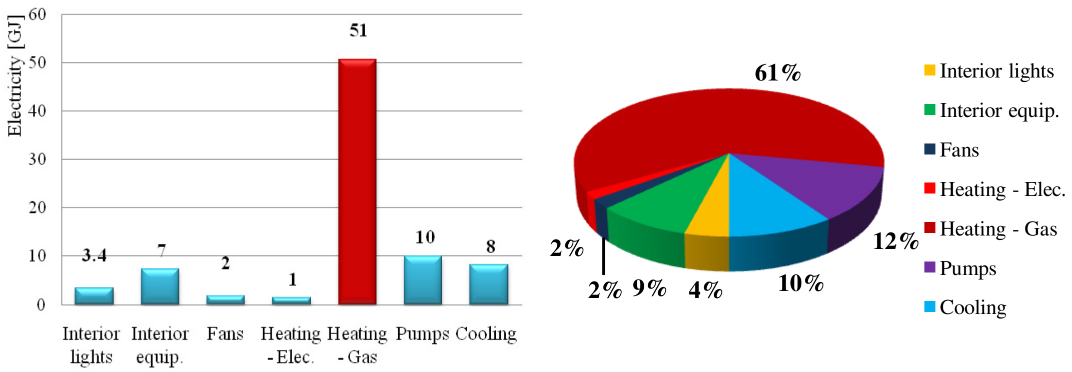


Figure VII - 10 Annual energy demand – System 4 – Fan coil system

The simulated heating load for system 4 (fan coil) resulted in an annual energy demand of 52 GJ from total 82.4 GJ, which is 61% from the total annual energy demand, Figure VII - 10. The annual energy demand with peak values for system 4 is shown in Table VII - 8 without the HR unit.

Table VII - 9 Building Energy Performance – Electricity – Fan coil system

	Int. light: elec. [MJ]	Int. eq.: elec. [MJ]	Fans: elec. [MJ]	Pumps: elec.[MJ]	Heating: gas [MJ]	Cooling: elec. [MJ]
Annual sum	3,385	7,276	1,752	10,039	**52,079**	8,150
Min. of months	259	558	121	787	-	60
Max. of months	292	623	217	904	12,438	1,594

The fan coil system has a higher energy demand since it operates with two coil loops; heating coil loop connected to the boiler and the coolingcoil loop connected to the rooftop chiller. Both loops have a separate electric pump which has an energy demand of 10 GJ annually. The answer to the high heating demand of 52 GJ is the gas supplied boiler. In comparison with the previous gas heater, HVAC system 2, the result is lower for 14 GJ, although system 2 had one coil loop with only one variable speed pump in operation.

7.3.1.2.2. Evaluation and comparison of the HVAC systems primary energy performance, secondary simulation – with HR unit

The second phase refers to the HR– Rotary Heat Exchanger unit’s connection to the outdoor HVAC system air loop in EnergyPlus with the following properties shown in Table VII - 10.

Table VII - 10 HR - Rotary Heat Exchanger air to air sensible and latent

Supply air flow rate	Autosized
Sensible effectiveness at 75% heating air flow	0,81
Latent effectiveness at 75% heating air flow	0.73
Sensible effectiveness at 75% cooling air flow	0,82
Latent effectiveness at 75% cooling air flow	0,73
Heat exchanger type	Rotary

Annual energy performance results of the four HVAC systems were converted into primary energy according to the HVAC systems’ supply fuel and fuel production technology. The conversion factor for electricity, for the Serbian power plant supplied by lignite coal equals approximately f_{prime}= 3.5. The conversion factor for gas is f_{prime}= 1.1 (Banjac 2014). The conversion factor refers to the production technology and transportation efficiency of energy. Gas has a low conversion factor, because it is excavated on site and after minor treatment transported directly to the user. On the contrary, power plant using lignite coal for electricity production in Serbia operates with conversion factor between f_{prime}= 3.0 – 4.0. Table VII - 11 shows the converted total annual primary energy demand for each HVAC system, applied to the identical multi-zone building models.

Table VII - 11 Total annual primary energy demand of multi-zone office building

SYSTEM 1 Heat pump air to air	SYSTEM 2 Gas and electricity	SYSTEM 3 Electrical	SYSTEM 4 Fan coil
Primary energy without HR unit			
127 [kWh/m^2/a]	124 [kWh/m^2/a]	209 [kWh/m^2/a]	218 [kWh/m^2/a]
∑ 38255 [kWh/a]	∑ 37451 [kWh/a]	∑ 62965 [kWh/a]	∑ 65588 [kWh/a]
Primary energy with HR unit			
87 [kWh/m^2/a]	84 [kWh/m^2/a]	135 [kWh/m^2/a]	151 [kWh/m^2/a]
∑ 26351 [kWh/a]	∑ 25332 [kWh/a]	∑ 40670 [kWh/a]	∑ 45585 [kWh/a]
Primary energy reduction with HR unit			
31.5%	32.3%	35.4%	30.7%

The result for the gas supplied HVAC system, due to its very low conversion factor has the least primary energy demand of 37.45 MWh/a, close to the primary energy demand of the highly efficient heat pump supplied by electricity. The HR unit’s efficiency shows a slight deviation among each system. Although the proportional deviation is low, the absolute deviation in significant. For example, as shown in tab. 14, the proportional deviation between the heat pump and the fan coil system is 0.8%, however the absolute deviation is approximately 20 MWh/a, 42%. Table VII - 12 shows the primary energy demand for the heating and cooling loads and the percentage of these loads in comparison with the total annual energy performance.

Table VII - 12 Annual heating and cooling loads primary energy

SYSTEM 1 Heat pump air to air	SYSTEM 2 Gas and electricity	SYSTEM 3 Electrical	SYSTEM 4 Fan coil
Heating and cooling demand without HR			
∑ 24566 [kWh/a]	∑ 20248 [kWh/a]	∑ 43006 [kWh/a]	∑ 24746 [kWh/a]
64% of the total energy requirement	54% of the total energy requirement	68% of the total energy requirement	38% of the total energy requirement
Heating and cooling demand with HR			
∑ 12785 [kWh/a]	∑ 8581 [kWh/a]	∑ 20693 [kWh/a]	∑ 23787 [kWh/a]
48% of the total energy requirement	34% of the total energy requirement	51% of the total energy requirement	32% of the total energy requirement

Heating and cooling demands without the HR unit show a relatively high percentage of 64% for the heat pump, 54% for the gas-electricity, 68% for the electrical system and 38% for the fan coil. The importance of the HR unit is significant since it lowers these demands drastically, from 64% to 48% for the heat pump, from 54% to 34% for the gas-electricity and finally from 68% to 51% for the electrical system. The Fan Coil system was specific because the HVAC system operation requires a constant energy supply, so the heating and the cooling demand was lowered the least, from 38% to 32%.

The evaluation of the HVAC systems indicates that the most efficient system among the compared for heating and cooling would be the heat pump (air to air) and the gas-electricity, since the primary energy need for these systems with the HR unit application is approximately equal. However, the simulation presented that a multi-zone office building with heat pump HVAC system demands three times less heating energy, compared to the gas-electricity HVAC system from previous calculations, shown in Table VII - 6 and VII - 7. In further research an economic evaluation will present a more detailed comparative overview of the mentioned systems.

The calculations also consider the HVAC systems' energy intensity as shown in Table VII - 13, without and with the application of the HR unit. This comparative analysis increases the importance of HR unit application, resulting in lower energy requierement for HVAC system operation.

Table VII - 13 Utility use per total floor area

HVAC System	Without HR, annual HVAC energy demand [kWh/m^2/a]	With HR, annual HVAC energy demand [kWh/m^2/a]
Heat pump	21.15	15.56
Gas and electricity	6.65 Electricity, 62.72 Gas ∑ 69.37	6.21 Electricity, 26.59 Gas ∑ 32.8
Electrical	51.24	29.50
Fan coil	23.56 Electricity, 48.36 Gas ∑ 71.92	29.16 Electricity, 31.91 Gas ∑ 61.07

Table VII - 14 shows the conversions from Table VII - 13 into primary energy for the operation of the four HVAC systems.

Table VII - 14 Primary energy use for HVAC operation per total floor area

HVAC System	Without HR, HVAC energy intensity [kWh/m²/a]	With HR, HVAC energy intensity [kWh/m²/a]
Heat pump	74.03	54.46
Gas and electricity	23.28 Electricity, 68.99 Gas ∑ 92.27	21.73 Electricity, 29.25 Gas ∑ 50.98
Electrical	179.34	103.25
Fan coil	82.46 Electricity, 53.19 Gas ∑ 135.65	102.06 Electricity, 35.10 Gas ∑ 137.16

The heat pump HVAC system with HR unit requires the least annual energy for operation (15 kWh/m^2/a, primary 54 kWh/m^2/a while the fan coil HVAC system with HR unit required the most (61 kWh/m^2/a, primary 137 kWh/m^2/a) among the four designed systems. From the comparative analysis the presented results indicate that for central Belgrade location and climate parameters a similar multi-zone office building with similar functional disposition, envelope construction and glazing properties requires the least amount of energy for the HVAC operation if the heat pump system is applied. The analysis indicates that the most preferable solution for a medium office building would be the application of the heat pump powered HVAC system with HR unit with an annual operating energy demand of 15.56 kWh/m^2/a. Althought the climate parameters and internal loads are variable, the same method can be applied for further investigation.

7.3.2. Existing buildings – Best Case HVAC for reference office tower building

According to the monitored indoor environmental parameters of the typical reference office tower of the Faculty of Technical Sciences it was concluded that the existing district heating system would be the most economic and preferable solution, after it undertakes significant improvement. Current situation has presented significant heat dissipation on the ground floor and very low heat dissipation on the 9th floor. Hydronic imbalance was observed in the heating system due to unsteady flow in the radiators on each floor. Hydronic balancing of the system needs to be insured in order to enable even heat dissipation on all levels.

Considering the ventilation and air-conditioning, the reference building has single air-condition units per offices, however some offices are not equipped with coolers. The most preferable solution would be the design and incorporation of centralized ventilation and air-conditioning system which could be connected to the central operating computer system. Indoor environment parameters and air quality should be monitored by system sensors in order to adjust the performance of the HVAC system to preferable thermal comfort conditions.

7.4. PMV and PPD categories for improved solutions

Assuming different criteria for the PMV and PPD (EN ISO 7730 2005) different categories of the indoor environment are established. Recommended PPD ranges are shown in Table VII - 15.

Table VII - 15 Examples of recommended PMV and PPD categories for design of mechanical heated and cooled buildings (EN ISO 7730 2005)

Category	Thermal state of the body as a whole	
	PPD [%]	PMV
I	< 6	-0.2 < PMV < +0.2
II	< 10	-0.5 < PMV < +0.5
III	< 15	-0.7 < PMV < +0.7
IV	> 15	PMV < -0.7 or +0.7 < PMV

Results from the static comfort model presented that buildings improved with this optimization model can highly reduce building energy demand and in more than 90% maintain in category I and II throughout an annual period. The results were elaborated in detail for three levels for the reference office building (ground level, 5th and 9th level). Figure VII - 11 present the results on the PMV and PPD graphs for an East oriented office on the ground level. All analyzed offices presented results in comfort categories I and II as presented previously in Chapter 6.

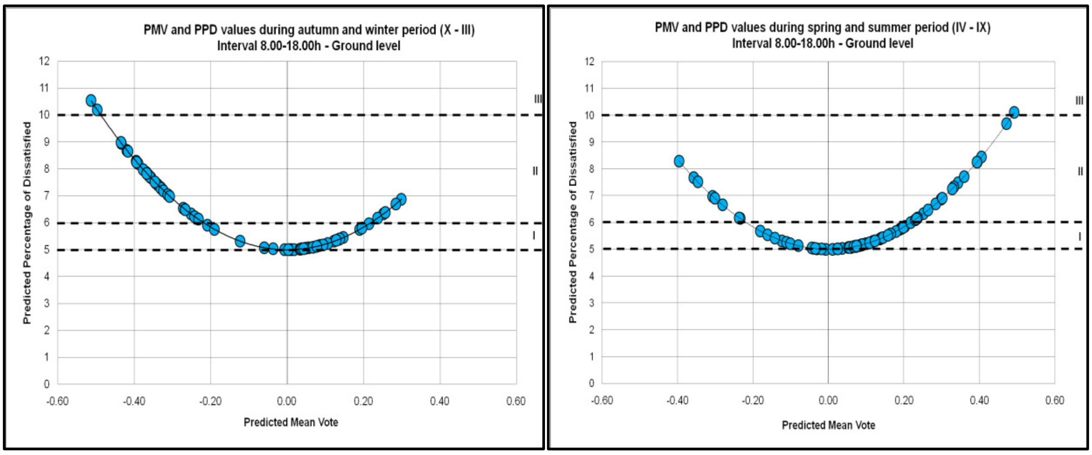


Figure VII - 11 PMV and PPD values on ground level

7.5. Overview of Best Case Scenario's energy performance and comfort category

The comparison of the reference building and Best Case Scenario could not be determined precisely since numerous data were not available, as listed previously in Chapter 5, or could not be measured. The annual heating energy demand for the Best Case Scenario compared to the reference office building can be reduced approximately by 83%.

In Table VII - 16 the annual energy performances for 2011, 2012 and 2013 are compared between the reference FTS office-tower building and the adopted Best Case Scenario. The 2011 annual heating energy consumption in case of the reference building per m^2 of single floor area was the highest 129 kWh/a, with unsatisfied indoor environmental standards. Compared to the Best Case Scenario the heating energy demand per m^2 of single floor area is reduced to 19 kWh/a, while indoor thermal satisfaction of occupants is satisfied. The heating energy demand according to the Best Case Scenario is 85% less compared to 2011 expenses, 83% compared to 2013 and 80% compared to 2012. Considering the state of indoor environment the reference office-tower had unsatisfactory results according to the comfort parameters from the monitoring, while the Best Case Scenario presented satisfied indoor environmental standards since the comfort parameter oscillations were set up according to the thermal satisfaction of occupants.

Considering the reference building's cooling energy demand the comparison could not be established because neither the cooling system's electricity consumption nor air-conditioning system performance is known. The energy expenses for lighting and equipment are added to the electricity demand of the cooling system, therefore the sum is issued together.

Table VII - 16 Energy expenses compared to simulated energy demands

<table>
<tr><th rowspan="2"></th><th colspan="2">Reference FTS office-tower (2011)</th><th colspan="2">Reference FTS office-tower (2012)</th><th colspan="2">Reference FTS office-tower (2013)</th></tr>
<tr><th>Heating energy [kWh]</th><th>Cooling, lighting and equipment electricity [kWh]</th><th>Heating energy [kWh]</th><th>Cooling, lighting and equipment electricity [kWh]</th><th>Heating energy [kWh]</th><th>Cooling, lighting and equipment electricity [kWh]</th></tr>
<tr><td>Sum [kWh/a]</td><td>442192</td><td>217719</td><td>338788</td><td>219823</td><td>378784</td><td>203810</td></tr>
<tr><td>Annual [kWh/m²/a]</td><td>129</td><td>64</td><td>99</td><td>64</td><td>110</td><td>59</td></tr>
<tr><td>Indoor environ. standards</td><td>Unsatisfied</td><td>Unsatisfied</td><td>Unsatisfied</td><td>Unsatisfied</td><td>Unsatisfied</td><td>Unsatisfied</td></tr>
<tr><td>Best Case Scenario ANNUAL ENERGY [kWh/m²/a]</td><td>19</td><td>63</td><td>19</td><td>63</td><td>19</td><td>63</td></tr>
<tr><td>Best Case Scenario PPD [%]</td><td colspan="3">Autumn – Winter
Average 97 %
(I and II comfort category)</td><td colspan="3">Spring – Summer
Average 97 %
(I and II comfort category)</td></tr>
<tr><td>Indoor environ. standards</td><td>Satisfied</td><td>Satisfied</td><td>Satisfied</td><td>Satisfied</td><td>Satisfied</td><td>Satisfied</td></tr>
<tr><td>Energy demand reduction</td><td>85 %</td><td>Identical</td><td>80 %</td><td>Identical</td><td>83 %</td><td>Slight deviation</td></tr>
</table>

It was concluded that with the developed methodology thermal dissatisfaction of occupants can be reduced during weekday occupancy intervals. The PPD index of dissatisfied occupants presented an average of 97% throughout an annual period covering the 1st and 2nd comfort category according to EN ISO 7730.

Chapter 8

Summary and conclusion

8.1. Summary

Dynamic energy performance simulation is significant in assessment and analysis of energy demands in buildings, by underlining the importance of decision-making in the early design stages of an existing or developing project. Therefore, engineering decisions in further stages of improvement or optimization process can be precise and efficient.

The developed methodology for energy performance evaluation will have the possibility of wide application on multi-level office buildings in order to offer efficient methods for energy performance improvement, occupant comfort maintenance and envelope performance rehabilitation. The dissertation investigated the possibility of determining an optimal solution for energy performance improvement of a typical inefficient administrative building on the territory of Novi Sad in temperate climate conditions. The criteria of energy performance optimization were in the function of comfort parameters, respecting building envelope’s thermal regulations according to the European Union and Serbia.

Optimal exterior glazing was investigated from three aspects; window to wall ratio reduction, window geometry determination in the function of visual comfort, and energetic aspects considering four criteria (illumination dispersion analysis, minimal daylight factor, photoelectric lighting simulation in order to save electricity and solar exposure analysis – radiation gains). The research concluded that climatic conditions have strong influence on the appropriate glazing selection. The developed methodology can be applied for various climatic conditions in order to formulate efficient solutions. Radiation analysis indicated the selection of preferable window types for the climate conditions of Novi Sad considering glazing parameters (U-vale, SHGC and VT) and their influence on the annual heating and cooling demands. It was concluded that the SHGC coefficient has the most significant influence on the energy demands due to high internal gains specific for office buildings.

The annual heating and cooling energy demand was investigated in the function of environmental and personal factors in order to determine the percentage of dissatisfied occupants. Predicted mean vote values emphasized the parameters considering both environmental and personal factors which had to undertake adjustments in order to reduce the predicted percentage of dissatisfied occupants. It was concluded that with the developed methodology thermal dissatisfaction of occupants can be reduced during weekday occupancy intervals. The PPD index of dissatisfied occupants presented an average of 97% throughout an annual period covering the 1st and 2nd comfort category according to EN ISO 7730.

HVAC system recommendations for temperate climate conditions were elaborated through comparative analysis of four different HVAC systems for new and existing office buildings. It was concluded that the heat pump HVAC system with heat recovery unit requires least annual energy for operation among the analyzed systems. Existing buildings supplied with district heating from the heating plant should be primarily monitored and regulated/repaired if system performance efficiency has decreased.

8.2. Conclusion

Energy efficiency, healthy environment and occupant comfort are today the most significant requirements in order to design and construct highly performative smart buildings. The determination of an optimal solution for energy performance improvement of administrative buildings in the function of occupant comfort is possible. The possibility of formulating an efficient improvement of existing buildings and developing plans for new ones undertake detailed analysis of numerous influential parameters. The admission of numerous aspects of interpretation plays a key role in energy performance assessment, whereas an energy simulation requires all segments of a parametric model to be designed precisely, so the integrated parameters create a virtual environment approximated to physical conditions.

The dissertation presented the complexity of designing a numerical energy model which interconnects the following elements: climate conditions, construction and materials, envelope properties, building function, occupants (intensity and activity), building operation schedules, lighting, equipment, thermostat and mechanical system schedules. Findings indicated that in order to achieve efficient and qualitative solutions all elements are mandatory to be interconnected.

Occupant health and comfort are an important topic of consideration in order to design healthy buildings and rationally use energy. To accomplish and maintain indoor environmental quality which strongly influences indoor well-being and productivity in the working environments, six factors have to be taken into consideration: metabolic rate, clothing insulation, mean air temperature, mean radiant temperature, air velocity and relative humidity. The problem is more complex since the six indicated factors are influenced by climatic conditions, envelope construction, HVAC system, occupants and operational schedules of the building.

The model is developed as an optimal solution for temperate climate conditions on the territory of Novi Sad, although it is flexible and adaptable for different climatic conditions.

8.3. Application of the results

Results present various possibilities of application, as the following:

- Improving the energy performance of administrative buildings with the same or similar characteristics
- Achieving a healthy and comfortable work environment for occupants
- Rational and efficient use of energy in the building sector by predictable occupancy intensity analysis
- Providing guidance in the early stages of designing new administrative building
- Providing guidance in rehabilitation of existing administrative building
- Flexibility of the model from the aspect of office building envelope design
- Suggesting installations of efficient HVAC systems, preferable for specific climate conditions
- The optimization model is flexible and can be applied for different climate conditions

8.4. Directions for further research

Further research directions consider testing the optimization model on inefficient administrative buildings in temperate climate conditions and evaluate its utilization. As a result an optional guidance for energy performance improvement can be formulated with emphasis on indoor environmental and personal factors which leads to designing healthy, functional and efficient buildings.

Future investigations will analyze the application of renewable energy sources and the environmental impact of the administrative building sector. HVAC system energy supply and primary energy demands of buildings will be the major topic of consideration. Ventilation and air quality analysis will be included respectively as topics of great significance in healthy building formulation. Further, the heat recoveries efficiency will be simulated in order to evaluate its efficiency on existing buildings with similar characteristics, all in the need of HVAC system supply energy reduction. The aim is to formulate a zero-energy building model in temperate climate conditions.

Occupant comfort parameters as; daylight intensity, mean radiant temperature (which depends from surface radiation) and relative humidity will be simulated and analyzed in the function of building envelope’s glazing ratio and window properties.

The following research will offer effective building envelope constructions for new buildings in specified climatic conditions.

Economical aspect is of important consideration when improving the thermal properties of building envelope and mechanical systems. Materials and construction expenses have to be taken under consideration from the performance and investment aspect.

Future cooperation with architects, civil, mechanical, electrical engineers and software developers is significant due to the multidisciplinarity and complexity of the topic. In order to achieve functional and efficient results the collaboration among engineers of different fields is required.

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Appendix

APPENDIX A

Monitored data sheets

60 primary records are presented from 1330 data in Period I

GROUND FLOOR

20.01. - 03.02.2014., Interval 15min

FTS Tower

n°	Date and time	Ground Floor air temperature	Ground Floor - Relative humidity [%]
1	12:00	23.98	35.30
2	12:15	23.90	35.10
3	12:30	23.66	32.80
4	12:45	23.66	34.40
5	13:00	23.74	34.70
6	13:15	23.90	35.50
7	13:30	23.98	35.90
8	13:45	24.03	35.30
9	14:00	23.99	35.10
10	14:15	24.05	34.80
11	14:30	24.05	34.50
12	14:45	23.74	32.40
13	15:00	23.64	33.30
14	15:15	23.67	33.30
15	15:30	23.67	33.40
16	15:45	23.58	33.40
17	16:00	23.54	33.40
18	16:15	23.54	33.40
19	16:30	23.51	33.30
20	16:45	23.44	33.20
21	17:00	23.51	33.10
22	17:15	23.38	33.10
23	17:30	23.42	33.10
24	17:45	23.40	33.00
25	18:00	23.38	33.10
26	18:15	23.34	33.10
27	18:30	23.37	33.10
28	18:45	23.37	33.00
29	19:00	23.32	33.00
30	19:15	23.35	32.90
31	19:30	23.29	32.80
32	19:45	23.34	32.80
33	20:00	23.35	32.90
34	20:15	23.35	32.90
35	20:30	23.35	33.00
36	20:45	23.37	33.20
37	21:00	23.31	33.30
38	21:15	23.24	33.40
39	21:30	23.19	33.50
40	21:45	23.19	33.50
41	22:00	23.19	33.40
42	22:15	23.19	33.40
43	22:30	23.13	33.40
44	22:45	23.09	33.40
45	23:00	23.05	33.40
46	23:15	23.02	33.50
47	23:30	22.96	33.50
48	23:45	22.92	33.60
49	0:00	22.87	33.60
50	0:15	22.84	33.70
51	0:30	22.84	33.70
52	0:45	22.79	33.70
53	1:00	22.77	33.70
54	1:15	22.73	33.70
55	1:30	22.66	33.70
56	1:45	22.64	33.70
57	2:00	22.66	33.70
58	2:15	22.61	33.60
59	2:30	22.58	33.60
60	2:45	22.60	33.40

5th FLOOR

20.01. - 03.02.2014., Interval 15min

FTS Tower

n°	Date and time	5th Floor air temperature [°C]
1	12:00	23.32
2	12:15	23.51
3	12:30	23.77
4	12:45	23.82
5	13:00	23.66
6	13:15	23.67
7	13:30	23.55
8	13:45	23.46
9	14:00	23.40
10	14:15	23.49
11	14:30	23.62
12	14:45	23.69
13	15:00	23.69
14	15:15	23.59
15	15:30	23.46
16	15:45	23.31
17	16:00	23.16
18	16:15	23.06
19	16:30	22.96
20	16:45	22.90
21	17:00	22.84
22	17:15	22.80
23	17:30	22.77
24	17:45	22.72
25	18:00	22.69
26	18:15	22.63
27	18:30	22.63
28	18:45	22.65
29	19:00	22.66
30	19:15	22.65
31	19:30	22.67
32	19:45	22.65
33	20:00	22.65
34	20:15	22.66
35	20:30	22.66
36	20:45	22.65
37	21:00	22.63
38	21:15	22.61
39	21:30	22.59
40	21:45	22.59
41	22:00	22.58
42	22:15	22.57
43	22:30	22.57
44	22:45	22.58
45	23:00	22.56
46	23:15	22.54
47	23:30	22.52
48	23:45	22.50
49	0:00	22.47
50	0:15	22.44
51	0:30	22.43
52	0:45	22.40
53	1:00	22.39
54	1:15	22.39
55	1:30	22.38
56	1:45	22.37
57	2:00	22.36
58	2:15	22.35
59	2:30	22.35
60	2:45	22.33

9th FLOOR

20.01. - 03.02.2014., Interval 15min

FTS Tower

n°	Date and time	9th Floor air temperature [°C]	9th Floor - Relative humidity [%]	Daylight intensity [lux]
1	12:00	23.58	43.80	256.00
2	12:15	23.85	42.80	510.00
3	12:30	24.05	41.80	586.00
4	12:45	23.84	41.70	236.00
5	13:00	23.83	41.10	471.00
6	13:15	24.00	40.40	235.00
7	13:30	23.65	40.80	230.00
8	13:45	23.60	40.80	730.00
9	14:00	24.05	40.10	731.00
10	14:15	25.73	37.80	762.00
11	14:30	33.02	28.40	866.00
12	14:45	33.66	28.10	834.00
13	15:00	28.63	33.80	466.00
14	15:15	29.23	33.30	243.00
15	15:30	25.38	38.30	53.00
16	15:45	24.21	40.00	27.00
17	16:00	23.69	40.60	6.00
18	16:15	23.39	41.00	2.00
19	16:30	23.19	41.20	0.00
20	16:45	23.05	41.30	0.00
21	17:00	22.96	41.30	0.00
22	17:15	22.89	41.30	0.00
23	17:30	22.83	41.30	0.00
24	17:45	22.78	41.10	0.00
25	18:00	22.71	41.00	0.00
26	18:15	22.64	41.10	0.00
27	18:30	22.62	41.20	0.00
28	18:45	22.60	41.40	0.00
29	19:00	22.58	41.60	0.00
30	19:15	22.58	41.90	0.00
31	19:30	22.56	42.00	0.00
32	19:45	22.58	41.90	0.00
33	20:00	22.56	41.80	0.00
34	20:15	22.53	41.70	0.00
35	20:30	22.53	41.90	0.00
36	20:45	22.53	42.00	0.00
37	21:00	22.50	42.00	0.00
38	21:15	22.46	42.40	0.00
39	21:30	22.46	42.40	0.00
40	21:45	22.46	42.30	0.00
41	22:00	22.46	42.60	0.00
42	22:15	22.44	42.70	0.00
43	22:30	22.44	42.70	0.00
44	22:45	22.42	42.50	0.00
45	23:00	22.40	42.60	0.00
46	23:15	22.39	42.60	0.00
47	23:30	22.37	42.60	0.00
48	23:45	22.33	42.60	0.00
49	0:00	22.31	42.60	0.00
50	0:15	22.28	42.70	0.00
51	0:30	22.28	42.70	0.00
52	0:45	22.26	42.60	0.00
53	1:00	22.24	42.60	0.00
54	1:15	22.23	42.60	0.00
55	1:30	22.21	42.60	0.00
56	1:45	22.19	42.60	0.00
57	2:00	22.19	42.60	0.00
58	2:15	22.16	42.60	0.00
59	2:30	22.15	42.60	0.00
60	2:45	22.14	42.50	0.00

70 primary records are presented from total 1138 data in Period II

GROUND FLOOR			
03. - 15.02.2014., Interval 15min			
FTS Tower			
n°	Date and time	Ground Floor air temperature	Ground Floor - Relative humidity
1	13:00	20.78	22.20
2	13:15	19.57	24.80
3	13:30	19.73	25.30
4	13:45	18.46	25.00
5	14:00	18.20	25.20
6	14:15	18.27	25.60
7	14:30	17.94	25.70
8	14:45	18.32	25.00
9	15:00	17.24	23.90
10	15:15	16.85	25.10
11	15:30	16.87	25.00
12	15:45	16.72	24.90
13	16:00	16.56	25.40
14	16:15	16.33	25.00
15	16:30	16.14	25.30
16	16:45	15.72	25.80
17	17:00	15.82	25.20
18	17:15	15.59	25.60
19	17:30	15.59	25.20
20	17:45	15.98	24.80
21	18:00	16.33	24.40
22	18:15	16.55	23.70
23	18:30	16.81	23.40
24	18:45	16.88	23.20
25	19:00	17.00	22.90
26	19:15	17.32	22.60
27	19:30	17.78	22.10
28	19:45	17.81	22.10
29	20:00	17.88	21.80
30	20:15	17.72	21.70
31	20:30	17.69	21.80
32	20:45	17.91	21.70
33	21:00	17.68	21.10
34	21:15	17.56	21.70
35	21:30	17.58	21.20
36	21:45	17.36	21.50
37	22:00	17.07	21.80
38	22:15	16.87	21.80
39	22:30	16.14	22.50
40	22:45	15.88	22.80
41	23:00	15.78	22.20
42	23:15	15.47	23.20
43	23:30	15.14	23.60
44	23:45	14.81	23.70
45	0:00	14.50	24.20
46	0:15	14.47	24.00
47	0:30	14.44	24.20
48	0:45	14.47	23.90
49	1:00	14.50	23.90
50	1:15	14.49	24.00
51	1:30	14.43	24.00
52	1:45	14.42	23.80
53	2:00	14.31	24.10
54	2:15	14.34	24.00
55	2:30	14.39	23.90
56	2:45	14.27	24.00
57	3:00	14.02	23.60
58	3:15	13.82	23.90
59	3:30	14.02	24.20
60	3:45	14.11	23.80
61	4:00	13.86	24.30
62	4:15	14.17	23.80
63	4:30	13.89	23.80
64	4:45	13.81	24.00
65	5:00	14.37	23.50
66	5:15	14.60	23.30
67	5:30	15.36	22.30
68	5:45	15.27	22.50
69	6:00	15.49	22.00
70	6:15	15.85	21.80

5th FLOOR		
03. - 15.02.2014., Interval 15min		
FTS Tower		
n°	Date and time	5th Floor air temperature [°C]
1	13:00	21.49
2	13:15	21.24
3	13:30	21.15
4	13:45	21.09
5	14:00	21.01
6	14:15	20.92
7	14:30	20.81
8	14:45	20.75
9	15:00	20.66
10	15:15	20.55
11	15:30	20.44
12	15:45	20.33
13	16:00	20.27
14	16:15	20.18
15	16:30	20.07
16	16:45	19.92
17	17:00	19.78
18	17:15	19.67
19	17:30	19.61
20	17:45	19.63
21	18:00	19.62
22	18:15	19.63
23	18:30	19.64
24	18:45	19.67
25	19:00	19.69
26	19:15	19.70
27	19:30	19.72
28	19:45	19.75
29	20:00	19.74
30	20:15	19.74
31	20:30	19.74
32	20:45	19.77
33	21:00	19.76
34	21:15	19.73
35	21:30	19.70
36	21:45	19.67
37	22:00	19.61
38	22:15	19.56
39	22:30	19.46
40	22:45	19.37
41	23:00	19.29
42	23:15	19.19
43	23:30	19.11
44	23:45	19.03
45	0:00	18.93
46	0:15	18.88
47	0:30	18.84
48	0:45	18.81
49	1:00	18.78
50	1:15	18.76
51	1:30	18.74
52	1:45	18.72
53	2:00	18.69
54	2:15	18.68
55	2:30	18.66
56	2:45	18.65
57	3:00	18.61
58	3:15	18.55
59	3:30	18.51
60	3:45	18.48
61	4:00	18.44
62	4:15	18.42
63	4:30	18.40
64	4:45	18.38
65	5:00	18.39
66	5:15	18.43
67	5:30	18.49
68	5:45	18.56
69	6:00	18.61
70	6:15	18.66

9th FLOOR				
03. - 15.02.2014., Interval 15min				
FTS Tower				
n°	Date and time	9th Floor air temperature [°C]	9th Floor - Relative humidity	Daylight intensity [lux]
1	13:00	21.80	29.70	821
2	13:15	22.30	29.10	854
3	13:30	22.44	29.00	868
4	13:45	22.75	28.80	870
5	14:00	23.23	28.40	880
6	14:15	29.06	23.00	900
7	14:30	31.10	21.40	900
8	14:45	30.42	22.00	889
9	15:00	29.88	22.20	849
10	15:15	26.33	25.10	2019
11	15:30	28.13	23.40	1470
12	15:45	28.17	23.40	965
13	16:00	27.48	23.90	563
14	16:15	25.88	25.20	269
15	16:30	24.05	26.60	86
16	16:45	21.94	28.60	13
17	17:00	21.24	29.20	0
18	17:15	20.94	29.40	0
19	17:30	20.83	29.40	0
20	17:45	20.78	29.30	0
21	18:00	20.71	29.50	0
22	18:15	20.66	29.80	0
23	18:30	20.65	29.70	0
24	18:45	20.64	29.50	0
25	19:00	20.59	29.50	0
26	19:15	20.60	29.40	0
27	19:30	20.60	29.10	0
28	19:45	20.59	29.10	0
29	20:00	20.59	29.00	0
30	20:15	20.58	28.90	0
31	20:30	20.60	28.90	0
32	20:45	20.62	28.80	0
33	21:00	20.58	28.70	0
34	21:15	20.55	28.70	0
35	21:30	20.51	28.70	0
36	21:45	20.48	28.60	0
37	22:00	20.42	28.60	0
38	22:15	20.33	28.60	0
39	22:30	20.24	28.50	0
40	22:45	20.14	28.50	0
41	23:00	20.05	28.50	0
42	23:15	19.92	28.50	0
43	23:30	19.85	28.40	0
44	23:45	19.76	28.40	0
45	0:00	19.69	28.40	0
46	0:15	19.59	28.50	0
47	0:30	19.55	28.40	0
48	0:45	19.49	28.40	0
49	1:00	19.46	28.30	0
50	1:15	19.42	28.30	0
51	1:30	19.37	28.30	0
52	1:45	19.32	28.30	0
53	2:00	19.28	28.30	0
54	2:15	19.23	28.30	0
55	2:30	19.20	28.30	0
56	2:45	19.15	28.30	0
57	3:00	19.12	28.30	0
58	3:15	19.08	28.30	0
59	3:30	19.09	28.20	0
60	3:45	19.08	28.20	0
61	4:00	19.08	28.20	0
62	4:15	19.06	28.10	0
63	4:30	19.05	28.10	0
64	4:45	19.06	28.10	0
65	5:00	19.08	28.20	0
66	5:15	19.10	28.40	0
67	5:30	19.19	28.30	0
68	5:45	19.21	28.20	0
69	6:00	19.26	28.00	0
70	6:15	19.34	28.00	0

80 primary records are presented from total 1337 data in Period III

GROUND FLOOR				5th FLOOR			9th FLOOR				
03. - 17.03.2014., Interval 15min				03. - 17.03.2014., Interval 15min			03. - 17.03.2014., Interval 15min				
FTS Tower				FTS Tower			FTS Tower				
n°	Date and time	Ground Floor air temperature	Ground Floor - Relative humidity	n°	Date and time	5th Floor air temperature [°C]	n°	Date and time	9th Floor air temperature [°C]	9th Floor - Relative humidity	Daylight intensity [lux]
1	12:00	20.23	36.40	1	12:00	19.86	1	12:00	22.76	39.30	183
2	12:15	20.04	36.20	2	12:15	19.89	2	12:15	22.83	39.20	162
3	12:30	20.00	38.00	3	12:30	19.91	3	12:30	22.72	39.40	124
4	12:45	20.39	38.00	4	12:45	19.90	4	12:45	22.76	39.60	168
5	13:00	20.22	38.50	5	13:00	19.88	5	13:00	22.80	39.30	655
6	13:15	21.19	39.30	6	13:15	19.97	6	13:15	23.00	39.00	242
7	13:30	21.06	40.20	7	13:30	20.13	7	13:30	23.81	37.90	399
8	13:45	21.09	35.90	8	13:45	20.22	8	13:45	23.46	38.40	204
9	14:00	20.07	39.10	9	14:00	20.03	9	14:00	23.06	39.00	156
10	14:15	19.78	39.70	10	14:15	19.78	10	14:15	22.89	39.20	100
11	14:30	19.91	38.10	11	14:30	19.59	11	14:30	22.75	39.50	111
12	14:45	19.87	38.70	12	14:45	19.54	12	14:45	23.30	38.80	316
13	15:00	19.88	37.80	13	15:00	19.52	13	15:00	24.19	37.40	303
14	15:15	19.83	36.90	14	15:15	19.41	14	15:15	23.49	38.50	153
15	15:30	19.58	37.00	15	15:30	19.21	15	15:30	23.17	39.10	113
16	15:45	20.25	41.30	16	15:45	19.18	16	15:45	25.67	35.30	267
17	16:00	20.58	39.10	17	16:00	19.16	17	16:00	23.35	38.70	108
18	16:15	20.38	38.40	18	16:15	19.05	18	16:15	23.10	39.00	99
19	16:30	20.32	37.30	19	16:30	18.87	19	16:30	22.94	39.30	92
20	16:45	20.00	37.30	20	16:45	18.66	20	16:45	22.83	39.50	62
21	17:00	19.97	37.60	21	17:00	18.47	21	17:00	22.65	39.70	41
22	17:15	20.13	37.20	22	17:15	18.42	22	17:15	22.49	39.90	11
23	17:30	19.93	37.40	23	17:30	18.20	23	17:30	22.40	40.10	2
24	17:45	19.94	37.00	24	17:45	18.05	24	17:45	22.30	40.30	0
25	18:00	19.84	37.10	25	18:00	17.91	25	18:00	22.23	40.40	0
26	18:15	19.73	37.10	26	18:15	17.89	26	18:15	22.19	40.40	0
27	18:30	19.42	36.90	27	18:30	17.74	27	18:30	22.14	40.40	0
28	18:45	19.03	37.70	28	18:45	17.50	28	18:45	22.09	40.40	0
29	19:00	18.81	37.70	29	19:00	17.26	29	19:00	22.08	40.40	0
30	19:15	18.46	38.00	30	19:15	16.91	30	19:15	22.05	40.40	0
31	19:30	18.62	37.20	31	19:30	16.91	31	19:30	22.03	40.40	0
32	19:45	18.87	37.10	32	19:45	17.11	32	19:45	22.00	40.30	0
33	20:00	19.10	36.80	33	20:00	17.31	33	20:00	21.97	40.20	0
34	20:15	18.93	36.60	34	20:15	17.29	34	20:15	21.96	40.10	0
35	20:30	18.81	36.60	35	20:30	17.19	35	20:30	21.94	40.00	0
36	20:45	18.77	36.60	36	20:45	17.14	36	20:45	21.92	39.80	0
37	21:00	18.59	36.50	37	21:00	17.24	37	21:00	21.89	39.60	0
38	21:15	18.54	36.70	38	21:15	17.18	38	21:15	21.86	39.30	0
39	21:30	18.65	36.40	39	21:30	17.20	39	21:30	21.83	39.20	0
40	21:45	18.62	36.50	40	21:45	17.18	40	21:45	21.80	39.10	0
41	22:00	18.62	36.40	41	22:00	17.18	41	22:00	21.78	39.00	0
42	22:15	18.52	36.00	42	22:15	17.04	42	22:15	21.74	38.90	0
43	22:30	18.36	36.40	43	22:30	16.98	43	22:30	21.71	38.90	0
44	22:45	18.03	37.00	44	22:45	16.80	44	22:45	21.67	38.80	0
45	23:00	18.04	36.70	45	23:00	16.71	45	23:00	21.64	38.70	0
46	23:15	17.88	36.90	46	23:15	16.58	46	23:15	21.61	38.60	0
47	23:30	17.90	36.80	47	23:30	16.58	47	23:30	21.59	38.50	0
48	23:45	17.72	37.20	48	23:45	16.54	48	23:45	21.58	38.50	0
49	0:00	17.88	37.00	49	0:00	16.40	49	0:00	21.55	38.40	0
50	0:15	17.87	36.90	50	0:15	16.46	50	0:15	21.51	38.40	0
51	0:30	17.88	36.70	51	0:30	16.54	51	0:30	21.49	38.30	0
52	0:45	17.85	36.70	52	0:45	16.53	52	0:45	21.47	38.30	0
53	1:00	17.78	36.90	53	1:00	16.45	53	1:00	21.46	38.30	0
54	1:15	17.58	37.00	54	1:15	16.09	54	1:15	21.42	38.30	0
55	1:30	17.59	37.00	55	1:30	16.00	55	1:30	21.40	38.20	0
56	1:45	17.51	36.90	56	1:45	15.93	56	1:45	21.39	38.20	0
57	2:00	17.43	36.90	57	2:00	15.84	57	2:00	21.35	38.20	0
58	2:15	17.39	37.10	58	2:15	15.79	58	2:15	21.33	38.10	0
59	2:30	17.46	36.80	59	2:30	15.96	59	2:30	21.33	38.10	0
60	2:45	17.39	36.80	60	2:45	15.92	60	2:45	21.30	38.00	0
61	3:00	17.22	37.00	61	3:00	15.77	61	3:00	21.28	38.00	0
62	3:15	17.14	37.10	62	3:15	15.54	62	3:15	21.26	38.00	0
63	3:30	16.49	38.30	63	3:30	15.23	63	3:30	21.25	38.00	0
64	3:45	16.21	38.50	64	3:45	15.10	64	3:45	21.23	38.00	0
65	4:00	16.32	38.10	65	4:00	15.05	65	4:00	21.23	37.90	0
66	4:15	16.75	37.40	66	4:15	15.07	66	4:15	21.22	37.80	0
67	4:30	17.01	36.90	67	4:30	15.25	67	4:30	21.24	37.80	0
68	4:45	16.77	37.30	68	4:45	15.21	68	4:45	21.25	37.80	0
69	5:00	16.69	36.70	69	5:00	15.10	69	5:00	21.26	37.80	0
70	5:15	17.01	36.30	70	5:15	15.11	70	5:15	21.26	37.60	0
71	5:30	16.77	36.30	71	5:30	15.07	71	5:30	21.30	37.60	0
72	5:45	16.62	36.60	72	5:45	14.79	72	5:45	21.28	37.40	0
73	6:00	16.62	36.80	73	6:00	14.73	73	6:00	21.33	37.30	0
74	6:15	16.49	36.30	74	6:15	14.63	74	6:15	21.33	37.10	0
75	6:30	15.49	38.70	75	6:30	14.61	75	6:30	21.34	37.10	8
76	6:45	15.23	39.00	76	6:45	14.73	76	6:45	21.37	37.00	23
77	7:00	15.07	39.30	77	7:00	14.83	77	7:00	21.42	36.80	53
78	7:15	15.53	39.00	78	7:15	15.40	78	7:15	21.50	36.80	73
79	7:30	16.27	38.20	79	7:30	16.43	79	7:30	21.55	36.80	88
80	7:45	16.05	38.10	80	7:45	17.36	80	7:45	21.62	36.70	102

70 primary records are presented from 1297 data in summer period

GROUND FLOOR
03. - 17.03.2014., Interval 15min
FTS Tower

n°	Date and time	Ground Floor air temperature	Ground Floor - Relative humidity
1	12:00	28.20	46.70
2	13:00	27.83	57.20
3	14:00	27.65	43.60
4	15:00	27.76	49.30
5	16:00	27.79	48.30
6	17:00	27.78	48.10
7	18:00	27.65	48.40
8	19:00	27.50	49.30
9	20:00	27.34	49.80
10	21:00	27.15	51.20
11	22:00	26.67	53.10
12	23:00	26.28	54.40
13	0:00	25.86	55.80
14	1:00	25.64	56.30
15	2:00	25.37	57.40
16	3:00	25.14	57.80
17	4:00	24.86	58.30
18	5:00	24.63	59.20
19	6:00	24.57	59.00
20	7:00	24.90	63.30
21	8:00	25.15	63.70
22	9:00	25.18	63.70
23	10:00	25.18	60.30
24	11:00	25.41	61.40
25	12:00	25.33	61.70
26	13:00	25.67	60.50
27	14:00	25.70	56.00
28	15:00	25.70	56.30
29	16:00	25.72	53.40
30	17:00	25.76	51.70
31	18:00	25.62	53.70
32	19:00	25.33	55.20
33	20:00	25.09	55.40
34	21:00	24.83	56.00
35	22:00	24.59	56.90
36	23:00	24.35	57.00
37	0:00	24.14	56.90
38	1:00	23.86	56.60
39	2:00	23.61	56.40
40	3:00	23.32	57.40
41	4:00	23.12	57.80
42	5:00	22.95	58.20
43	6:00	22.83	58.60
44	7:00	23.22	57.40
45	8:00	23.79	57.80
46	9:00	24.77	56.10
47	10:00	27.20	50.20
48	11:00	26.50	52.30
49	12:00	26.44	48.50
50	13:00	26.47	50.00
51	14:00	26.41	51.00
52	15:00	26.31	53.10
53	16:00	25.96	55.60
54	17:00	25.76	55.70
55	18:00	25.43	55.60
56	19:00	25.15	55.30
57	20:00	24.80	55.80
58	21:00	24.44	56.30
59	22:00	24.16	57.00
60	23:00	23.90	57.00
61	0:00	23.67	56.90
62	1:00	23.41	57.70
63	2:00	23.24	58.10
64	3:00	23.03	58.40
65	4:00	22.87	58.60
66	5:00	22.71	58.10
67	6:00	22.55	58.70
68	7:00	22.51	56.60
69	8:00	22.79	58.80
70	9:00	23.25	56.10

5th FLOOR
03. - 17.03.2014., Interval 15min
FTS Tower

n°	Date and time	5th Floor air temperature [°C]
1	12:00	30.28
2	13:00	30.34
3	14:00	30.46
4	15:00	30.84
5	16:00	30.73
6	17:00	30.90
7	18:00	30.88
8	19:00	31.05
9	20:00	30.91
10	21:00	30.79
11	22:00	30.70
12	23:00	30.59
13	0:00	30.50
14	1:00	30.40
15	2:00	30.30
16	3:00	30.17
17	4:00	30.05
18	5:00	29.92
19	6:00	29.78
20	7:00	29.69
21	8:00	28.85
22	9:00	27.80
23	10:00	27.52
24	11:00	27.32
25	12:00	27.80
26	13:00	27.50
27	14:00	28.29
28	15:00	28.83
29	16:00	29.28
30	17:00	29.58
31	18:00	29.73
32	19:00	30.13
33	20:00	29.93
34	21:00	29.61
35	22:00	29.38
36	23:00	29.24
37	0:00	29.10
38	1:00	28.95
39	2:00	28.83
40	3:00	28.71
41	4:00	28.55
42	5:00	28.40
43	6:00	28.27
44	7:00	28.16
45	8:00	28.12
46	9:00	27.01
47	10:00	27.32
48	11:00	27.63
49	12:00	27.63
50	13:00	27.83
51	14:00	28.15
52	15:00	28.19
53	16:00	28.08
54	17:00	28.20
55	18:00	28.31
56	19:00	28.16
57	20:00	27.97
58	21:00	27.78
59	22:00	27.59
60	23:00	27.43
61	0:00	27.23
62	1:00	27.04
63	2:00	26.84
64	3:00	26.63
65	4:00	26.37
66	5:00	26.00
67	6:00	25.87
68	7:00	25.71
69	8:00	25.57
70	9:00	24.91

9th FLOOR
03. - 17.03.2014., Interval 15min
FTS Tower

n°	Date and time	9th Floor air temperature [°C]	9th Floor - Relative humidity	Daylight intensity [lux]
1	12:00	33.91	45.00	146
2	13:00	33.63	44.90	152
3	14:00	34.41	43.80	333
4	15:00	34.84	40.30	61
5	16:00	33.99	42.30	70
6	17:00	34.45	42.10	77
7	18:00	34.09	42.80	125
8	19:00	34.49	42.10	52
9	20:00	33.77	43.50	1
10	21:00	33.38	44.70	0
11	22:00	33.19	45.10	0
12	23:00	33.06	45.50	0
13	0:00	32.95	45.90	0
14	1:00	32.83	45.80	0
15	2:00	32.73	46.10	0
16	3:00	32.63	46.40	0
17	4:00	32.52	46.40	0
18	5:00	32.41	46.60	0
19	6:00	32.36	46.60	20
20	7:00	32.36	46.50	11
21	8:00	32.30	46.80	66
22	9:00	31.91	48.30	24
23	10:00	31.84	47.10	39
24	11:00	32.02	46.50	84
25	12:00	31.89	46.80	99
26	13:00	32.27	46.20	182
27	14:00	32.88	44.90	328
28	15:00	34.02	42.90	413
29	16:00	35.00	40.30	499
30	17:00	34.20	41.10	32
31	18:00	34.61	42.00	695
32	19:00	34.70	41.50	612
33	20:00	33.88	42.10	144
34	21:00	32.73	43.90	0
35	22:00	32.34	44.50	0
36	23:00	32.10	44.80	0
37	0:00	31.91	44.70	0
38	1:00	31.70	44.00	0
39	2:00	31.50	43.50	0
40	3:00	31.34	43.50	0
41	4:00	31.19	43.80	0
42	5:00	31.03	44.10	0
43	6:00	30.99	43.80	28
44	7:00	31.02	43.70	61
45	8:00	31.05	44.30	68
46	9:00	30.14	47.00	107
47	10:00	29.67	48.60	171
48	11:00	30.81	46.30	137
49	12:00	31.24	45.00	186
50	13:00	31.38	44.40	243
51	14:00	32.03	43.20	405
52	15:00	31.08	44.80	0
53	16:00	30.99	45.40	129
54	17:00	30.92	46.30	36
55	18:00	31.35	43.60	60
56	19:00	30.69	44.70	55
57	20:00	30.38	45.00	8
58	21:00	30.14	45.30	0
59	22:00	29.89	45.50	0
60	23:00	29.78	45.60	0
61	0:00	29.60	45.70	0
62	1:00	29.48	45.90	0
63	2:00	29.38	46.00	0
64	3:00	29.16	46.10	0
65	4:00	28.83	46.20	0
66	5:00	28.28	46.00	0
67	6:00	28.46	45.60	2
68	7:00	28.41	45.30	45
69	8:00	28.42	45.00	52
70	9:00	28.50	44.30	94

APPENDIX B

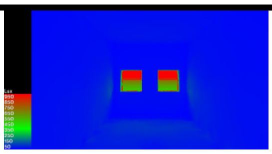
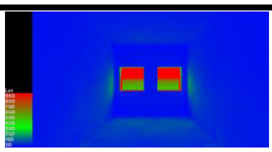
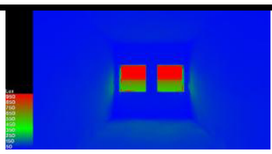
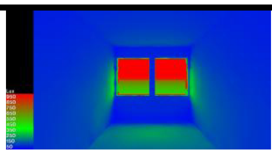
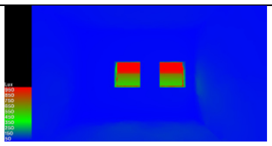
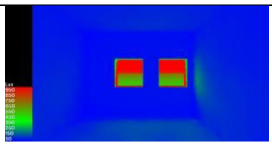
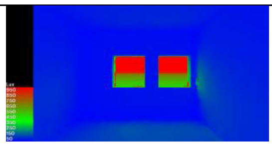
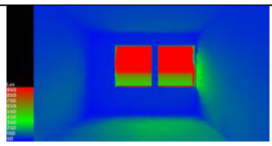
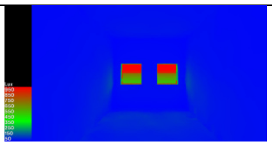
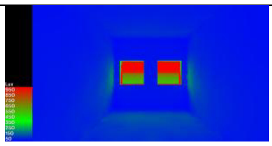
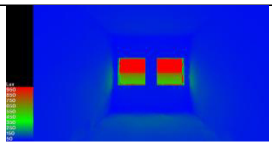
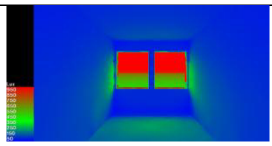
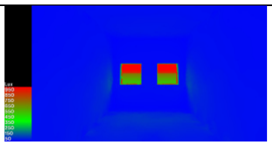
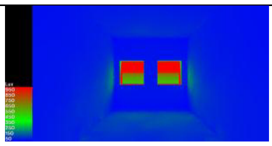
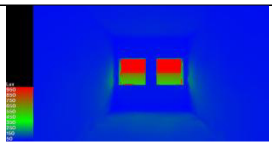
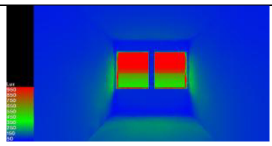
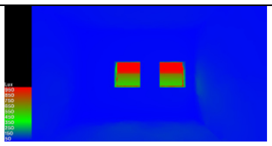
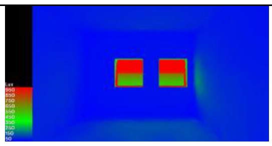
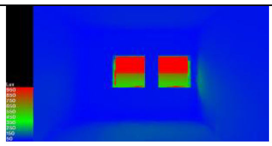
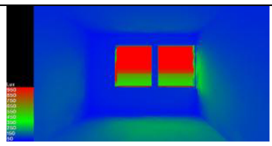
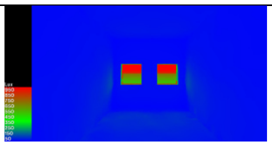
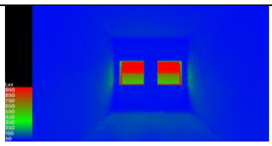
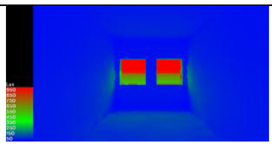
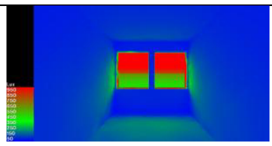
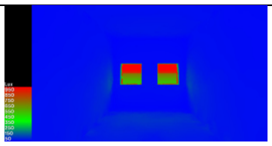
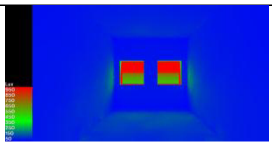
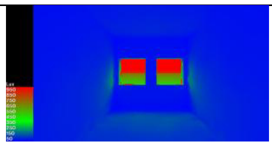
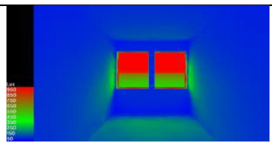
Illumination intensity analysis

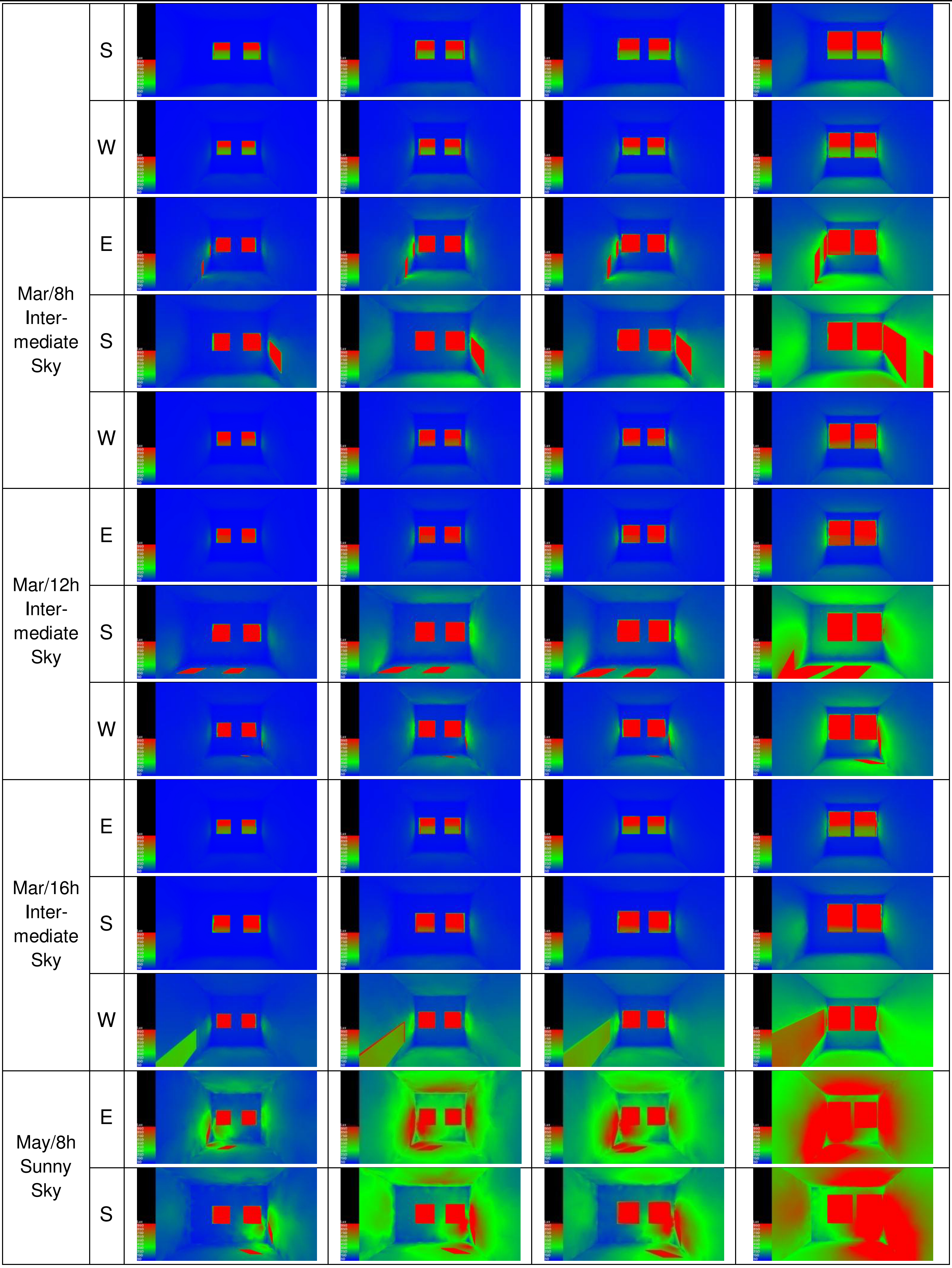
Advanced illumination analysis in Radiance CP

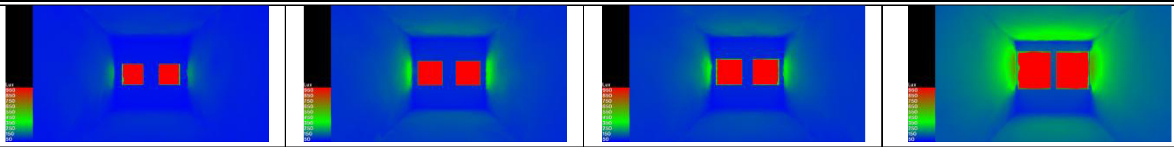
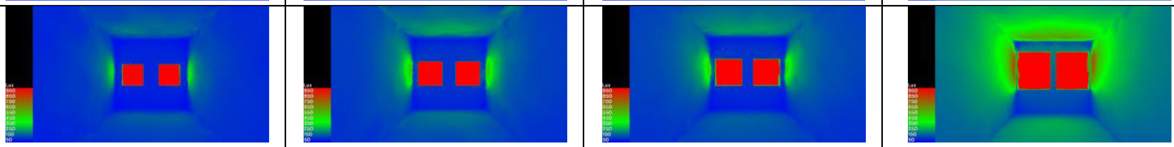
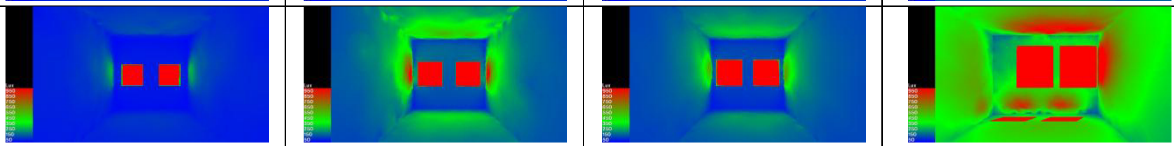
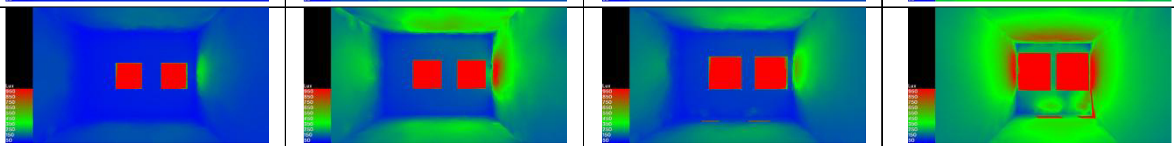
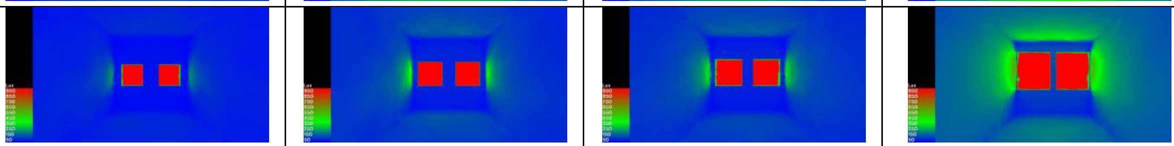
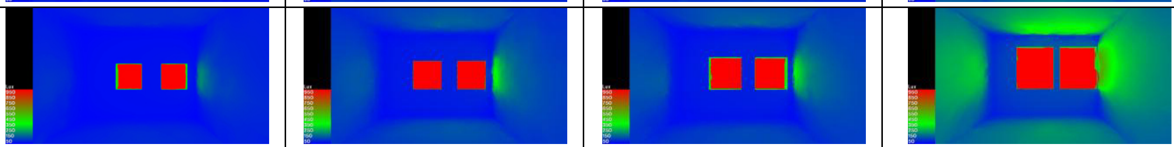
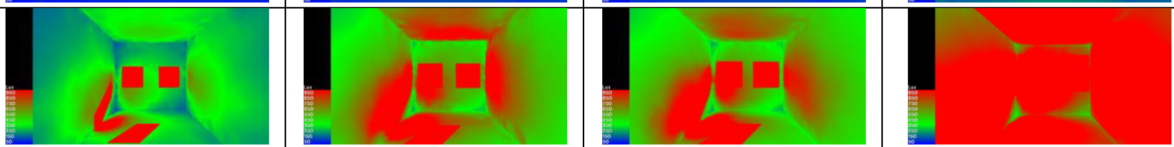
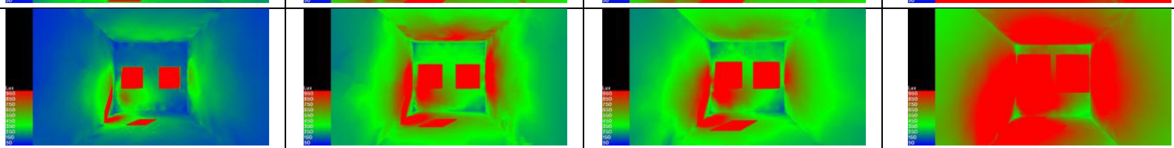
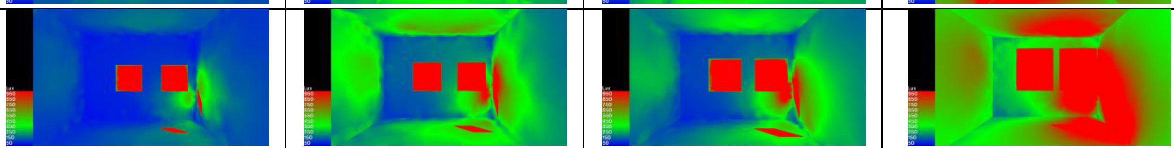
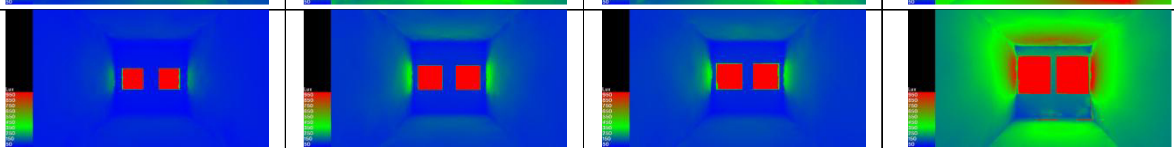
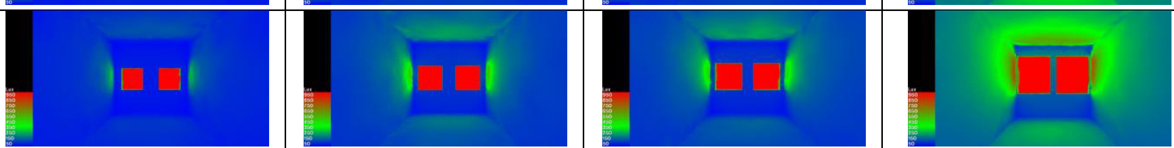
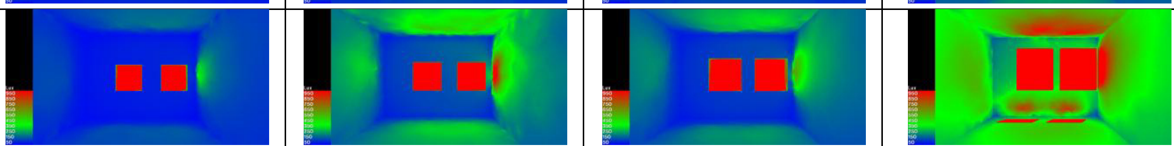
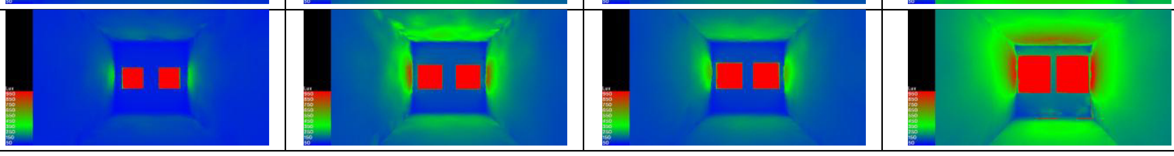
Simulation with integrated illumination distribution and sky condition factor

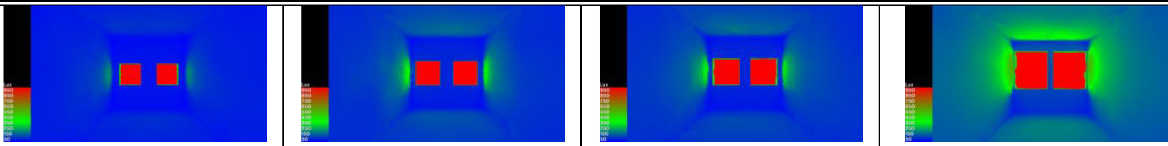
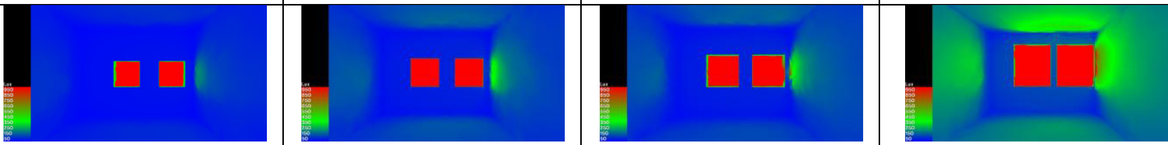
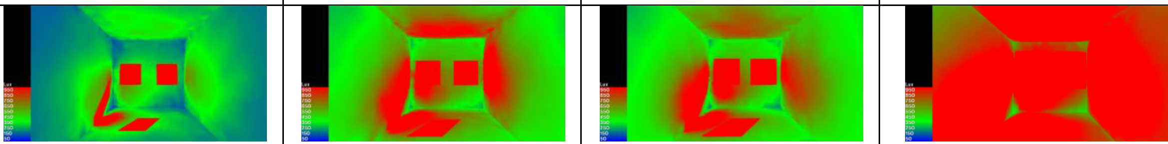
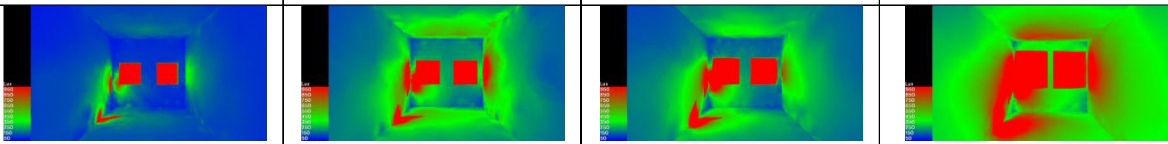
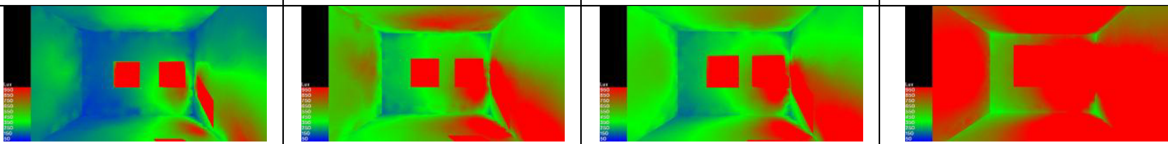
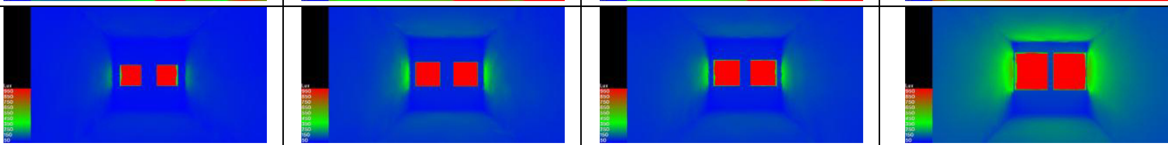
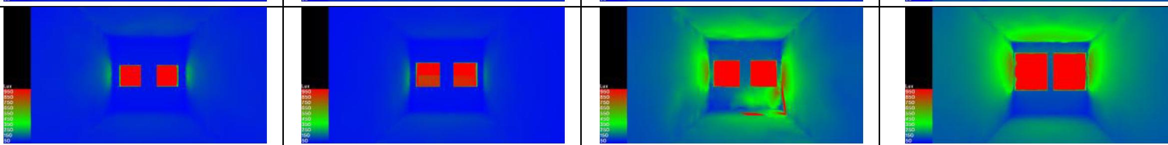
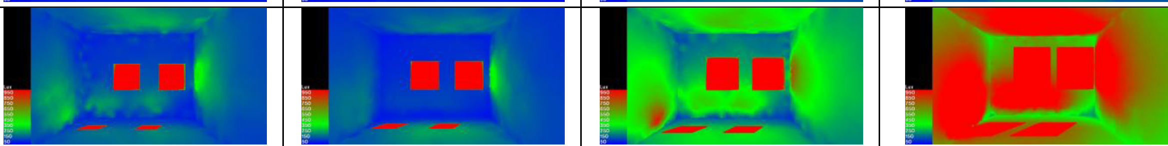
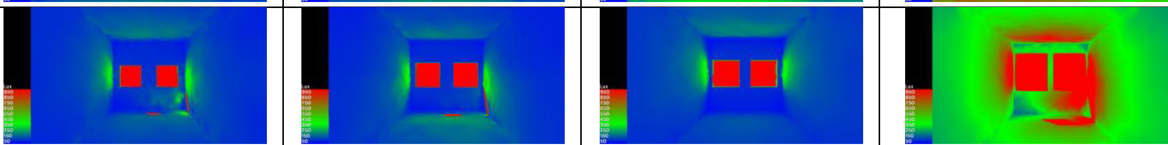
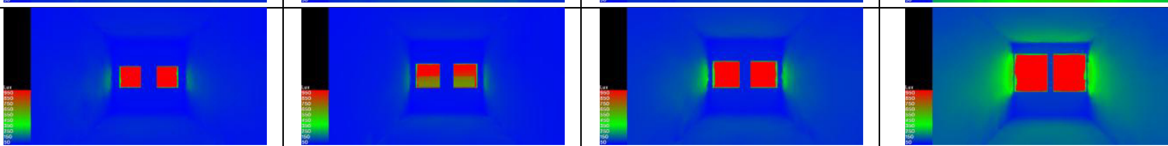
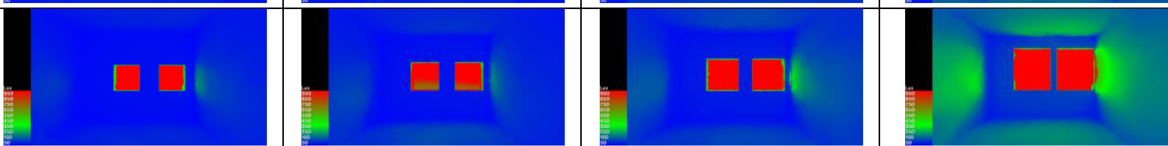
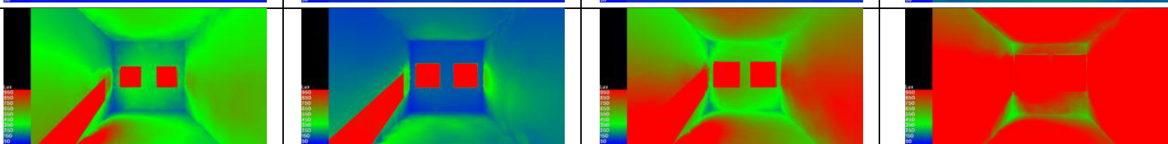
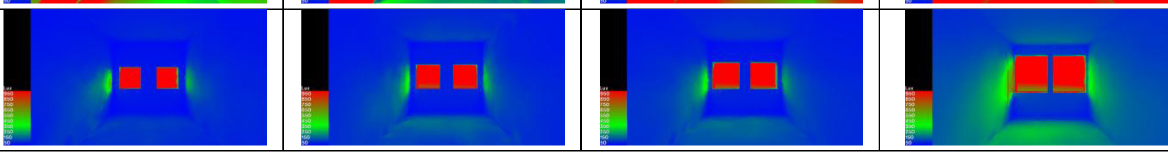
Building plan rotation is 30˚ counterclockwise from North axis

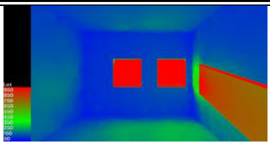
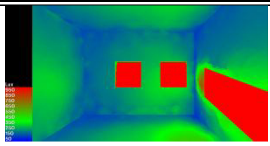
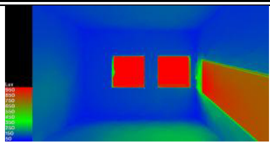
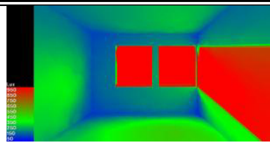
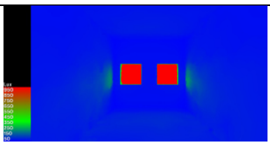
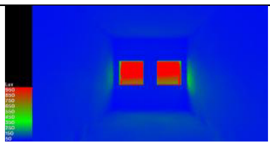
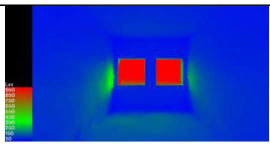
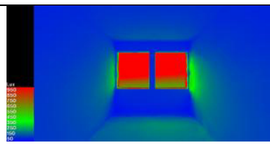
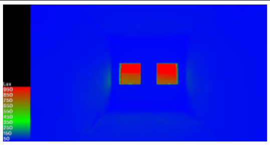
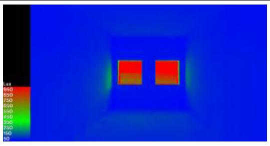
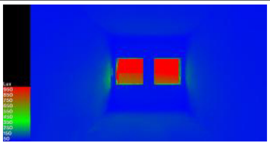
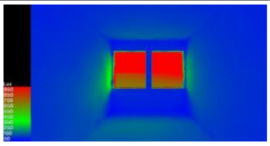
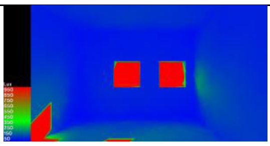
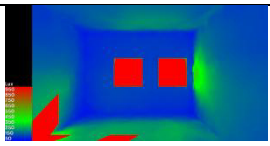
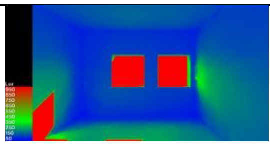
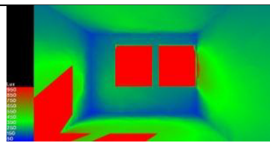
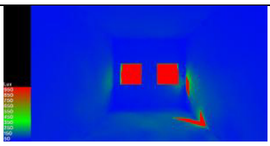
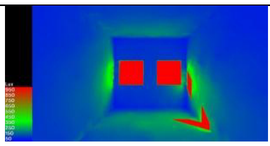
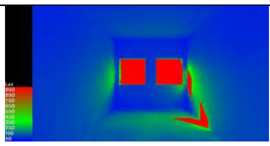
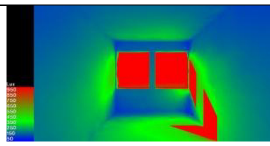
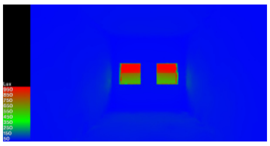
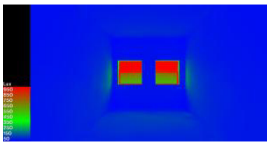
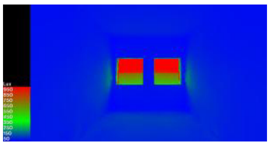
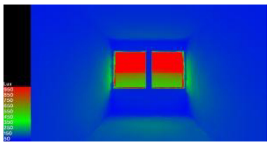
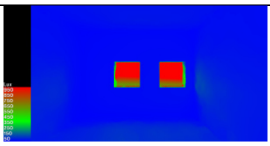
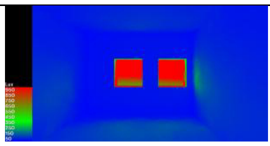
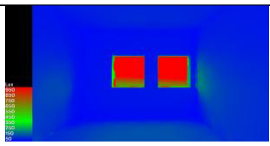
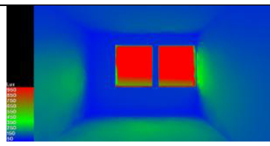
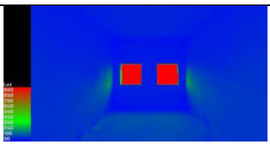
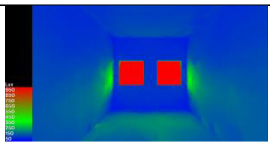
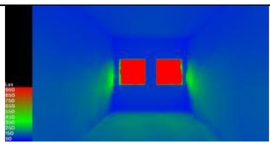
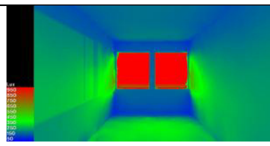
Daylight intensity (lx) is defined by the color specter as shown.

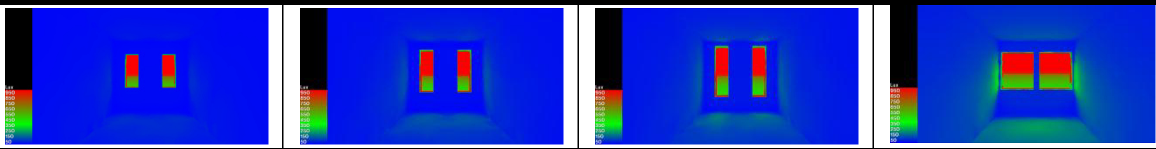
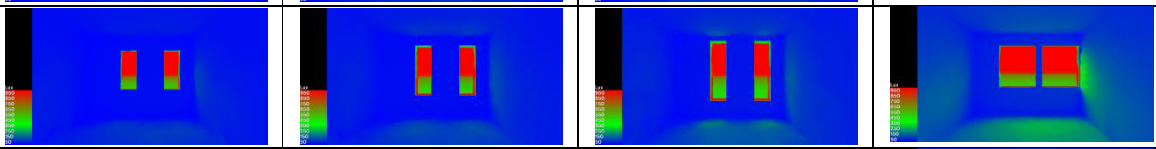
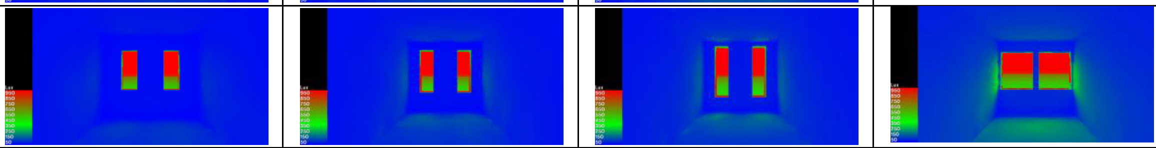
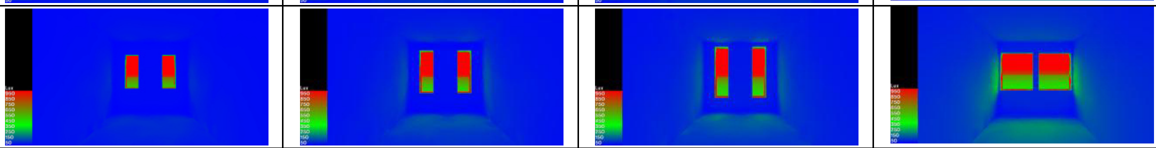
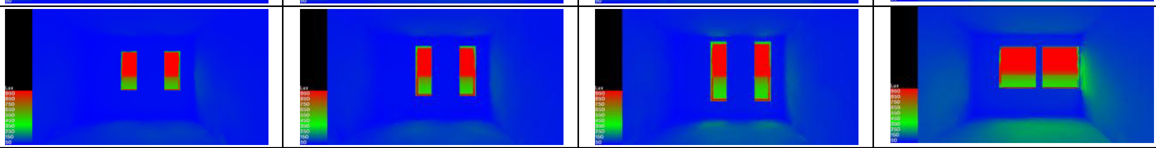
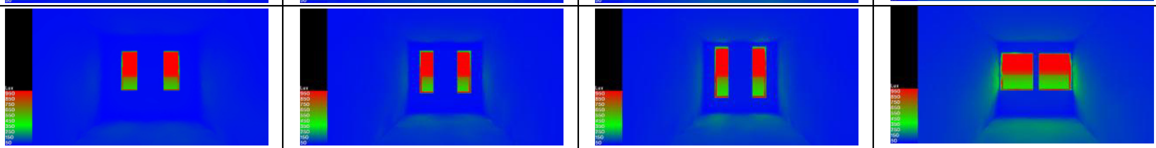
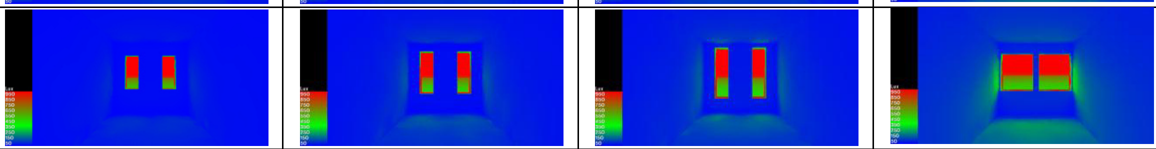
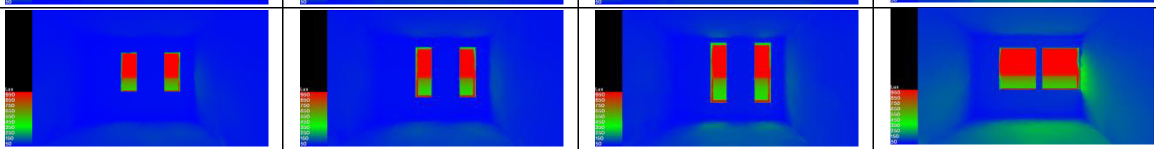
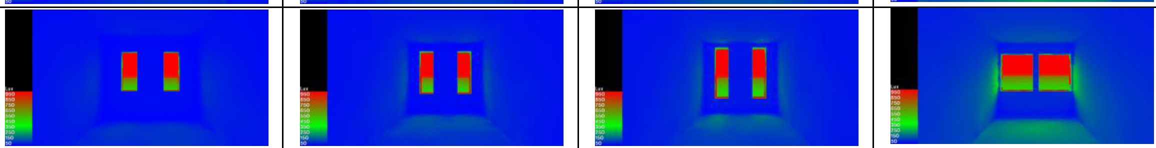
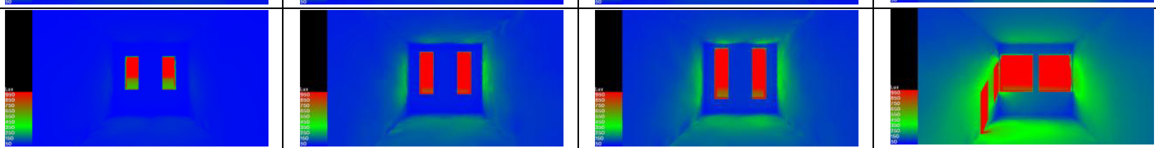
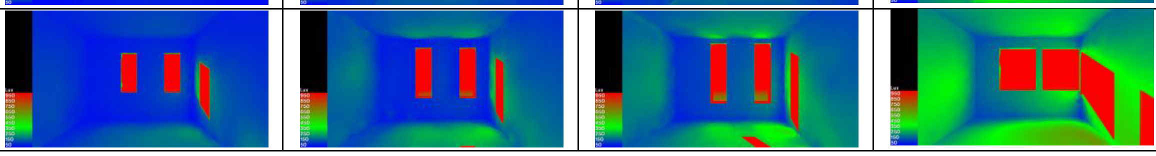
WWR for SQUARE window geometry					
Date/time Sky condition	Orient.	20%	25%	30%	Base Case 50%
Jan/8h Cloudy sky	E				
	S				
	W				
Jan/12h Cloudy sky	E				
	S				
	W				
Jan/16h Cloudy sky	E				


S
W
Mar/8h Inter-mediate Sky
E
S
W
Mar/12h Inter-mediate Sky
E
S
W
Mar/16h Inter-mediate Sky
E
S
W
May/8h Sunny Sky
E
S

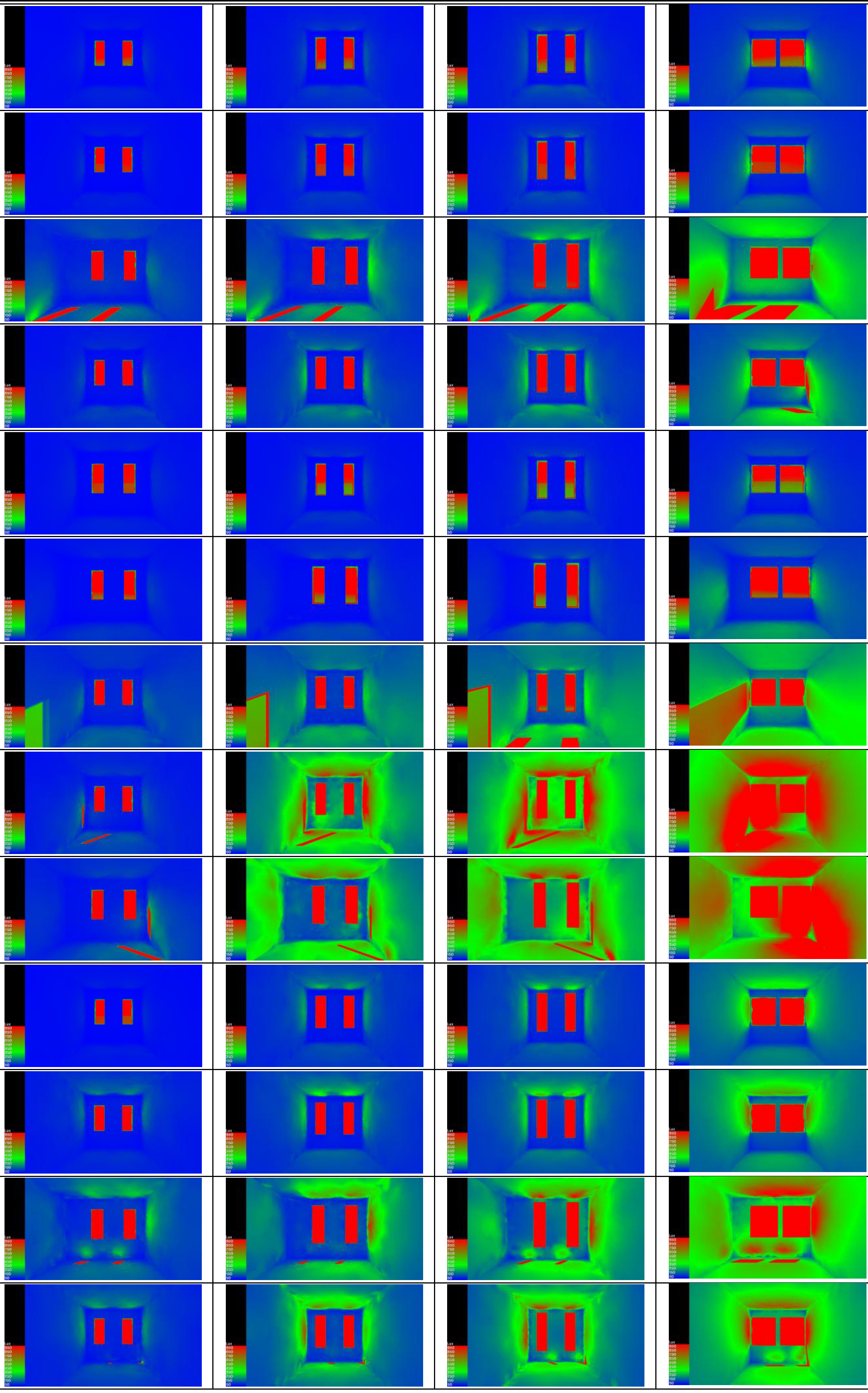
	W	
May/12h Sunny Sky	E	
	S	
	W	
May/16h Sunny Sky	E	
	S	
	W	
Jul/8h Sunny Sky	E	
	S	
	W	
Jul/12h Sunny Sky	E	
	S	
	W	

Jul/16h Sunny Sky	E	
	S	
	W	
Sept/8h Sunny Sky	E	
	S	
	W	
Sept/12h Sunny Sky	E	
	S	
	W	
Sept/16h Sunny Sky	E	
	S	
	W	
	E	

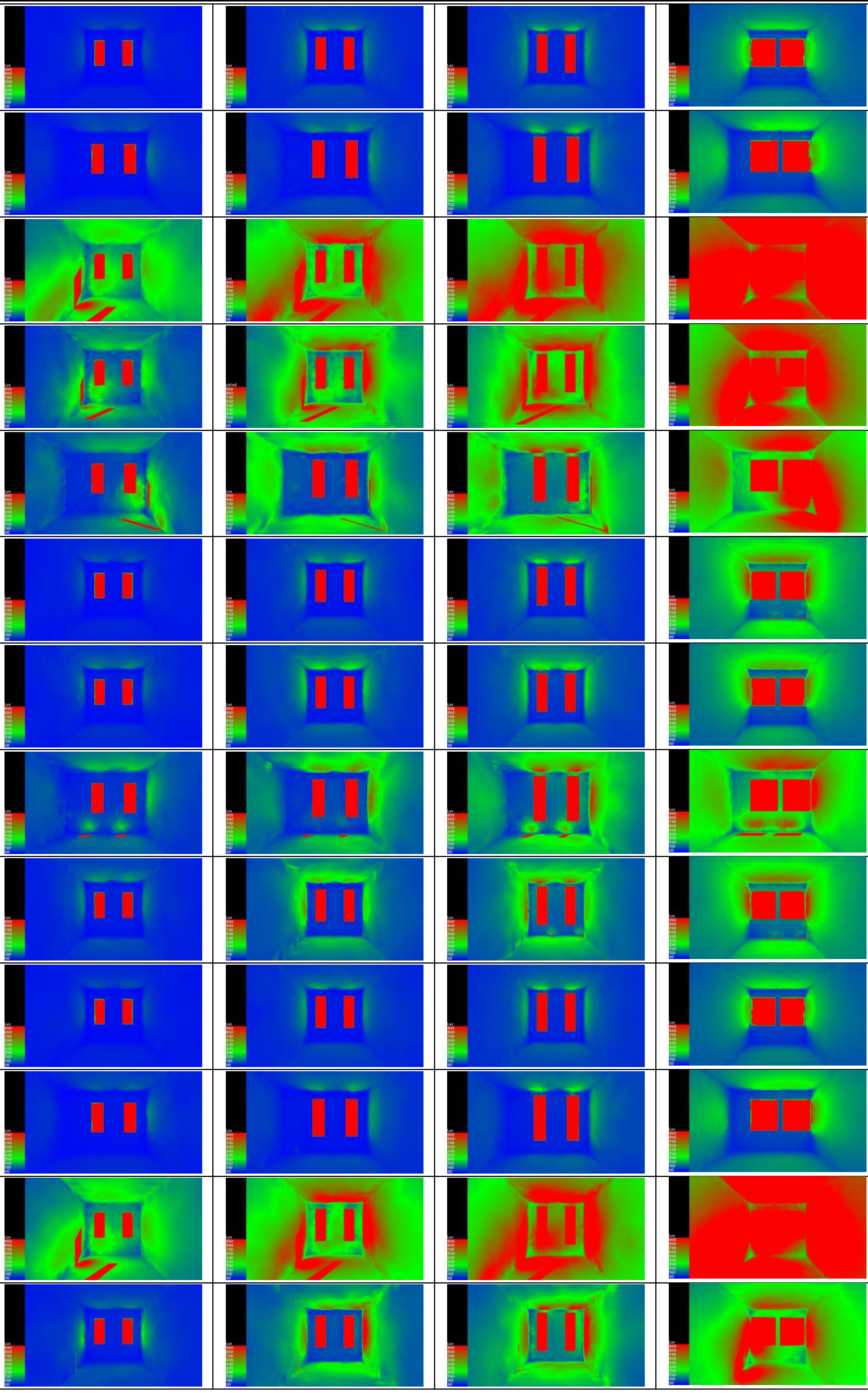
Nov/8h Inter-mediate Sky	S				
	W				
Nov/12h Inter-mediate Sky	E				
	S				
	W				
Nov/16h Inter-mediate Sky	E				
	S				
	W				

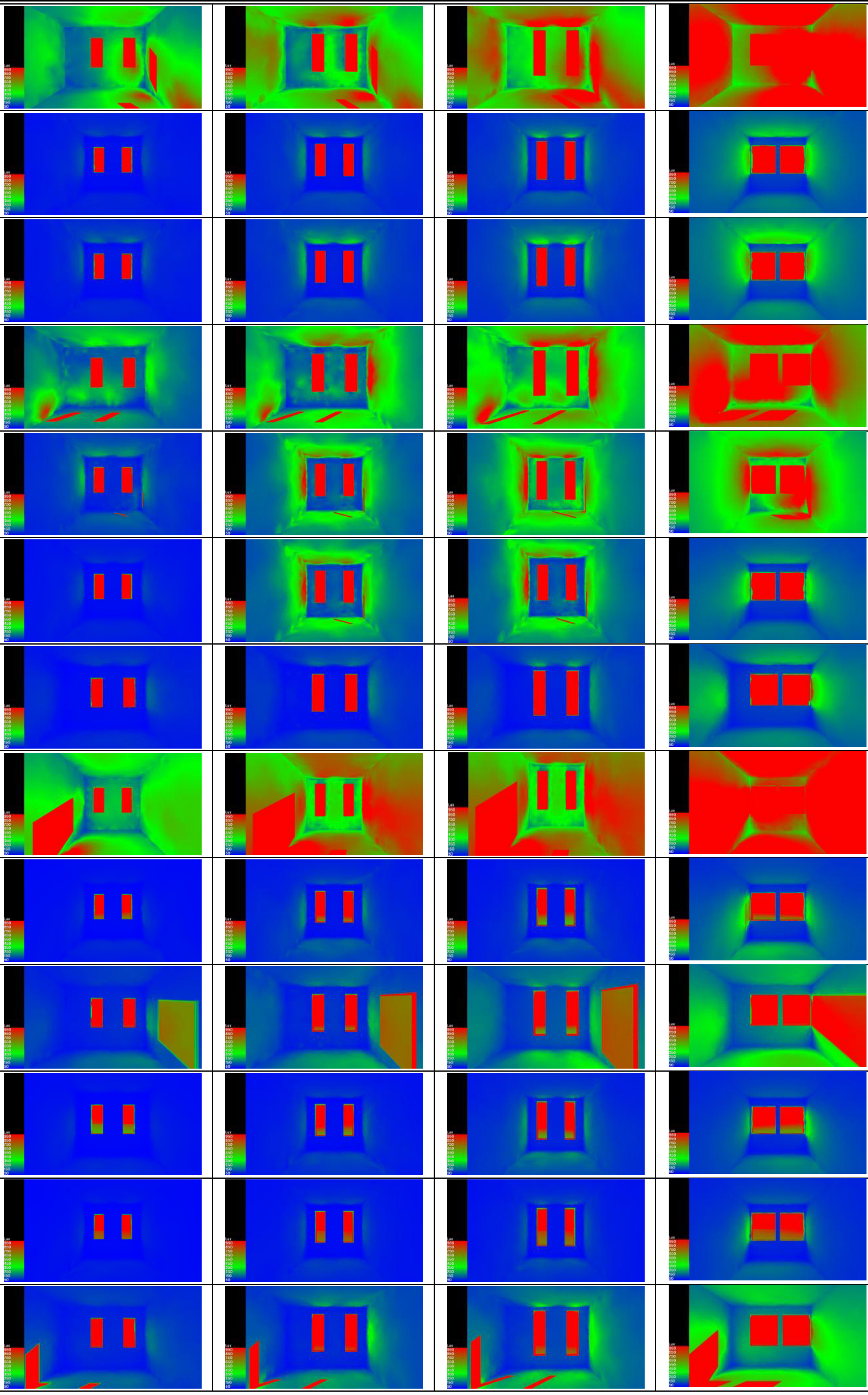
WWR for VERTICAL window geometry					
Date/time Sky condition	Orient.	20%	25%	30%	Base Case 50%
Jan/8h Cloudy sky	E				
	S				
	W				
Jan/12h Cloudy sky	E				
	S				
	W				
Jan/16h Cloudy sky	E				
	S				
	W				
Mar/8h Inter-mediate Sky	E				
	S				

	W
Mar/12h Inter-mediate Sky	E
	S
	W
Mar/16h Inter-mediate Sky	E
	S
	W
May/8h Sunny Sky	E
	S
	W
May/12h Sunny Sky	E
	S
	W

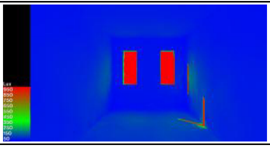
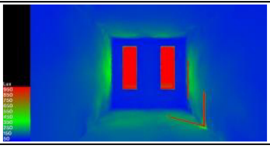
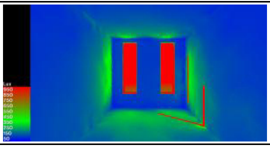
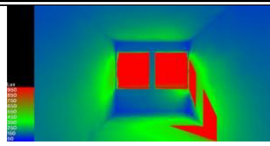
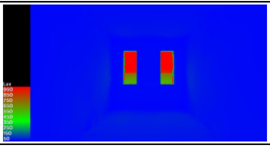
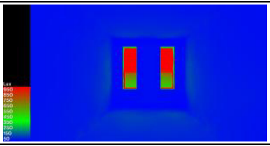
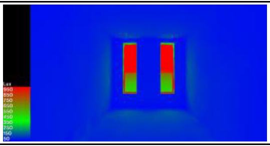
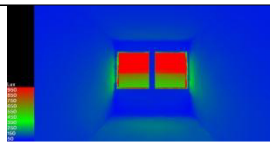
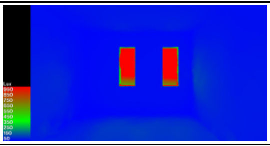
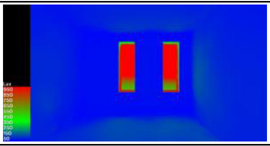
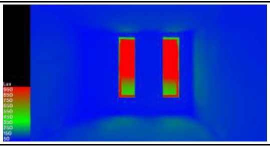
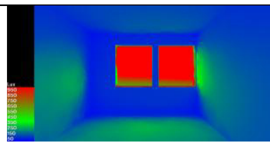
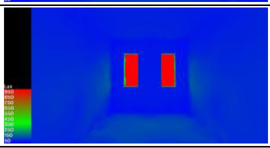
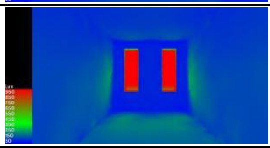
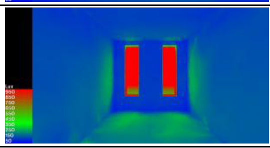
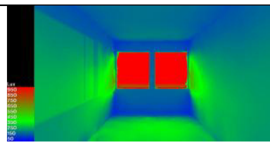


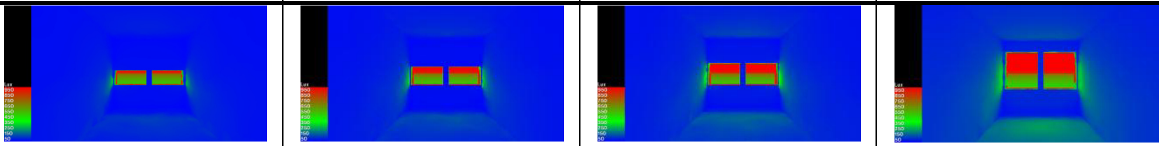
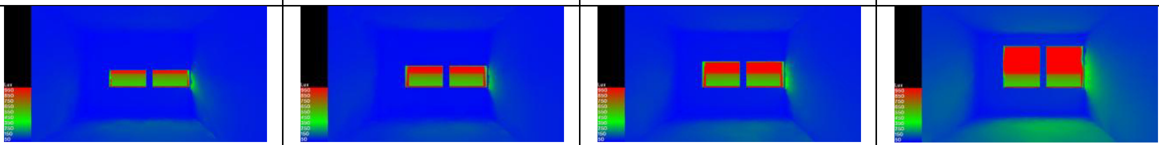
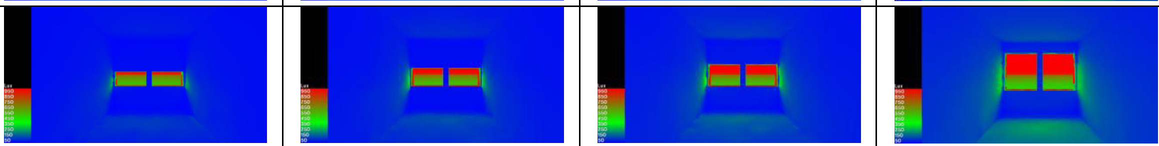
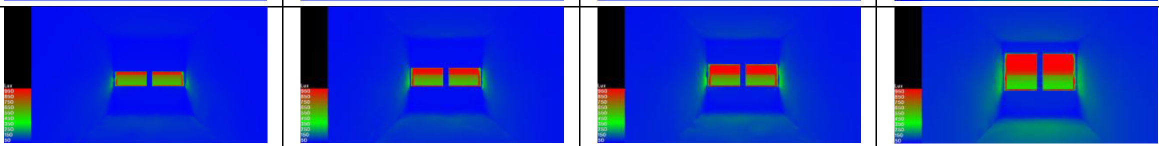
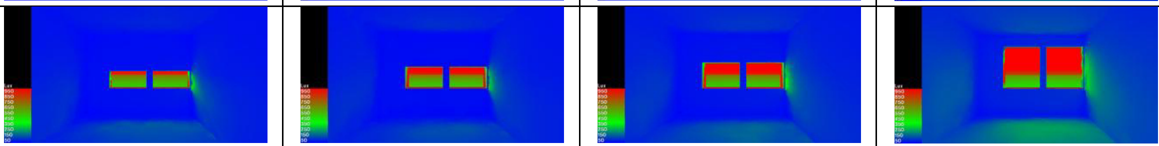
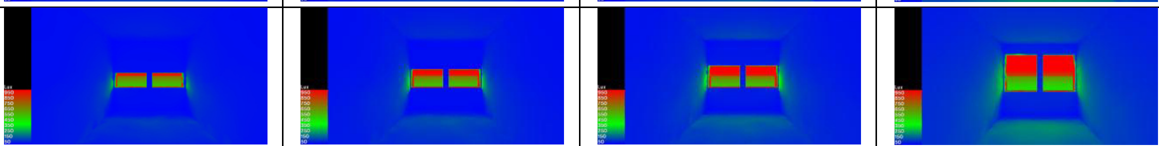
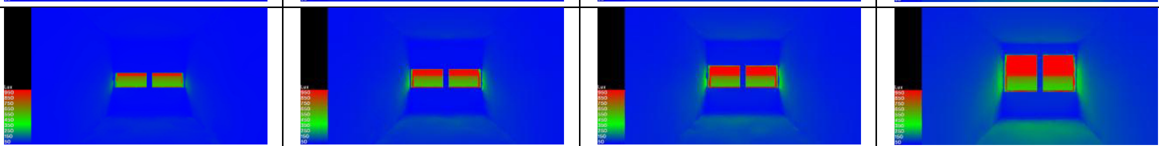
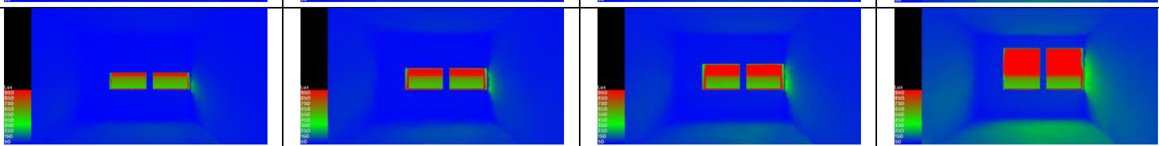
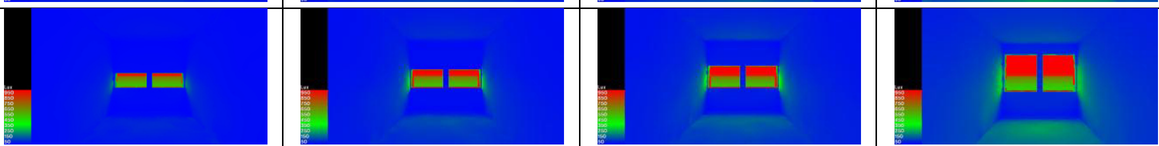
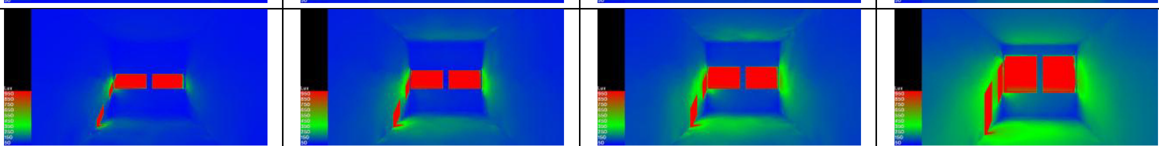
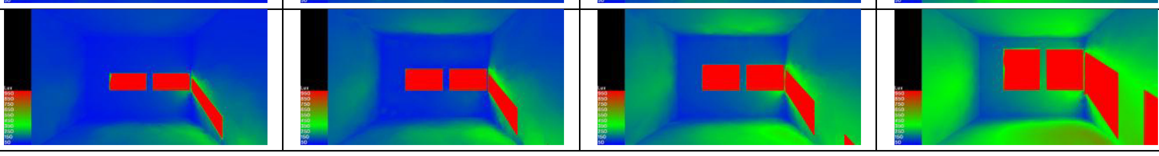
May/16h Sunny Sky	E
	S
	W
Jul/8h Sunny Sky	E
	S
	W
Jul/12h Sunny Sky	E
	S
	W
Jul/16h Sunny Sky	E
	S
	W
Sept/8h Sunny Sky	E

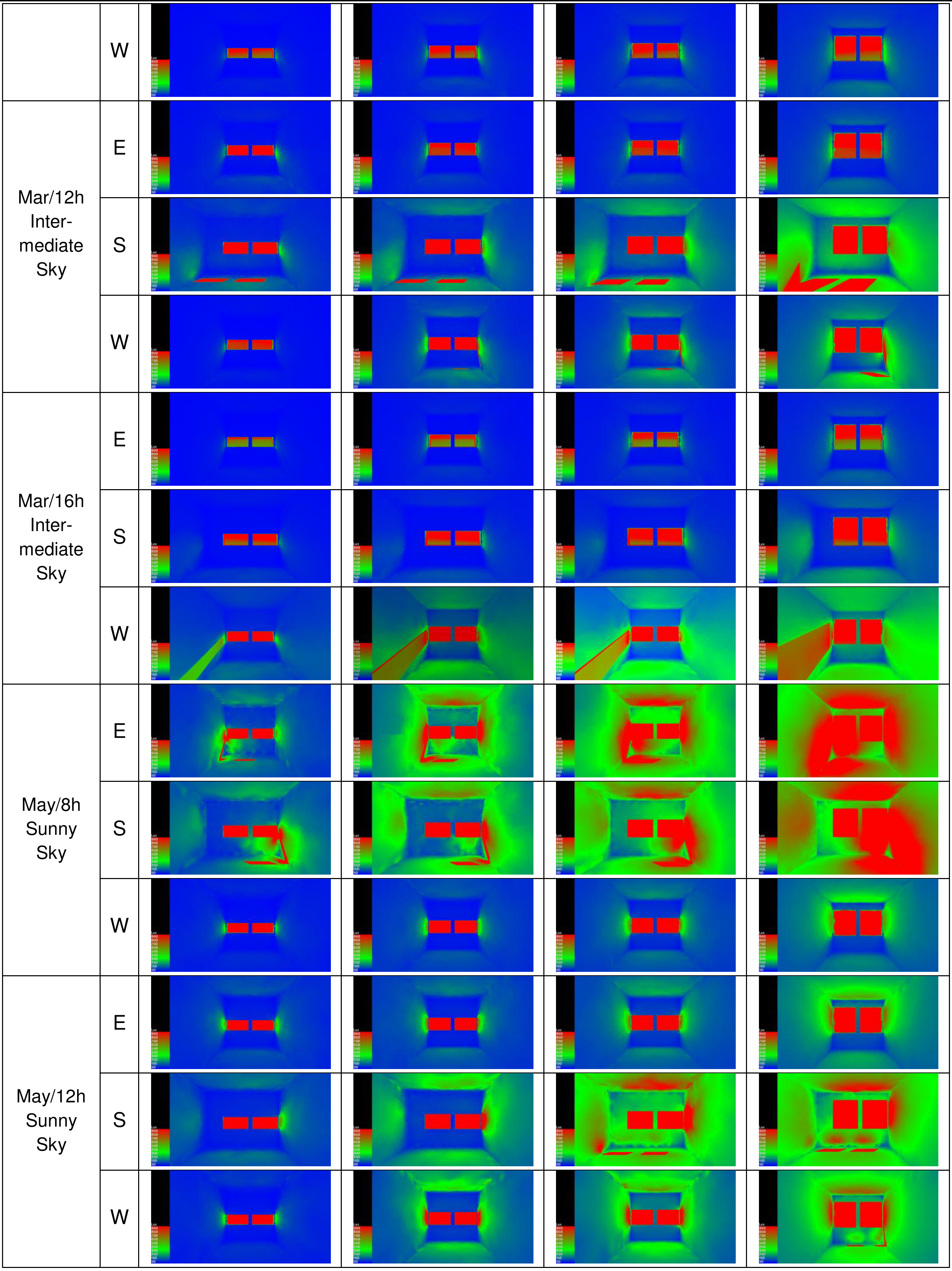


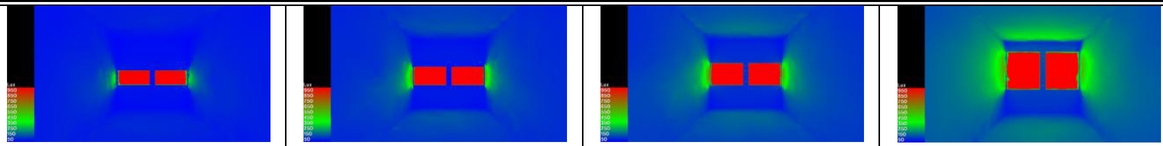
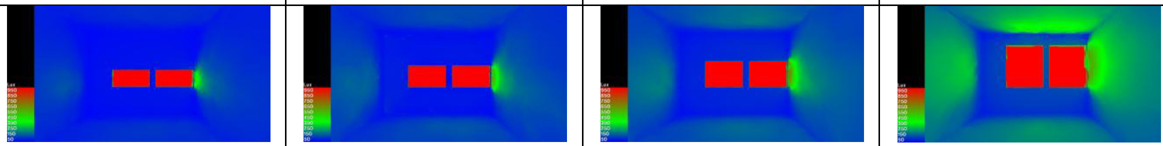
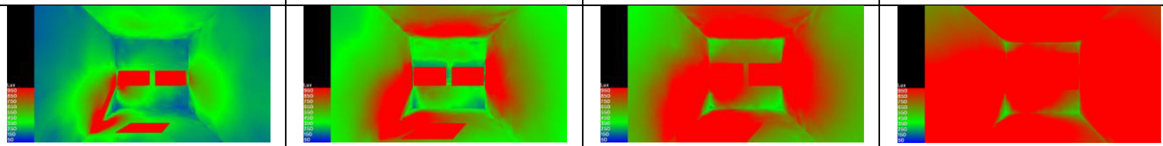
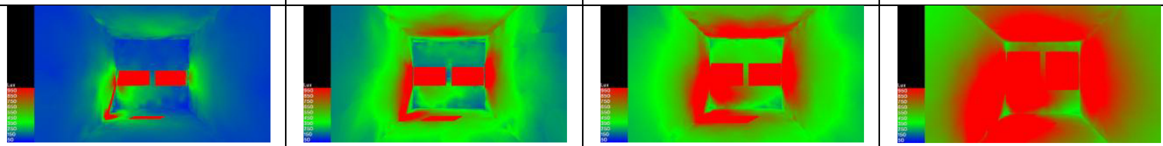
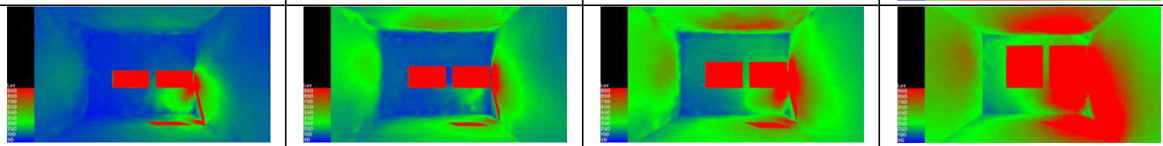
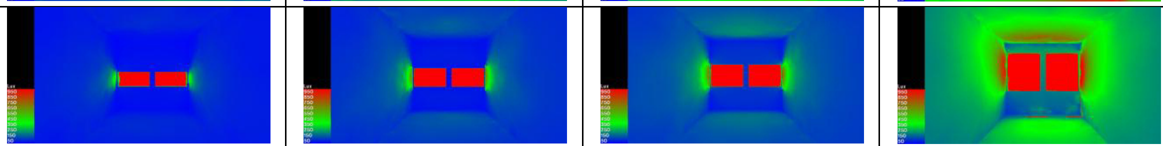
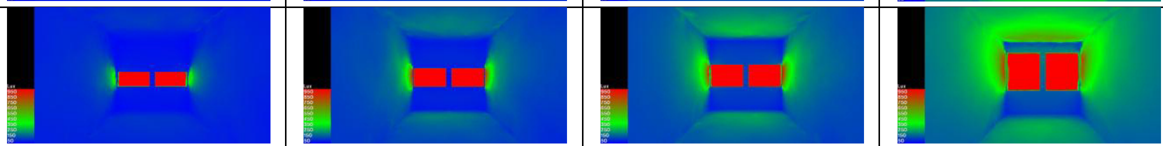
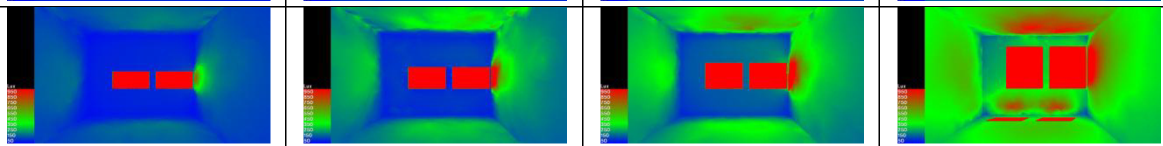
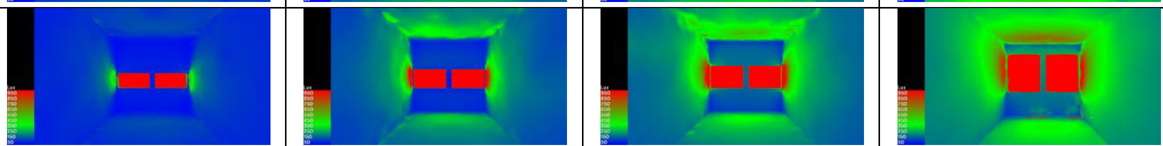
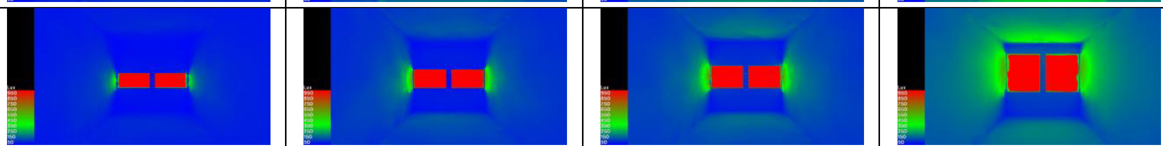
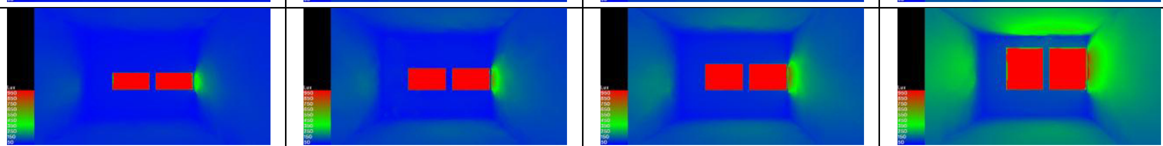
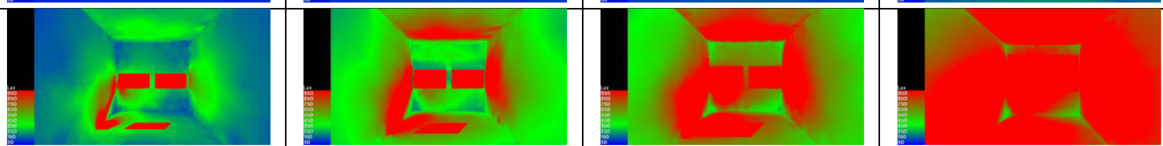
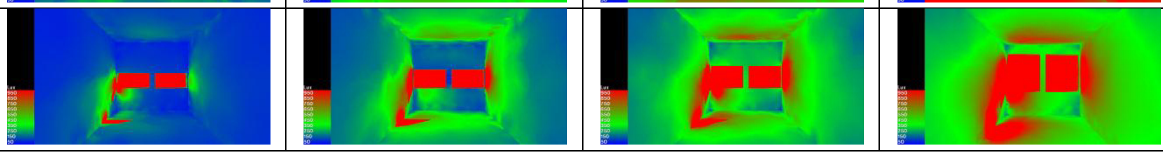


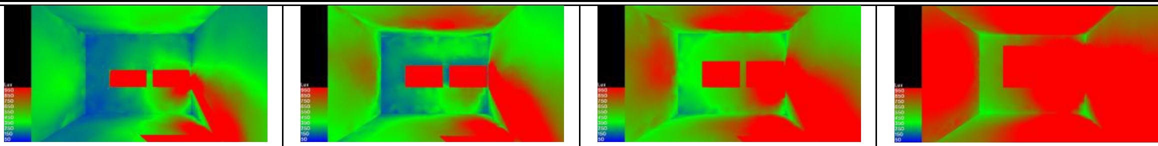
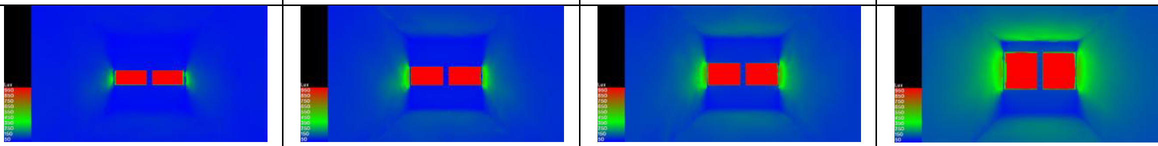
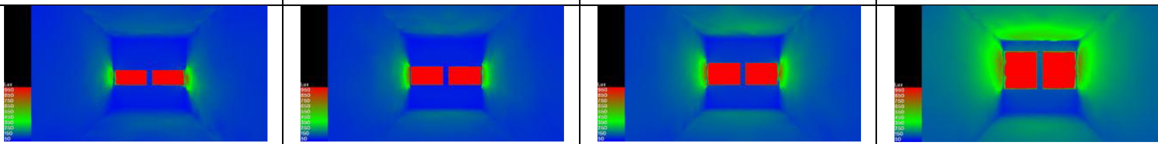
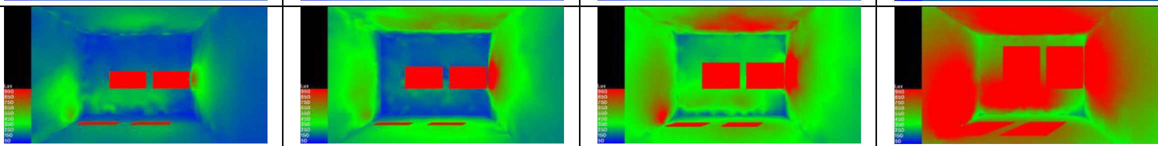
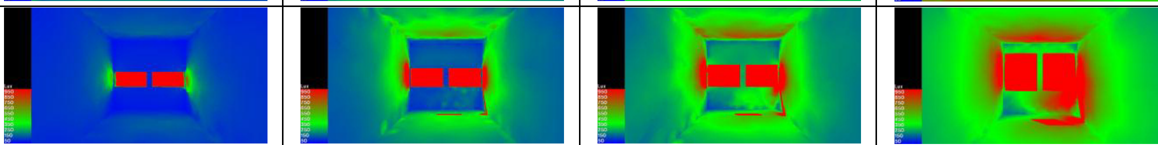
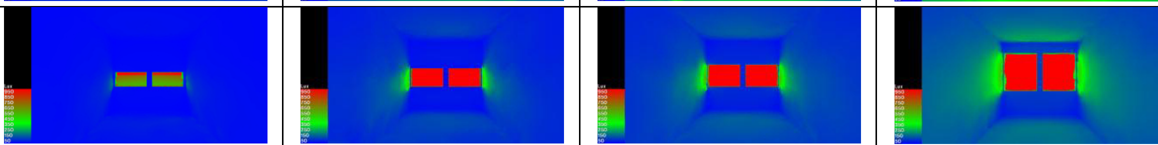
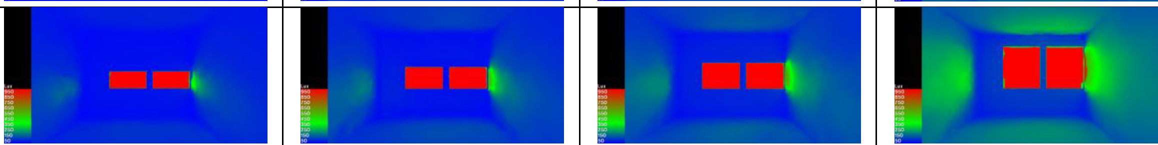
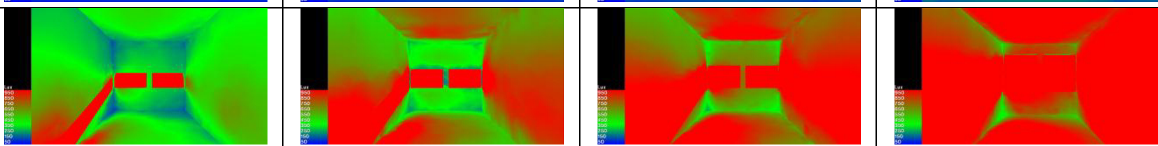
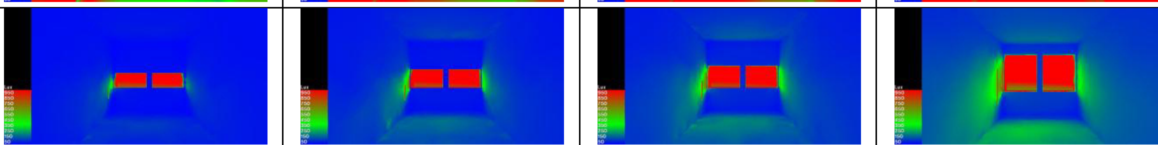
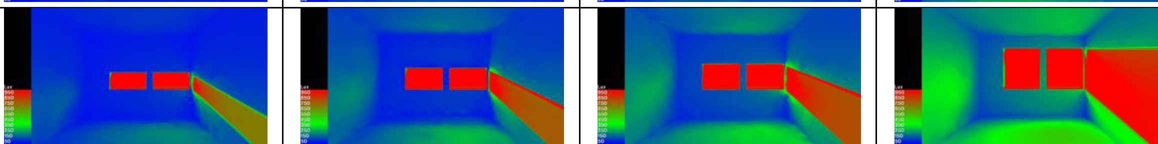
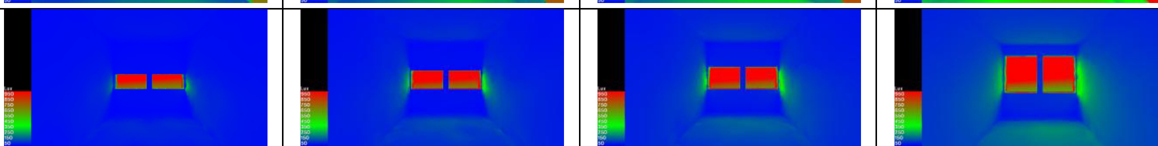
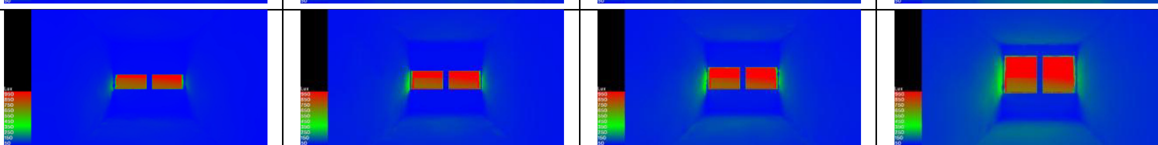
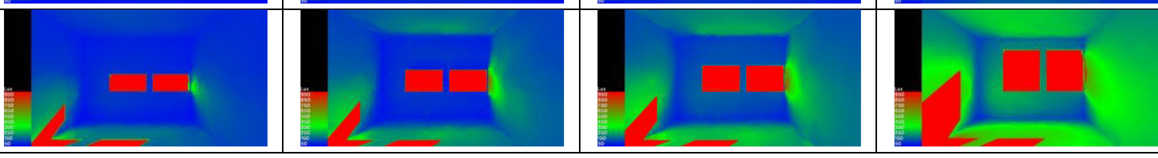
	S
	W
Sept/12h Sunny Sky	E
	S
	W
Sept/16h Sunny Sky	E
	S
	W
Nov/8h Inter-mediate Sky	E
	S
	W
Nov/12h Inter-mediate Sky	E
	S

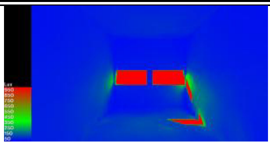
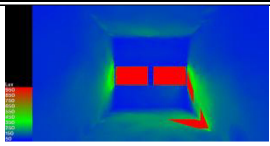
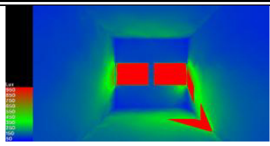
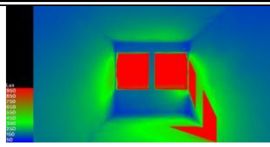
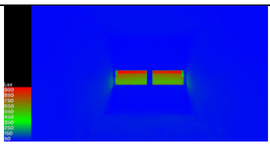
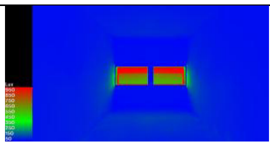
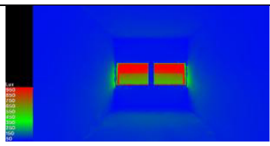
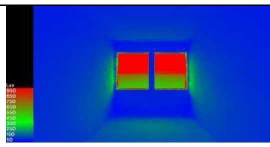
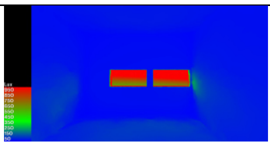
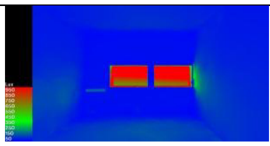
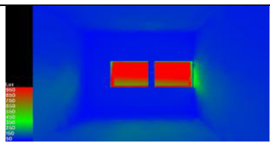
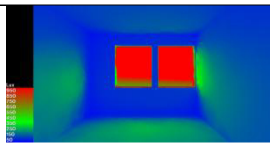
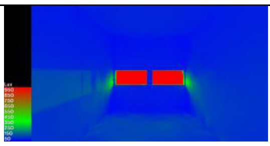
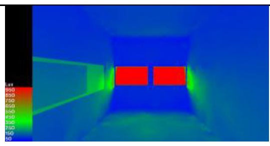
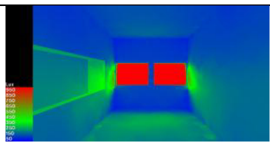
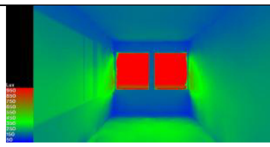
	W				
Nov/16h Inter-mediate Sky	E				
	S				
	W				

WWR for HORIZONTAL window geometry					
Date/time Sky condition		20%	25%	30%	Base Case 50%
Jan/8h Cloudy sky	E				
	S				
	W				
Jan/12h Cloudy sky	E				
	S				
	W				
Jan/16h Cloudy sky	E				
	S				
	W				
Mar/8h Inter-mediate Sky	E				
	S				

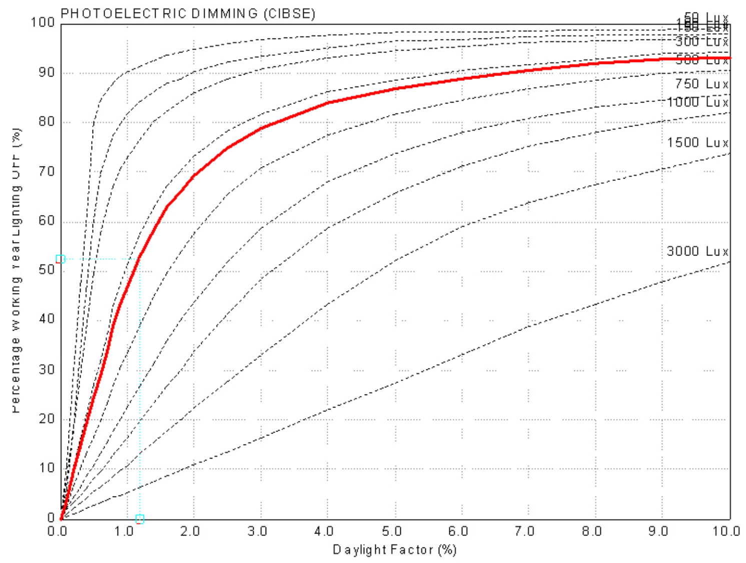
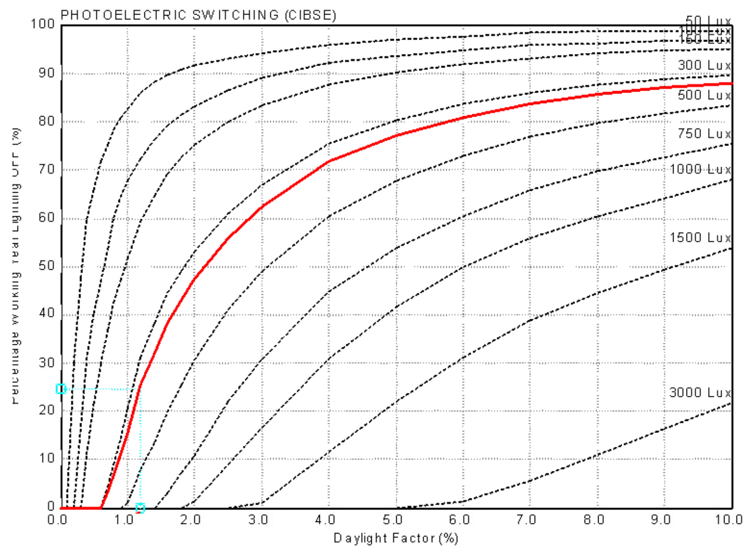
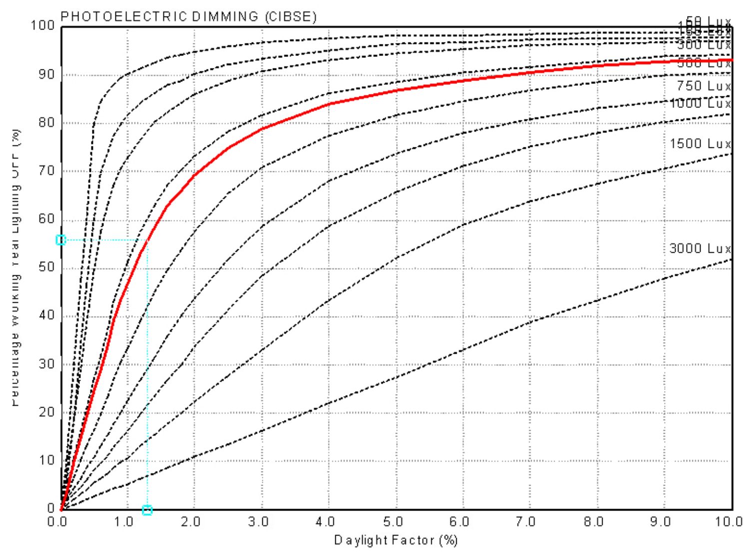

W
Mar/12h Inter-mediate Sky
E
S
W
Mar/16h Inter-mediate Sky
E
S
W
May/8h Sunny Sky
E
S
W
May/12h Sunny Sky
E
S
W

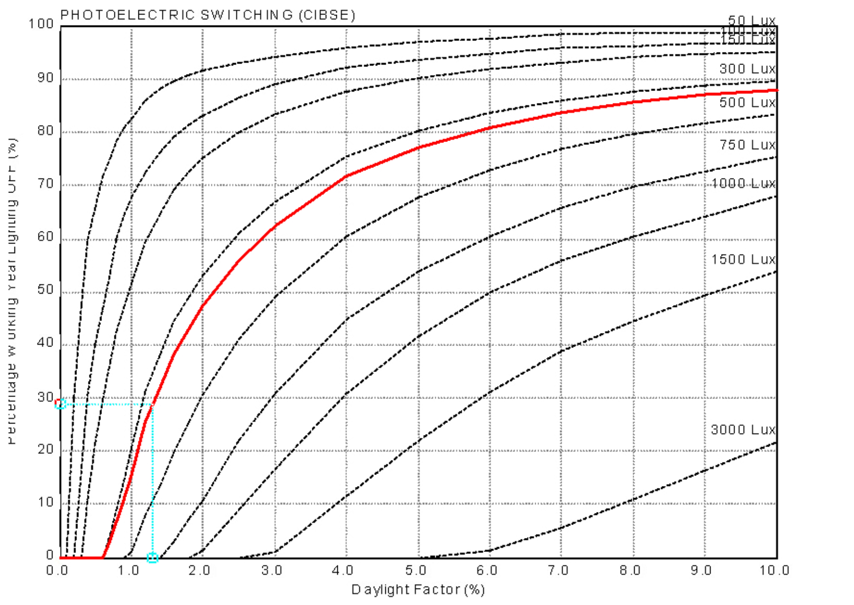
May/16h Sunny Sky	E	
	S	
	W	
Jul/8h Sunny Sky	E	
	S	
	W	
Jul/12h Sunny Sky	E	
	S	
	W	
Jul/16h Sunny Sky	E	
	S	
	W	
Sept/8h Sunny Sky	E	

	S	
	W	
Sept/12h Sunny Sky	E	
	S	
	W	
Sept/16h Sunny Sky	E	
	S	
	W	
Nov/8h Inter-mediate Sky	E	
	S	
	W	
Nov/12h Inter-mediate Sky	E	
	S	

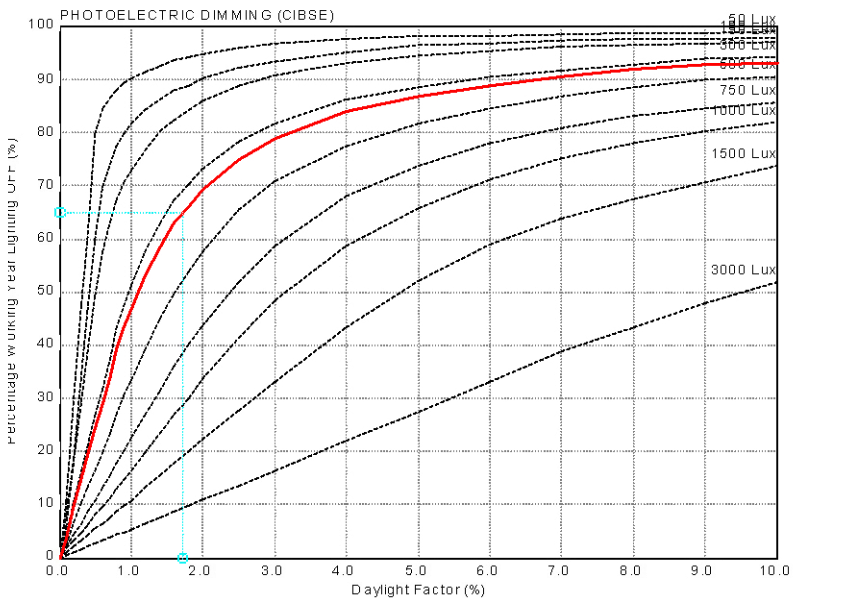
	W				
Nov/16h Inter-mediate Sky	E				
	S				
	W				

APPENDIX C
Photoelectrics; on/off and dimming mode

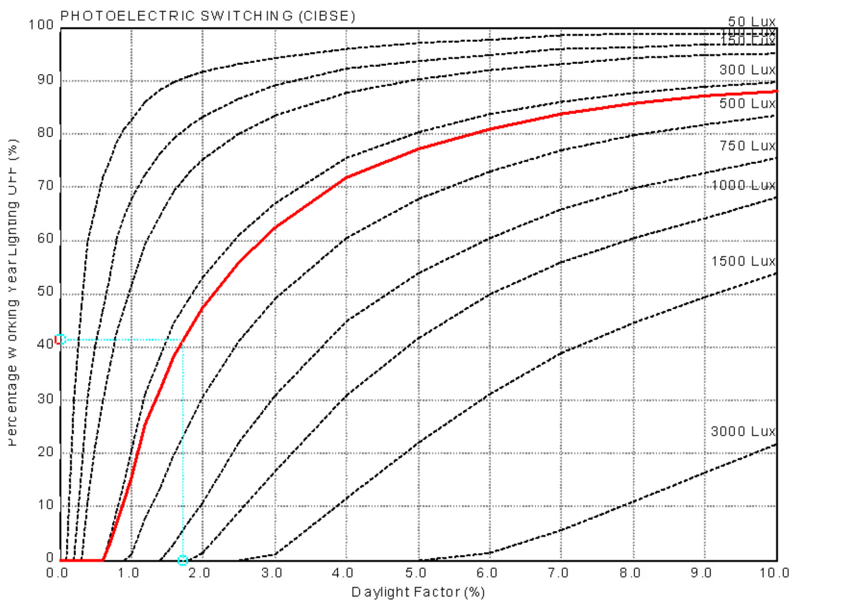
	**20% WWR** East orient. min 350 lx Dimming DF 1.19 Light. off 52%
	**20% WWR** East orient. min 350 lx On/Off DF 1.19 Light. off 24%
	**20% WWR** West orient. min 350 lx Dimming DF 1.30 Light. off 56%



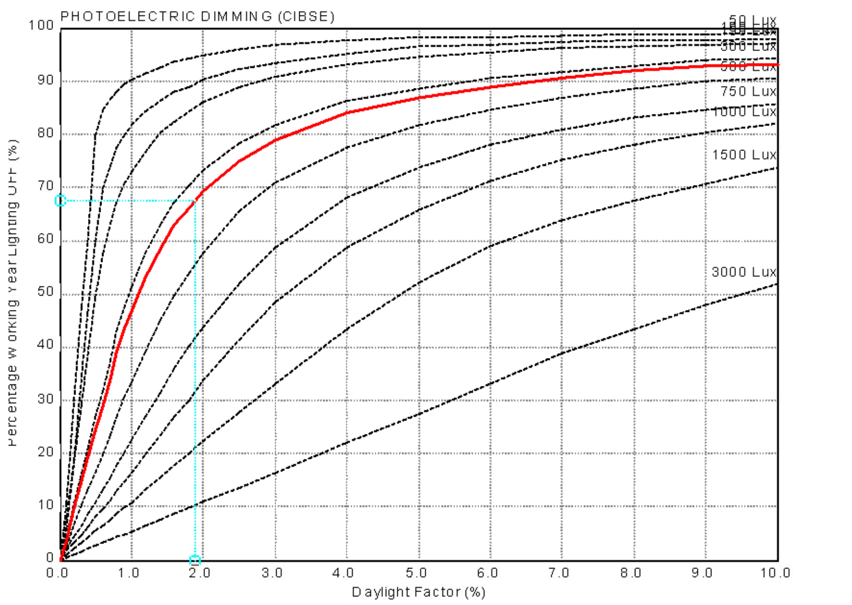
20% WWR
West orient.
min 350 lx
On/Off
DF 1.30
Light. off 29%



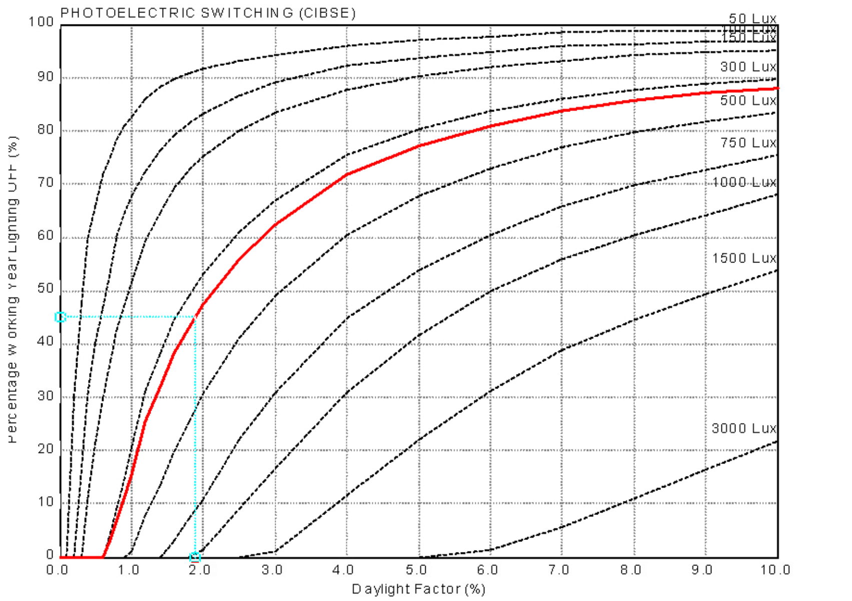
20% WWR
South orient.
min 350 lx
Dimming
DF 1.73
Light. off 65%



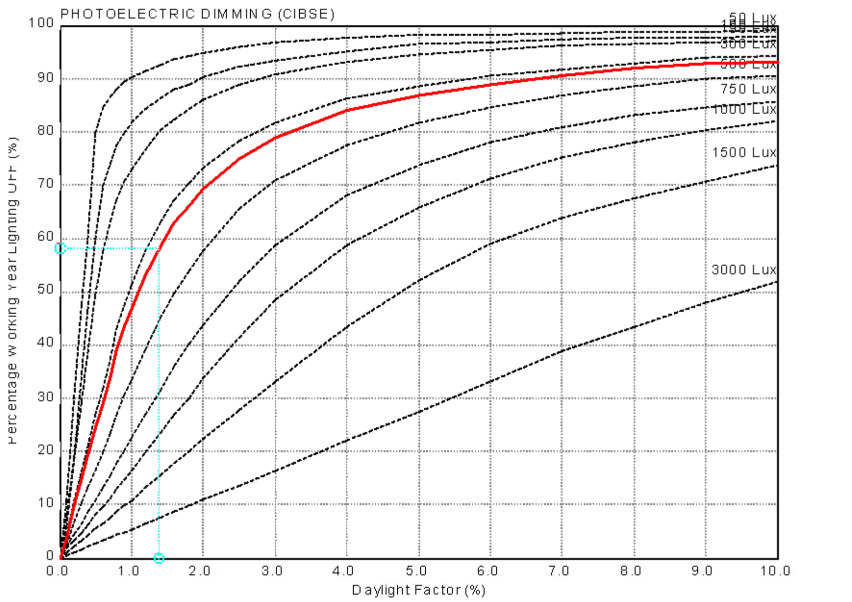
20% WWR
South orient.
min 350 lx
On/Off
DF 1.73
Light. off 41%



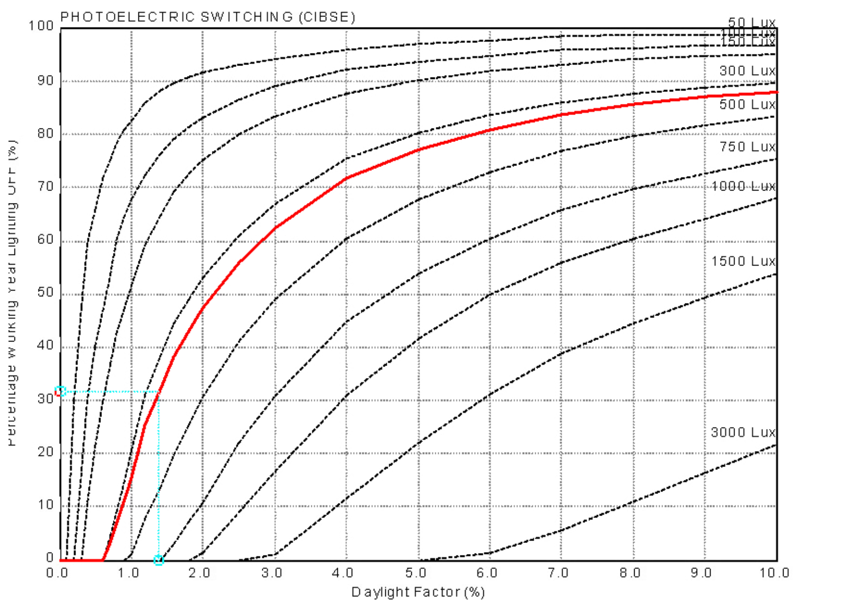
20% WWR
North orient.
min 350 lx
Dimming
DF 1.89
Light. off 68%



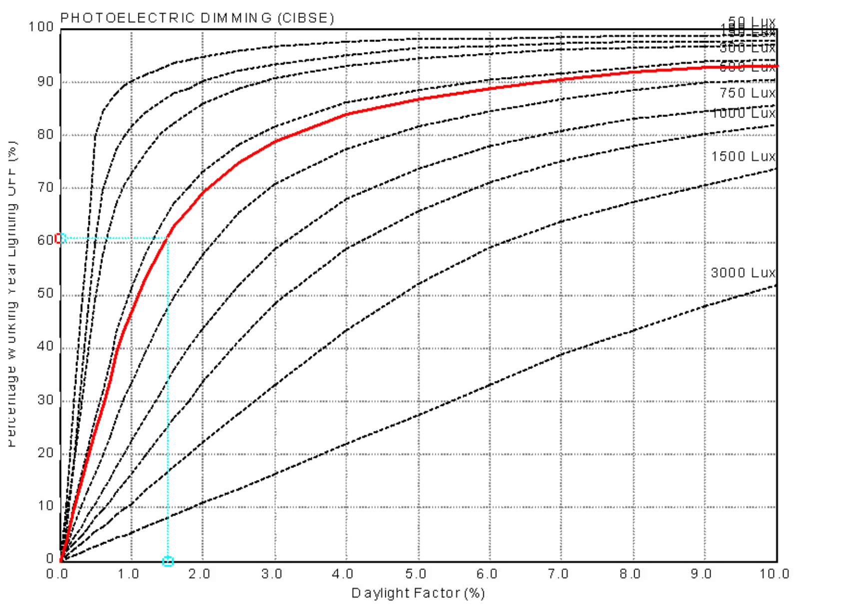
20% WWR
North orient.
min 350 lx
On/Off
DF 1.89
Light. off 45%



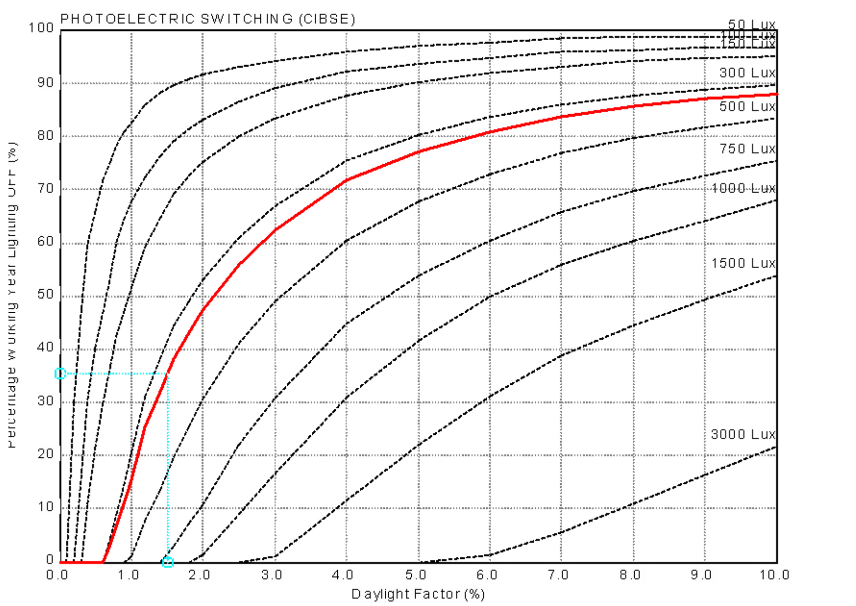
25% WWR
East orient.
min 350 lx
Dimming
DF 1.39
Light. off 58%



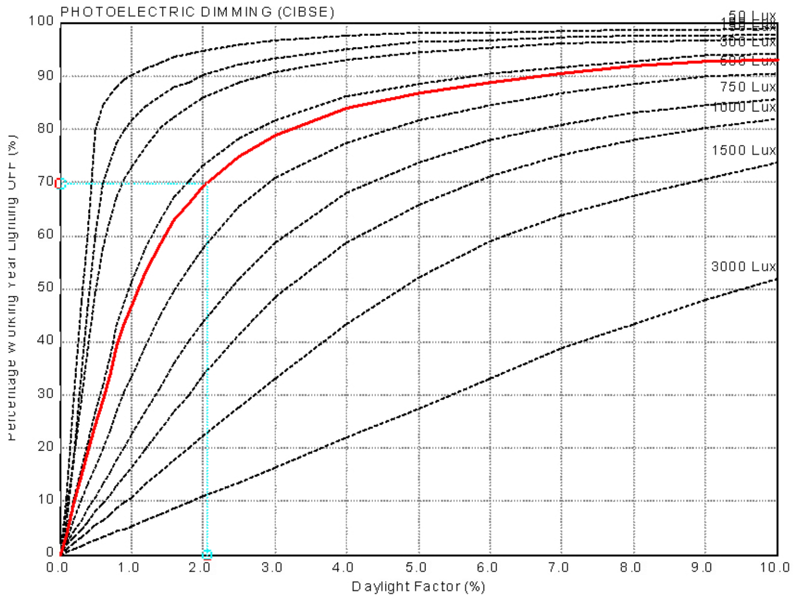
25% WWR
East orient.
min 350 lx
On/Off
DF 1.39
Light. off 32%



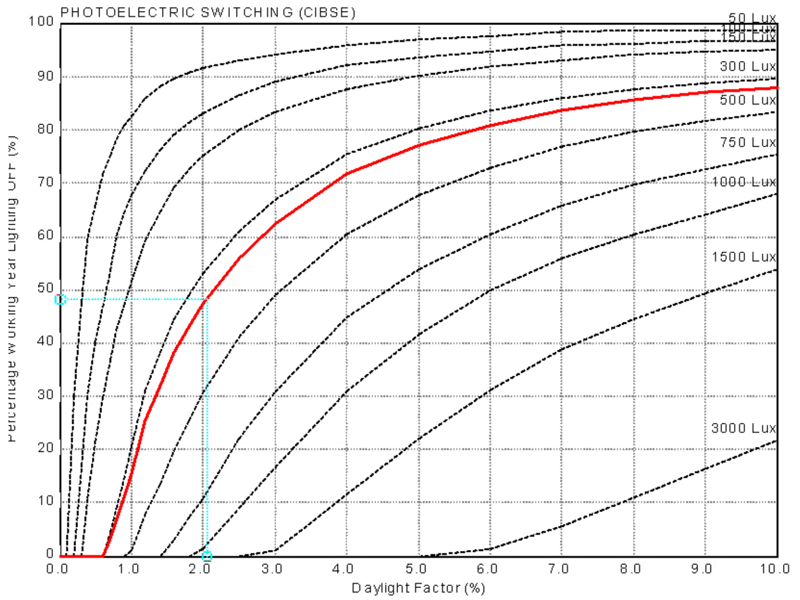
25% WWR
West orient.
min 350 lx
Dimming
DF 1.51
Light. off 61%



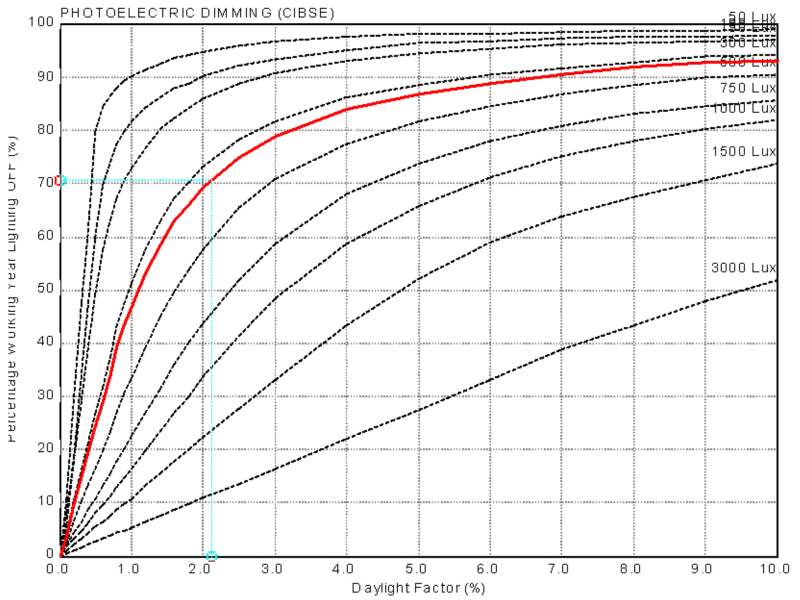
25% WWR
West orient.
min 350 lx
On/Off
DF 1.51
Light. off 35%



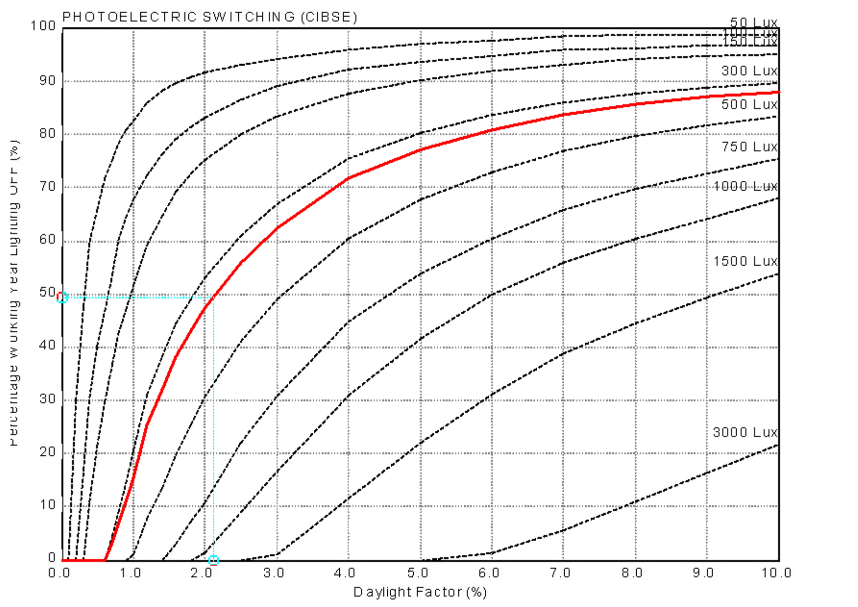
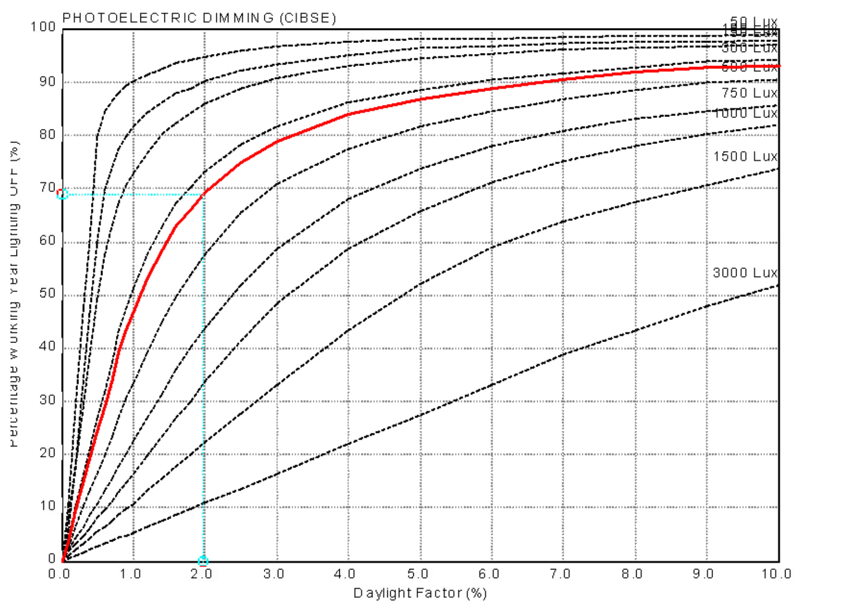
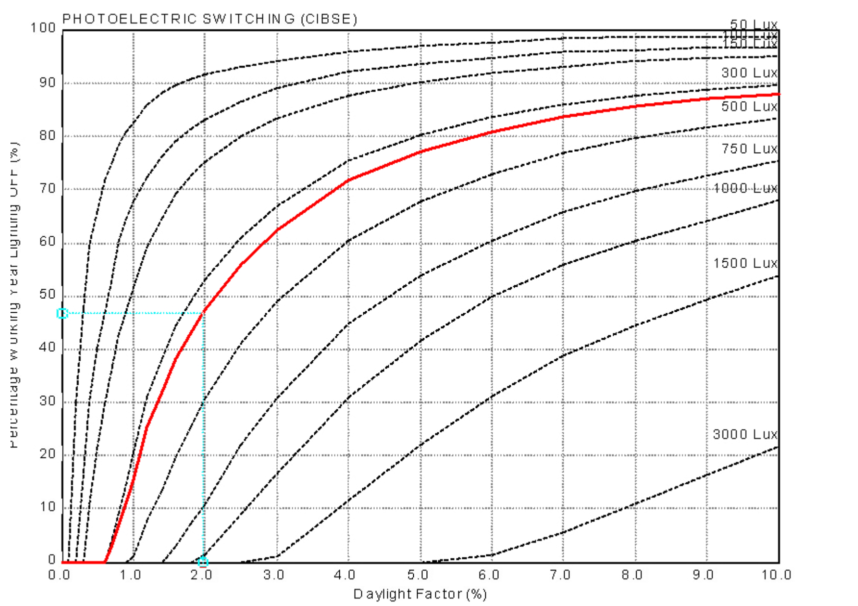
25% WWR
South orient.
min 350 lx
Dimming
DF 2.05
Light. off 70%

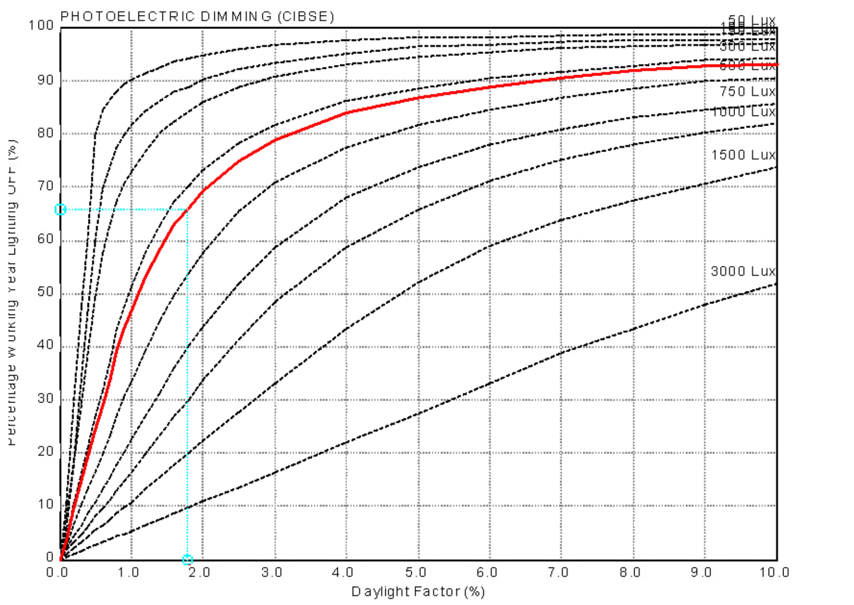


25% WWR
South orient.
min 350 lx
On/Off
DF 2.05
Light. off 49%

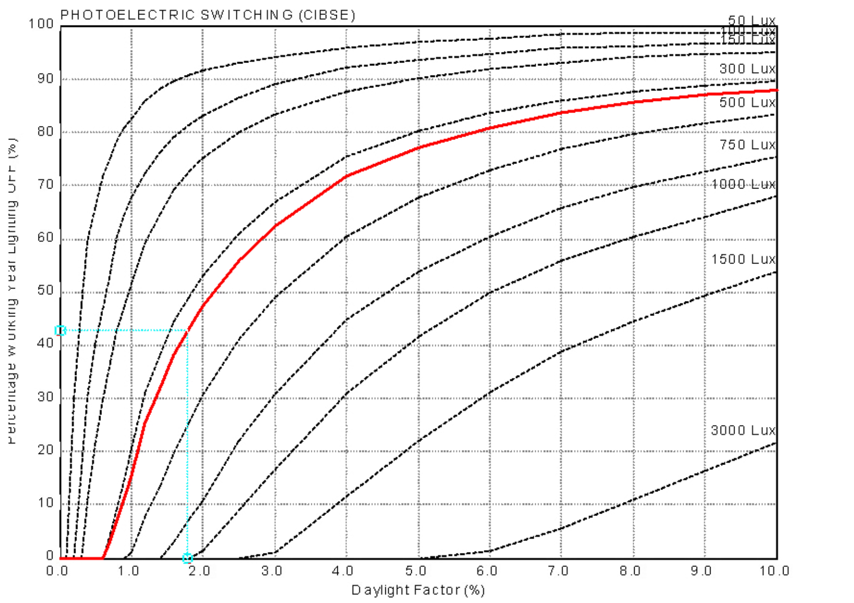


25% WWR
North orient.
min 350 lx
Dimming
DF 2.11
Light. off 70%

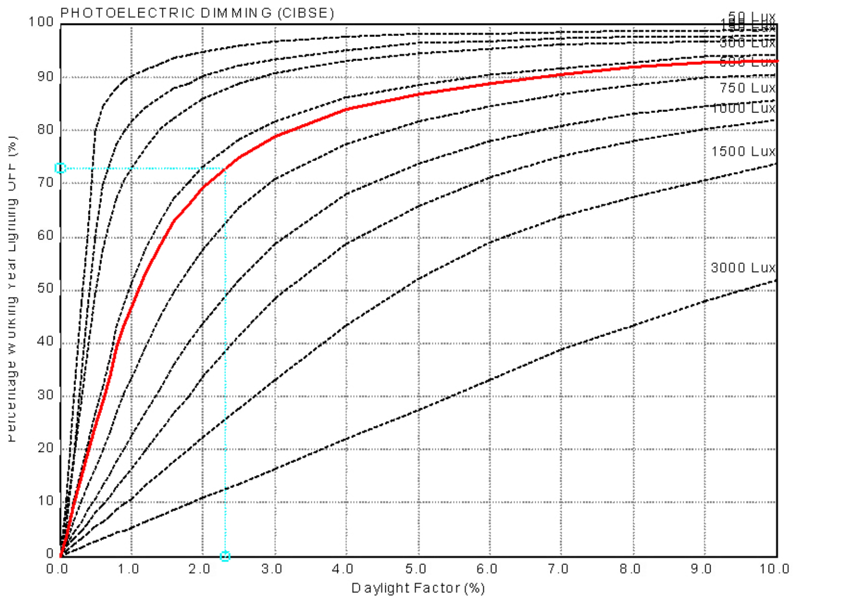
	**25% WWR** North orient. min 350 lx On/Off DF 2.11 Light. off 49%
	**30% WWR** East orient. min 350 lx Dimming DF 1.97 Light. off 70%
	**30% WWR** East orient. min 350 lx On/Off DF 1.97 Light. off 47%



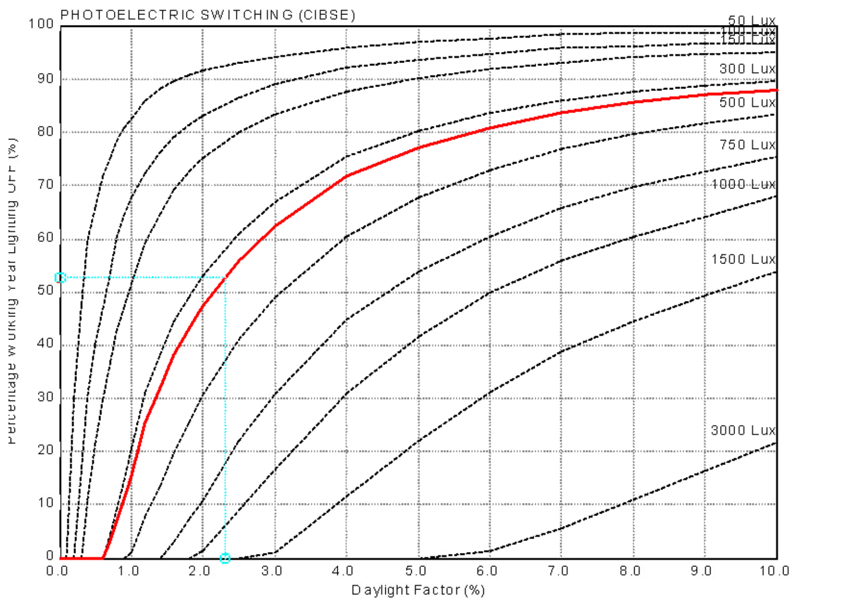
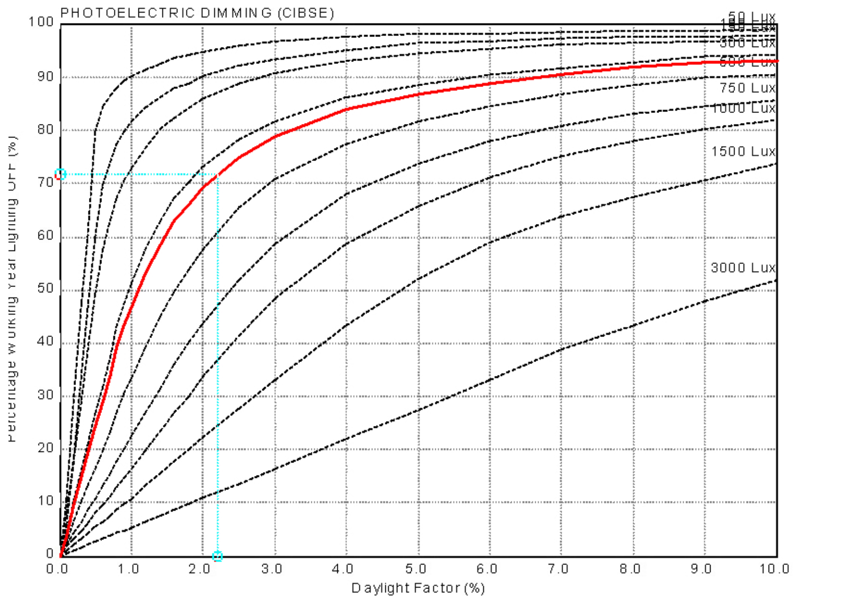
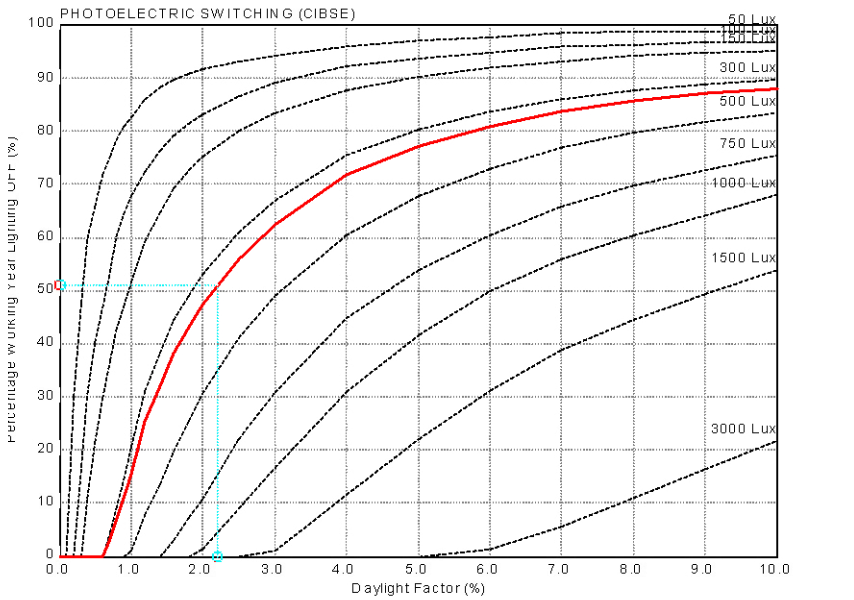
30% WWR
West orient.
min 350 lx
Dimming
DF 1.78
Light. off 66%

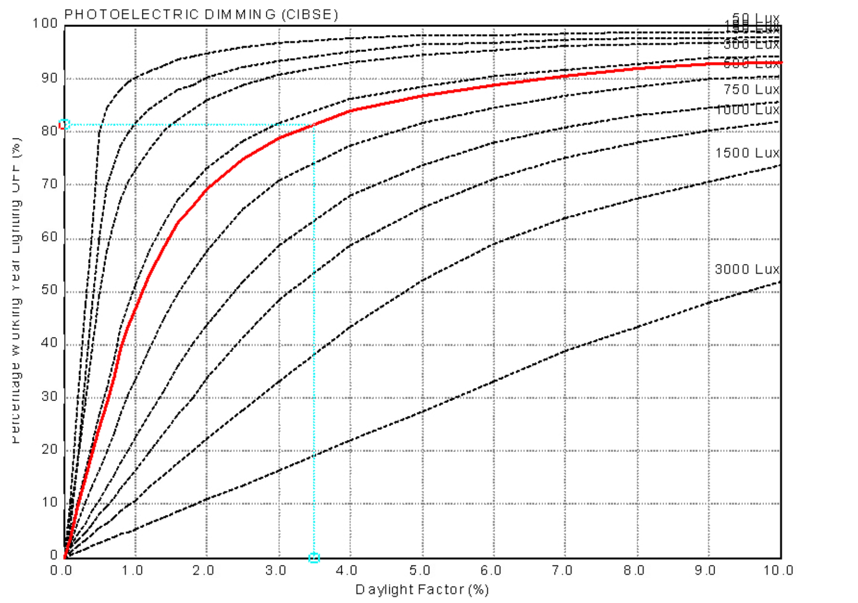
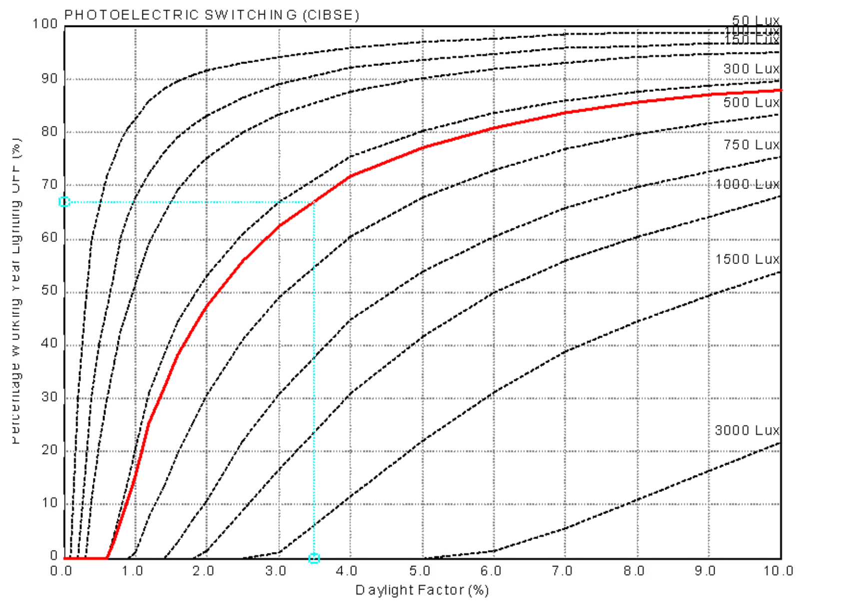
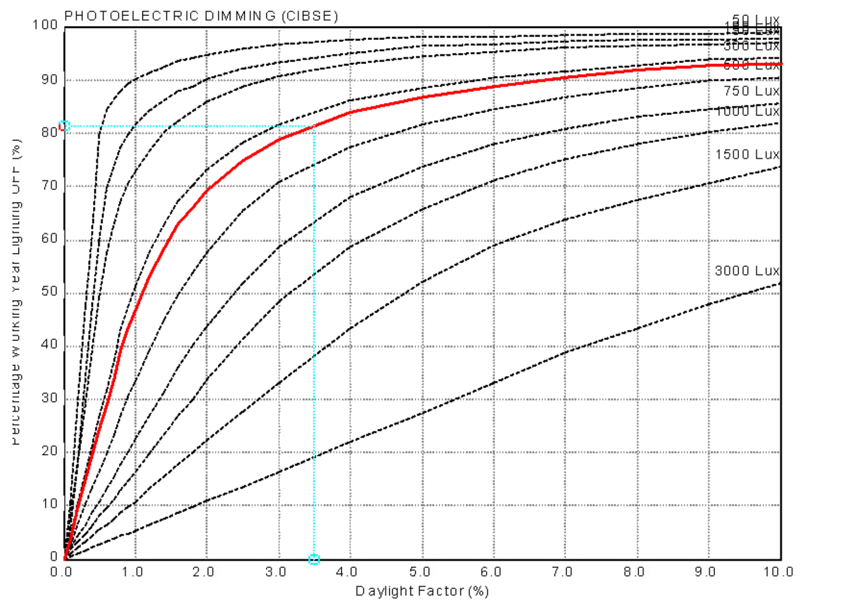


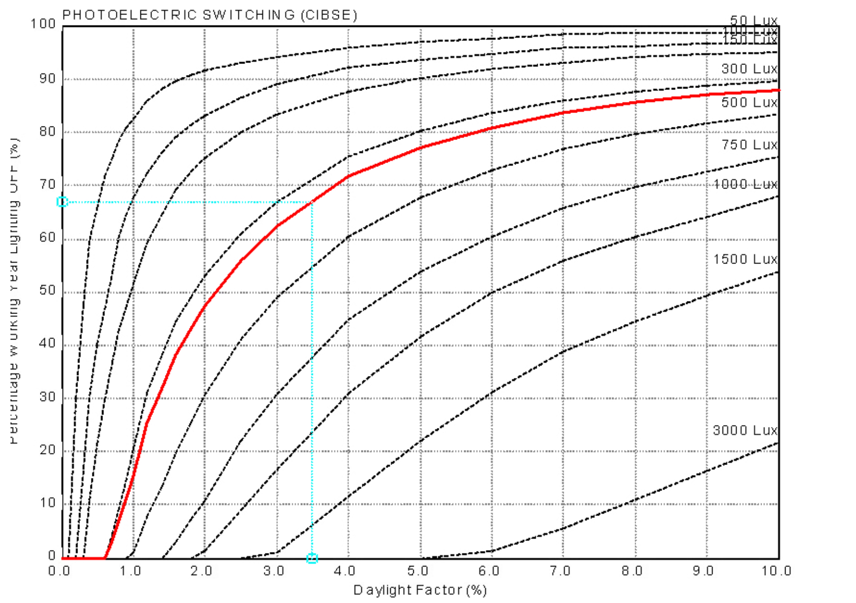
30% WWR
West orient.
min 350 lx
On/Off
DF 1.78
Light. off 42%



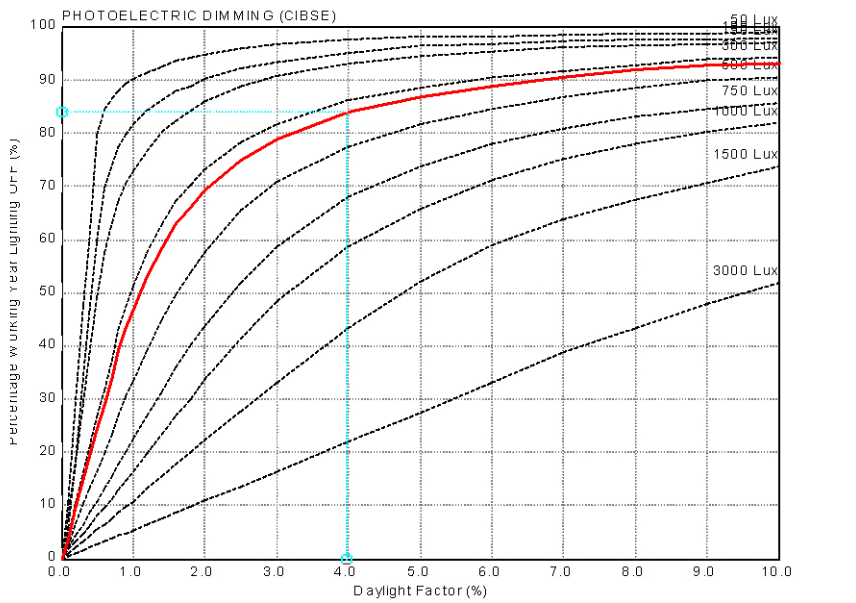
30% WWR
South orient.
min 350 lx
Dimming
DF 2.32
Light. off 72%

	**30% WWR** South orient. min 350 lx On/Off DF 2.32 Light. off 52%
	**30% WWR** North orient. min 350 lx Dimming DF 2.21 Light. off 70%
	**30% WWR** North orient. min 350 lx On/Off DF 2.21 Light. off 51%

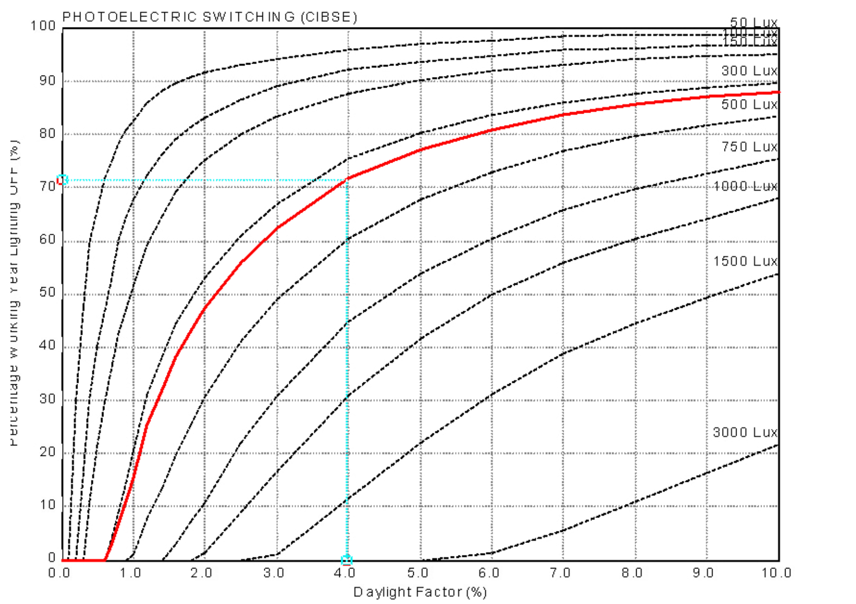
	**50% WWR** East orient. min 350 lx Dimming DF 3.49 Light. off 82%
	**50% WWR** East orient. min 350 lx On/Off DF 3.49 Light. off 68%
	**50% WWR** West orient. min 350 lx Dimming DF 3.49 Light. off 82%



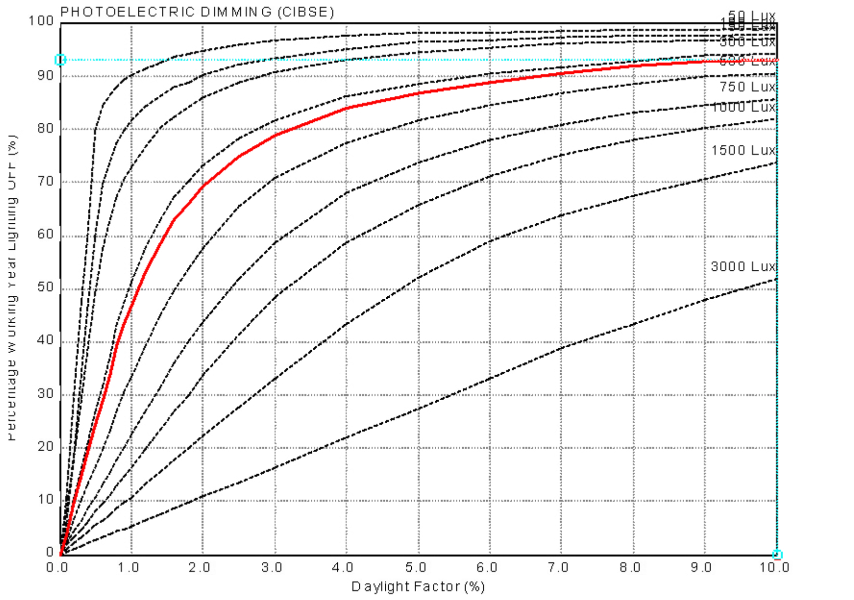
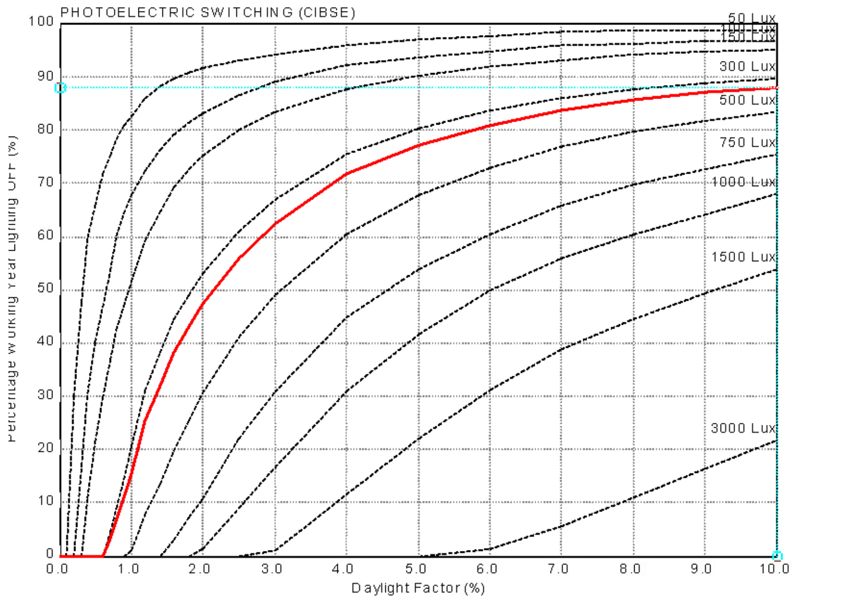
50% WWR
West orient.
min 350 lx
On/Off
DF 3.49
Light. off 67%



50% WWR
South orient.
min 350 lx
Dimming
DF 3.98
Light. off 84%



50% WWR
South orient.
min 350 lx
On/Off
DF 3.98
Light. off 70%

	**80% WWR** North orient. min 350 lx Dimming DF 16.85 Light. off 93%
	**80% WWR** North orient. min 350 lx On/Off DF 16.85 Light. off 88%

APPENDIX D
Total monthly solar exposure analysis

EAST 50%; Objects: 2 (Exposed Area: 4.480 m²)								
	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	[Wh/m²]	SHADE	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]
Jan	46932	74%	3336	14.947	697	3.121	1727	7.736
Feb	54871	61%	5432	24.334	1259	5.638	2811	12.595
Mar	102153	59%	13951	62.5	3324	14.892	7221	32.35
Apr	99701	54%	21382	95.793	5296	23.728	11067	49.581
May	126375	55%	32003	143.373	8185	36.668	16564	74.208
Jun	129642	56%	33107	148.321	8509	38.118	17136	76.77
Jul	161033	57%	38043	170.431	9775	43.791	19691	88.214
Aug	143884	56%	31559	141.383	7944	35.587	16335	73.179
Sep	110251	57%	18001	80.645	4407	19.742	9317	41.741
Oct	92840	67%	9438	42.28	2193	9.826	4885	21.884
Nov	61830	66%	4956	22.203	1034	4.63	2565	11.492
Dec	29655	78%	1141	5.113	142	0.635	591	2.646
TOTALS	**1159167**	**62%**	**212349**	**951.324**	**52763**	**236.378**	**109910**	**492.396**
EAST 20%; Objects: 2 (Exposed Area: 1.767 m²)								
	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	[Wh/m²]	SHADE	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]
Jan	46932	74%	3443	6.085	637	1.125	2386	4.216
Feb	54871	61%	5355	9.463	1031	1.821	3710	6.555
Mar	102153	59%	13975	24.697	2799	4.947	9682	17.109
Apr	99701	54%	21209	37.481	4439	7.845	14693	25.966
May	126375	55%	31479	55.63	6791	12	21808	38.539
Jun	129642	56%	32979	58.281	7161	12.656	22848	40.376
Jul	161033	57%	37452	66.186	8121	14.351	25946	45.852
Aug	143884	56%	31173	55.088	6625	11.707	21596	38.164
Sep	110251	57%	17841	31.528	3700	6.538	12360	21.842
Oct	92840	67%	9623	17.006	1925	3.402	6667	11.781
Nov	61830	66%	4922	8.699	901	1.592	3410	6.026
Dec	29655	78%	1286	2.272	197	0.348	891	1.574
TOTALS	**1159167**		**210738**	**372.415**	**44325**	**78.332**	**145995**	**258.002**
EAST 25%; Objects: 2 (Exposed Area: 2.205 m²)								
	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	[Wh/m²]	SHADE	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]
Jan	46932	74%	3443	7.593	637	1.404	2386	5.26
Feb	54871	61%	5355	11.807	1031	2.272	3710	8.179
Mar	102153	59%	13975	30.815	2799	6.172	9682	21.348
Apr	99701	54%	21209	46.766	4439	9.789	14693	32.399
May	126375	55%	31479	69.412	6791	14.973	21808	48.087
Jun	129642	56%	32979	72.72	7161	15.791	22848	50.379
Jul	161033	57%	37452	82.582	8121	17.906	25946	57.211
Aug	143884	56%	31173	68.735	6625	14.607	21596	47.619
Sep	110251	57%	17841	39.339	3700	8.158	12360	27.253
Oct	92840	67%	9623	21.219	1925	4.245	6667	14.7
Nov	61830	66%	4922	10.853	901	1.986	3410	7.519
Dec	29655	78%	1286	2.835	197	0.434	891	1.964
TOTALS	**1159167**		**210738**	**464.676**	**44325**	**97.738**	**145995**	**321.918**
EAST 30%; Objects: 2 (Exposed Area: 2.619 m²)								
	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	[Wh/m²]	SHADE	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]
Jan	46932	74%	3443	9.267	637	1.713	2386	6.42
Feb	54871	61%	5355	14.41	1031	2.773	3710	9.983
Mar	102153	59%	13975	37.61	2799	7.533	9682	26.055
Apr	99701	54%	21209	57.078	4439	11.947	14693	39.543
May	126375	55%	31479	84.717	6791	18.275	21808	58.69
Jun	129642	56%	32979	88.754	7161	19.273	22848	61.487
Jul	161033	57%	37452	100.791	8121	21.854	25946	69.826
Aug	143884	56%	31173	83.892	6625	17.828	21596	58.118
Sep	110251	57%	17841	48.013	3700	9.957	12360	33.263
Oct	92840	67%	9623	25.898	1925	5.181	6667	17.941
Nov	61830	66%	4922	13.247	901	2.424	3410	9.177
Dec	29655	78%	1286	3.46	197	0.53	891	2.397
TOTALS	**1159167**		**210738**	**567.137**	**44325**	**119.289**	**145995**	**392.901**
SOUTH 50%; Objects: 2 (Exposed Area: 4.480 m²)								
	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	

MONTH	[Wh/m²]	SHADE	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]
Jan	46932	1%	33788	151.372	9007	40.35	17489	78.349
Feb	54871	5%	35839	160.56	9480	42.47	18550	83.104
Mar	102153	9%	55515	248.709	14524	65.068	28734	128.729
Apr	99701	17%	42962	192.47	10917	48.906	22237	99.62
May	126375	27%	39239	175.79	9563	42.842	20310	90.987
Jun	129642	33%	32454	145.395	7538	33.769	16798	75.255
Jul	161033	31%	42180	188.967	10038	44.971	21832	97.807
Aug	143884	23%	54206	242.844	13509	60.519	28057	125.693
Sep	110251	17%	55005	246.422	14248	63.831	28470	127.545
Oct	92840	4%	56573	253.446	14927	66.874	29282	131.181
Nov	61830	0%	45617	204.363	12166	54.504	23611	105.776
Dec	29655	0%	23346	104.588	6259	28.04	12083	54.134
TOTALS	**1159167**		**516724**	**2314.925**	**132175**	**592.145**	**267451**	**1198.182**

SOUTH 20%; Objects: 2 (Exposed Area: 1.176 m²)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	**[Wh/m²]**	**SHADE**	**[Wh/m²]**	**TOT.[kWh]**	**[Wh/m²]**	**TOT.[kWh]**	**[Wh/m²]**	**TOT.[kWh]**
Jan	46932	1%	33627	59.426	7574	13.385	23296	41.169
Feb	54871	5%	35638	62.979	7964	14.074	24689	43.631
Mar	102153	8%	55510	98.097	12224	21.602	38456	67.96
Apr	99701	17%	43024	76.033	9249	16.345	29806	52.674
May	126375	27%	39513	69.827	8138	14.381	27374	48.375
Jun	129642	33%	32744	57.866	6451	11.4	22685	40.088
Jul	161033	31%	42895	75.805	8635	15.259	29717	52.516
Aug	143884	23%	54417	96.165	11463	20.257	37699	66.621
Sep	110251	17%	54934	97.079	12034	21.267	38057	67.255
Oct	92840	3%	56522	99.885	12549	22.176	39157	69.198
Nov	61830	0%	45362	80.164	10223	18.066	31426	55.536
Dec	29655	0%	23191	40.983	5253	9.284	16066	28.392
TOTALS	**1159167**		**517377**	**914.309**	**111757**	**197.497**	**358429**	**633.415**

SOUTH 25%; Objects: 2 (Exposed Area: 2.205 m²)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	**[Wh/m²]**	**SHADE**	**[Wh/m²]**	**TOT.[kWh]**	**[Wh/m²]**	**TOT.[kWh]**	**[Wh/m²]**	**TOT.[kWh]**
Jan	46932	1%	33627	74.149	7574	16.701	23296	51.369
Feb	54871	5%	35638	78.581	7964	17.56	24689	54.439
Mar	102153	8%	55510	122.4	12224	26.954	38456	84.796
Apr	99701	17%	43024	94.869	9249	20.394	29806	65.723
May	126375	27%	39513	87.126	8138	17.944	27374	60.359
Jun	129642	33%	32744	72.201	6451	14.225	22685	50.02
Jul	161033	31%	42895	94.584	8635	19.04	29717	65.526
Aug	143884	23%	54417	119.989	11463	25.275	37699	83.126
Sep	110251	17%	54934	121.129	12034	26.536	38057	83.916
Oct	92840	3%	56522	124.63	12549	27.67	39157	86.341
Nov	61830	0%	45362	100.023	10223	22.541	31426	69.294
Dec	29655	0%	23191	51.136	5253	11.584	16066	35.426
TOTALS	**1159167**		**517377**	**1140.817**	**111757**	**246.424**	**358429**	**790.335**

SOUTH 30%; Objects: 2 (Exposed Area: 2.691 m²)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	**[Wh/m²]**	**SHADE**	**[Wh/m²]**	**TOT.[kWh]**	**[Wh/m²]**	**TOT.[kWh]**	**[Wh/m²]**	**TOT.[kWh]**
Jan	46932	1%	33627	90.498	7574	20.384	23296	62.695
Feb	54871	5%	35638	95.908	7964	21.432	24689	66.443
Mar	102153	8%	55510	149.389	12224	32.897	38456	103.494
Apr	99701	17%	43024	115.787	9249	24.89	29806	80.215
May	126375	27%	39513	106.337	8138	21.901	27374	73.668
Jun	129642	33%	32744	88.122	6451	17.361	22685	61.049
Jul	161033	31%	42895	115.44	8635	23.238	29717	79.975
Aug	143884	23%	54417	146.446	11463	30.848	37699	101.455
Sep	110251	17%	54934	147.838	12034	32.387	38057	102.419
Oct	92840	3%	56522	152.111	12549	33.771	39157	105.379
Nov	61830	0%	45362	122.078	10223	27.512	31426	84.573
Dec	29655	0%	23191	62.412	5253	14.138	16066	43.238
TOTALS	**1159167**		**517377**	**1392.366**	**111757**	**300.76**	**358429**	**964.603**

WEST 50%; Objects: 2 (Exposed Area: 4.480 m²)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	**[Wh/m²]**	**SHADE**	**[Wh/m²]**	**TOT.[kWh]**	**[Wh/m²]**	**TOT.[kWh]**	**[Wh/m²]**	**TOT.[kWh]**
Jan	46932	26%	15587	69.832	3965	17.764	8068	36.144
Feb	54871	39%	19264	86.301	4977	22.295	9971	44.669
Mar	102153	41%	34133	152.917	8811	39.474	17667	79.148
Apr	99701	46%	25913	116.091	6558	29.381	13412	60.087
May	126375	45%	29274	131.149	7298	32.696	15152	67.882
Jun	129642	44%	29681	132.971	7494	33.572	15363	68.824
Jul	161033	43%	40655	182.134	10384	46.52	21043	94.271

Aug	143884	44%	36226	162.295	9108	40.806	18750	84.002
Sep	110251	43%	33914	151.934	8741	39.161	17553	78.64
Oct	92840	33%	33142	148.476	8506	38.105	17154	76.85
Nov	61830	34%	20966	93.929	5231	23.437	10852	48.617
Dec	29655	22%	10622	47.588	2624	11.755	5498	24.631
TOTALS	**1159167**		**329379**	**1475.617**	**83698**	**374.967**	**170483**	**763.765**

WEST 20%; Objects: 2 (Exposed Area: 1.176 m^2)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	**[Wh/m^2]**	**SHADE**	**[Wh/m^2]**	**TOT.[kWh]**	**[Wh/m^2]**	**TOT.[kWh]**	**[Wh/m^2]**	**TOT.[kWh]**
Jan	46932	26%	15915	28.124	3425	6.052	11025	19.484
Feb	54871	39%	19528	34.509	4269	7.543	13528	23.907
Mar	102153	41%	34411	60.81	7515	13.28	23839	42.128
Apr	99701	46%	26056	46.046	5627	9.944	18051	31.9
May	126375	45%	29382	51.925	6194	10.947	20356	35.972
Jun	129642	44%	29579	52.272	6305	11.142	20492	36.213
Jul	161033	43%	40857	72.203	8793	15.54	28305	50.021
Aug	143884	44%	36425	64.369	7795	13.776	25234	44.594
Sep	110251	43%	34175	60.395	7437	13.143	23676	41.84
Oct	92840	33%	33611	59.398	7278	12.861	23285	41.15
Nov	61830	34%	21415	37.845	4614	8.153	14836	26.218
Dec	29655	22%	10800	19.085	2315	4.091	7482	13.222
TOTALS	**1159167**		**332154**	**586.983**	**71566**	**126.472**	**230110**	**406.65**

WEST 25%; Objects: 2 (Exposed Area: 2.205 m^2)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	**[Wh/m^2]**	**SHADE**	**[Wh/m^2]**	**TOT.[kWh]**	**[Wh/m^2]**	**TOT.[kWh]**	**[Wh/m^2]**	**TOT.[kWh]**
Jan	46932	26%	15915	35.092	3425	7.551	11025	24.311
Feb	54871	39%	19528	43.059	4269	9.412	13528	29.83
Mar	102153	41%	34411	75.875	7515	16.57	23839	52.565
Apr	99701	46%	26056	57.453	5627	12.408	18051	39.803
May	126375	45%	29382	64.788	6194	13.659	20356	44.884
Jun	129642	44%	29579	65.222	6305	13.903	20492	45.184
Jul	161033	43%	40857	90.09	8793	19.39	28305	62.413
Aug	143884	44%	36425	80.316	7795	17.188	25234	55.641
Sep	110251	43%	34175	75.357	7437	16.399	23676	52.206
Oct	92840	33%	33611	74.113	7278	16.047	23285	51.344
Nov	61830	34%	21415	47.22	4614	10.173	14836	32.713
Dec	29655	22%	10800	23.814	2315	5.104	7482	16.498
TOTALS	**1159167**		**332154**	**732.4**	**71566**	**157.804**	**230110**	**507.392**

WEST 30%; Objects: 2 (Exposed Area: 2.691 m^2)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	**[Wh/m^2]**	**SHADE**	**[Wh/m^2]**	**TOT.[kWh]**	**[Wh/m^2]**	**TOT.[kWh]**	**[Wh/m^2]**	**TOT.[kWh]**
Jan	46932	26%	15915	42.83	3425	9.217	11025	29.671
Feb	54871	39%	19528	52.553	4269	11.488	13528	36.408
Mar	102153	41%	34411	92.606	7515	20.224	23839	64.155
Apr	99701	46%	26056	70.122	5627	15.144	18051	48.579
May	126375	45%	29382	79.074	6194	16.671	20356	54.781
Jun	129642	44%	29579	79.603	6305	16.968	20492	55.148
Jul	161033	43%	40857	109.955	8793	23.665	28305	76.175
Aug	143884	44%	36425	98.026	7795	20.978	25234	67.91
Sep	110251	43%	34175	91.973	7437	20.015	23676	63.717
Oct	92840	33%	33611	90.455	7278	19.585	23285	62.666
Nov	61830	34%	21415	57.632	4614	12.416	14836	39.927
Dec	29655	22%	10800	29.064	2315	6.23	7482	20.135
TOTALS	**1159167**		**332154**	**893.893**	**71566**	**192.599**	**230110**	**619.271**

NORTH ~90%; Objects: 2 (Exposed Area: 9.660 m^2)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	**[Wh/m^2]**	**SHADE**	**[Wh/m^2]**	**TOT.[kWh]**	**[Wh/m^2]**	**TOT.[kWh]**	**[Wh/m^2]**	**TOT.[kWh]**
Jan	46932	26%	15915	42.83	3425	9.217	11025	29.671
Feb	54871	39%	19528	52.553	4269	11.488	13528	36.408
Mar	102153	41%	34411	92.606	7515	20.224	23839	64.155
Apr	99701	46%	26056	70.122	5627	15.144	18051	48.579
May	126375	45%	29382	79.074	6194	16.671	20356	54.781
Jun	129642	44%	29579	79.603	6305	16.968	20492	55.148
Jul	161033	43%	40857	109.955	8793	23.665	28305	76.175
Aug	143884	44%	36425	98.026	7795	20.978	25234	67.91
Sep	110251	43%	34175	91.973	7437	20.015	23676	63.717
Oct	92840	33%	33611	90.455	7278	19.585	23285	62.666
Nov	61830	34%	21415	57.632	4614	12.416	14836	39.927
Dec	29655	22%	10800	29.064	2315	6.23	7482	20.135
TOTALS	**1159167**		**332154**	**893.893**	**71566**	**192.599**	**230110**	**619.271**

NORTH 20%; Objects: 2 (Exposed Area: 1.176 m²)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	[Wh/m²]	SHADE	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]
Jan	46932	26%	15915	42.83	3425	9.217	11025	29.671
Feb	54871	39%	19528	52.553	4269	11.488	13528	36.408
Mar	102153	41%	34411	92.606	7515	20.224	23839	64.155
Apr	99701	46%	26056	70.122	5627	15.144	18051	48.579
May	126375	45%	29382	79.074	6194	16.671	20356	54.781
Jun	129642	44%	29579	79.603	6305	16.968	20492	55.148
Jul	161033	43%	40857	109.955	8793	23.665	28305	76.175
Aug	143884	44%	36425	98.026	7795	20.978	25234	67.91
Sep	110251	43%	34175	91.973	7437	20.015	23676	63.717
Oct	92840	33%	33611	90.455	7278	19.585	23285	62.666
Nov	61830	34%	21415	57.632	4614	12.416	14836	39.927
Dec	29655	22%	10800	29.064	2315	6.23	7482	20.135
TOTALS	**1159167**		**332154**	**893.893**	**71566**	**192.599**	**230110**	**619.271**

NORTH 25%; Objects: 2 (Exposed Area: 2.205 m²)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	[Wh/m²]	SHADE	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]
Jan	46932	26%	15915	42.83	3425	9.217	11025	29.671
Feb	54871	39%	19528	52.553	4269	11.488	13528	36.408
Mar	102153	41%	34411	92.606	7515	20.224	23839	64.155
Apr	99701	46%	26056	70.122	5627	15.144	18051	48.579
May	126375	45%	29382	79.074	6194	16.671	20356	54.781
Jun	129642	44%	29579	79.603	6305	16.968	20492	55.148
Jul	161033	43%	40857	109.955	8793	23.665	28305	76.175
Aug	143884	44%	36425	98.026	7795	20.978	25234	67.91
Sep	110251	43%	34175	91.973	7437	20.015	23676	63.717
Oct	92840	33%	33611	90.455	7278	19.585	23285	62.666
Nov	61830	34%	21415	57.632	4614	12.416	14836	39.927
Dec	29655	22%	10800	29.064	2315	6.23	7482	20.135
TOTALS	**1159167**		**332154**	**893.893**	**71566**	**192.599**	**230110**	**619.271**

NORTH 30%; Objects: 2 (Exposed Area: 2.691 m²)

	AVAILABLE	AVG.	INCIDENT		ABSORBED		TRANSMITTED	
MONTH	[Wh/m²]	SHADE	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]	[Wh/m²]	TOT.[kWh]
Jan	46932	26%	15915	42.83	3425	9.217	11025	29.671
Feb	54871	39%	19528	52.553	4269	11.488	13528	36.408
Mar	102153	41%	34411	92.606	7515	20.224	23839	64.155
Apr	99701	46%	26056	70.122	5627	15.144	18051	48.579
May	126375	45%	29382	79.074	6194	16.671	20356	54.781
Jun	129642	44%	29579	79.603	6305	16.968	20492	55.148
Jul	161033	43%	40857	109.955	8793	23.665	28305	76.175
Aug	143884	44%	36425	98.026	7795	20.978	25234	67.91
Sep	110251	43%	34175	91.973	7437	20.015	23676	63.717
Oct	92840	33%	33611	90.455	7278	19.585	23285	62.666
Nov	61830	34%	21415	57.632	4614	12.416	14836	39.927
Dec	29655	22%	10800	29.064	2315	6.23	7482	20.135
TOTALS	**1159167**		**332154**	**893.893**	**71566**	**192.599**	**230110**	**619.271**

APPENDIX E

Output: variable and output: meter outputs before processing into variable file

```
Program Version,EnergyPlus-Windows-OMP-64 7.2.0.006, YMD=2014.12.19 11:58
1,5,Environment Title[],Latitude[degrees],Longitude[degrees],Time Zone[],Elevation[m]
2,6,Day of Simulation[],Month[],Day of Month[],DST Indicator[1=yes 0=no],Hour[],StartMinute[],EndMinute[],DayType
3,3,Cumulative Day of Simulation[],Month[],Day of Month[],DST Indicator[1=yes 0=no],DayType  ! When Daily Report
Variables Requested
4,2,Cumulative Days of Simulation[],Month[]  ! When Monthly Report Variables Requested
5,1,Cumulative Days of Simulation[] ! When Run Period Report Variables Requested
834,1,THERMAL ZONE -1 BASEMENT,Zone Mean Radiant Temperature [C] !Hourly
835,1,THERMAL ZONE 0,Zone Mean Radiant Temperature [C] !Hourly
836,1,THERMAL ZONE 0 E-CORNER,Zone Mean Radiant Temperature [C] !Hourly
837,1,THERMAL ZONE 0 N-HALL,Zone Mean Radiant Temperature [C] !Hourly
838,1,THERMAL ZONE 0 S,Zone Mean Radiant Temperature [C] !Hourly
839,1,THERMAL ZONE 0 W-CORNER_HALL,Zone Mean Radiant Temperature [C] !Hourly
840,1,THERMAL ZONE 1,Zone Mean Radiant Temperature [C] !Hourly
841,1,THERMAL ZONE 2,Zone Mean Radiant Temperature [C] !Hourly
842,1,THERMAL ZONE 3,Zone Mean Radiant Temperature [C] !Hourly
843,1,THERMAL ZONE 4,Zone Mean Radiant Temperature [C] !Hourly
844,1,THERMAL ZONE 5,Zone Mean Radiant Temperature [C] !Hourly
845,1,THERMAL ZONE 5 E,Zone Mean Radiant Temperature [C] !Hourly
846,1,THERMAL ZONE 5 N-HALL,Zone Mean Radiant Temperature [C] !Hourly
847,1,THERMAL ZONE 5 S,Zone Mean Radiant Temperature [C] !Hourly
848,1,THERMAL ZONE 5 W,Zone Mean Radiant Temperature [C] !Hourly
849,1,THERMAL ZONE 5 W-CORNER,Zone Mean Radiant Temperature [C] !Hourly
850,1,THERMAL ZONE 6,Zone Mean Radiant Temperature [C] !Hourly
851,1,THERMAL ZONE 7,Zone Mean Radiant Temperature [C] !Hourly
852,1,THERMAL ZONE 8,Zone Mean Radiant Temperature [C] !Hourly
853,1,THERMAL ZONE 9,Zone Mean Radiant Temperature [C] !Hourly
854,1,THERMAL ZONE 9 E,Zone Mean Radiant Temperature [C] !Hourly
855,1,THERMAL ZONE 9 N-HALL,Zone Mean Radiant Temperature [C] !Hourly
856,1,THERMAL ZONE 9 S,Zone Mean Radiant Temperature [C] !Hourly
857,1,THERMAL ZONE 9 W,Zone Mean Radiant Temperature [C] !Hourly
858,1,THERMAL ZONE -1 BASEMENT,Zone Mean Air Temperature [C] !Hourly
859,1,THERMAL ZONE -1 BASEMENT,Zone Operative Temperature [C] !Hourly
860,1,THERMAL ZONE 0,Zone Mean Air Temperature [C] !Hourly
861,1,THERMAL ZONE 0,Zone Operative Temperature [C] !Hourly
862,1,THERMAL ZONE 0 E-CORNER,Zone Mean Air Temperature [C] !Hourly
863,1,THERMAL ZONE 0 E-CORNER,Zone Operative Temperature [C] !Hourly
864,1,THERMAL ZONE 0 N-HALL,Zone Mean Air Temperature [C] !Hourly
865,1,THERMAL ZONE 0 N-HALL,Zone Operative Temperature [C] !Hourly
866,1,THERMAL ZONE 0 S,Zone Mean Air Temperature [C] !Hourly
867,1,THERMAL ZONE 0 S,Zone Operative Temperature [C] !Hourly
868,1,THERMAL ZONE 0 W-CORNER_HALL,Zone Mean Air Temperature [C] !Hourly
869,1,THERMAL ZONE 0 W-CORNER_HALL,Zone Operative Temperature [C] !Hourly
870,1,THERMAL ZONE 1,Zone Mean Air Temperature [C] !Hourly
871,1,THERMAL ZONE 1,Zone Operative Temperature [C] !Hourly
872,1,THERMAL ZONE 2,Zone Mean Air Temperature [C] !Hourly
873,1,THERMAL ZONE 2,Zone Operative Temperature [C] !Hourly
874,1,THERMAL ZONE 3,Zone Mean Air Temperature [C] !Hourly
875,1,THERMAL ZONE 3,Zone Operative Temperature [C] !Hourly
876,1,THERMAL ZONE 4,Zone Mean Air Temperature [C] !Hourly
877,1,THERMAL ZONE 4,Zone Operative Temperature [C] !Hourly
878,1,THERMAL ZONE 5,Zone Mean Air Temperature [C] !Hourly
879,1,THERMAL ZONE 5,Zone Operative Temperature [C] !Hourly
880,1,THERMAL ZONE 5 E,Zone Mean Air Temperature [C] !Hourly
881,1,THERMAL ZONE 5 E,Zone Operative Temperature [C] !Hourly
882,1,THERMAL ZONE 5 N-HALL,Zone Mean Air Temperature [C] !Hourly
883,1,THERMAL ZONE 5 N-HALL,Zone Operative Temperature [C] !Hourly
884,1,THERMAL ZONE 5 S,Zone Mean Air Temperature [C] !Hourly
885,1,THERMAL ZONE 5 S,Zone Operative Temperature [C] !Hourly
886,1,THERMAL ZONE 5 W,Zone Mean Air Temperature [C] !Hourly
887,1,THERMAL ZONE 5 W,Zone Operative Temperature [C] !Hourly
```

```
888,1,THERMAL ZONE 5 W-CORNER,Zone Mean Air Temperature [C] !Hourly
889,1,THERMAL ZONE 5 W-CORNER,Zone Operative Temperature [C] !Hourly
890,1,THERMAL ZONE 6,Zone Mean Air Temperature [C] !Hourly
891,1,THERMAL ZONE 6,Zone Operative Temperature [C] !Hourly
892,1,THERMAL ZONE 7,Zone Mean Air Temperature [C] !Hourly
893,1,THERMAL ZONE 7,Zone Operative Temperature [C] !Hourly
894,1,THERMAL ZONE 8,Zone Mean Air Temperature [C] !Hourly
895,1,THERMAL ZONE 8,Zone Operative Temperature [C] !Hourly
896,1,THERMAL ZONE 9,Zone Mean Air Temperature [C] !Hourly
897,1,THERMAL ZONE 9,Zone Operative Temperature [C] !Hourly
898,1,THERMAL ZONE 9 E,Zone Mean Air Temperature [C] !Hourly
899,1,THERMAL ZONE 9 E,Zone Operative Temperature [C] !Hourly
900,1,THERMAL ZONE 9 N-HALL,Zone Mean Air Temperature [C] !Hourly
901,1,THERMAL ZONE 9 N-HALL,Zone Operative Temperature [C] !Hourly
902,1,THERMAL ZONE 9 S,Zone Mean Air Temperature [C] !Hourly
903,1,THERMAL ZONE 9 S,Zone Operative Temperature [C] !Hourly
904,1,THERMAL ZONE 9 W,Zone Mean Air Temperature [C] !Hourly
905,1,THERMAL ZONE 9 W,Zone Operative Temperature [C] !Hourly
1262,1,THERMAL ZONE -1 BASEMENT,Zone Air Relative Humidity [%] !Hourly
1295,1,THERMAL ZONE 0,Zone Air Relative Humidity [%] !Hourly
1328,1,THERMAL ZONE 0 E-CORNER,Zone Air Relative Humidity [%] !Hourly
1361,1,THERMAL ZONE 0 N-HALL,Zone Air Relative Humidity [%] !Hourly
1394,1,THERMAL ZONE 0 S,Zone Air Relative Humidity [%] !Hourly
1427,1,THERMAL ZONE 0 W-CORNER_HALL,Zone Air Relative Humidity [%] !Hourly
1460,1,THERMAL ZONE 1,Zone Air Relative Humidity [%] !Hourly
1493,1,THERMAL ZONE 2,Zone Air Relative Humidity [%] !Hourly
1526,1,THERMAL ZONE 3,Zone Air Relative Humidity [%] !Hourly
1559,1,THERMAL ZONE 4,Zone Air Relative Humidity [%] !Hourly
1592,1,THERMAL ZONE 5,Zone Air Relative Humidity [%] !Hourly
1625,1,THERMAL ZONE 5 E,Zone Air Relative Humidity [%] !Hourly
1658,1,THERMAL ZONE 5 N-HALL,Zone Air Relative Humidity [%] !Hourly
1691,1,THERMAL ZONE 5 S,Zone Air Relative Humidity [%] !Hourly
1724,1,THERMAL ZONE 5 W,Zone Air Relative Humidity [%] !Hourly
1757,1,THERMAL ZONE 5 W-CORNER,Zone Air Relative Humidity [%] !Hourly
1790,1,THERMAL ZONE 6,Zone Air Relative Humidity [%] !Hourly
1823,1,THERMAL ZONE 7,Zone Air Relative Humidity [%] !Hourly
1856,1,THERMAL ZONE 8,Zone Air Relative Humidity [%] !Hourly
1889,1,THERMAL ZONE 9,Zone Air Relative Humidity [%] !Hourly
1922,1,THERMAL ZONE 9 E,Zone Air Relative Humidity [%] !Hourly
1955,1,THERMAL ZONE 9 N-HALL,Zone Air Relative Humidity [%] !Hourly
1988,1,THERMAL ZONE 9 S,Zone Air Relative Humidity [%] !Hourly
2021,1,THERMAL ZONE 9 W,Zone Air Relative Humidity [%] !Hourly
End of Data Dictionary
1,RUN PERIOD 1,  45.33,  19.85,   1.00,  84.00
```

Report data dictionary containing requested variables

```
! Program Version,EnergyPlus-Windows-OMP-64 7.2.0.006, YMD=2014.12.19 11:58,IDD_Version 7.2.0.006
! Output:Variable Objects (applicable to this run)
Output:Variable,*,Outdoor Dry Bulb,hourly; !- Zone Average [C]
Output:Variable,*,Outdoor Dew Point,hourly; !- Zone Average [C]
Output:Variable,*,Outdoor Wet Bulb,hourly; !- Zone Average [C]
Output:Variable,*,Outdoor Humidity Ratio,hourly; !- Zone Average [kgWater/kgDryAir]
Output:Variable,*,Outdoor Relative Humidity,hourly; !- Zone Average [%]
Output:Variable,*,Outdoor Barometric Pressure,hourly; !- Zone Average [Pa]
Output:Variable,*,Wind Speed,hourly; !- Zone Average [m/s]
Output:Variable,*,Wind Direction,hourly; !- Zone Average [deg]
Output:Variable,*,Sky Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Horizontal Infrared Radiation Intensity,hourly; !- Zone Average [W/m2]
Output:Variable,*,Diffuse Solar,hourly; !- Zone Average [W/m2]
Output:Variable,*,Direct Solar,hourly; !- Zone Average [W/m2]
Output:Variable,*,Liquid Precipitation,hourly; !- Zone Average [mm]
Output:Variable,*,Ground Reflected Solar,hourly; !- Zone Average [W/m2]
Output:Variable,*,Ground Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Surface Ground Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Deep Ground Temperature,hourly; !- Zone Average [C]
Output:Variable,*,FCFactor Ground Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Outdoor Enthalpy,hourly; !- Zone Average [J/kg]
```

```
Output:Variable,*,Outdoor Air Density,hourly; !- Zone Average [kg/m3]
Output:Variable,*,Solar Azimuth Angle,hourly; !- Zone Average [deg]
Output:Variable,*,Solar Altitude Angle,hourly; !- Zone Average [deg]
Output:Variable,*,Solar Hour Angle,hourly; !- Zone Average [deg]
Output:Variable,*,Fraction of Time Raining,hourly; !- Zone Average []
Output:Variable,*,Fraction of Time Snow On Ground,hourly; !- Zone Average []
Output:Variable,*,Exterior Horizontal Illuminance From Sky,hourly; !- Zone Average [lux]
Output:Variable,*,Exterior Horizontal Beam Illuminance,hourly; !- Zone Average [lux]
Output:Variable,*,Exterior Beam Normal Illuminance,hourly; !- Zone Average [lux]
Output:Variable,*,Luminous Efficacy of Sky Diffuse Solar Radiation,hourly; !- Zone Average [lum/W]
Output:Variable,*,Luminous Efficacy of Beam Solar Radiation,hourly; !- Zone Average [lum/W]
Output:Variable,*,Sky Clearness for Daylighting Calculation,hourly; !- Zone Average []
Output:Variable,*,Sky Brightness for Daylighting Calculation,hourly; !- Zone Average []
Output:Variable,*,Daylight Saving Time Indicator,hourly; !- Zone Average []
Output:Variable,*,DayType Index,hourly; !- Zone Average []
Output:Variable,*,Water Mains Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Zone Outdoor Dry Bulb,hourly; !- Zone Average [C]
Output:Variable,*,Zone Outdoor Wet Bulb,hourly; !- Zone Average [C]
Output:Variable,*,Zone Outdoor Wind Speed,hourly; !- Zone Average [m/s]
Output:Variable,*,Zone Total Internal Radiant Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Total Internal Radiant Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Total Internal Visible Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Total Internal Visible Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Total Internal Convective Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Total Internal Convective Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Total Internal Latent Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Total Internal Latent Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Total Internal Total Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Total Internal Total Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,People Number Of Occupants,hourly; !- Zone Average []
Output:Variable,*,People Radiant Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,People Radiant Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,People Convective Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,People Convective Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,People Sensible Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,People Sensible Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,People Latent Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,People Latent Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,People Total Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,People Total Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,People Air Temperatures,hourly; !- Zone Average [C]
Output:Variable,*,People Air Relative Humidity,hourly; !- Zone Average [%]
Output:Variable,*,Zone People Number Of Occupants,hourly; !- Zone Average []
Output:Variable,*,Zone People Radiant Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone People Radiant Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone People Convective Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone People Convective Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone People Sensible Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone People Sensible Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone People Latent Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone People Latent Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone People Total Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone People Total Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Lights Electric Power,hourly; !- Zone Average [W]
Output:Variable,*,Lights Radiant Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Lights Radiant Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Lights Visible Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Lights Visible Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Lights Convective Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Lights Convective Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Lights Return Air Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Lights Return Air Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Lights Total Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Lights Total Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Lights Electric Consumption,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Lights Electric Power,hourly; !- Zone Average [W]
Output:Variable,*,Zone Lights Electric Consumption,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Lights Radiant Heat Gain,hourly; !- Zone Sum [J]
```

```
Output:Variable,*,Zone Lights Radiant Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Lights Visible Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Lights Visible Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Lights Convective Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Lights Convective Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Lights Return Air Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Lights Return Air Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Lights Total Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Lights Total Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Electric Equipment Electric Power,hourly; !- Zone Average [W]
Output:Variable,*,Electric Equipment Electric Consumption,hourly; !- Zone Sum [J]
Output:Variable,*,Electric Equipment Radiant Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Electric Equipment Radiant Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Electric Equipment Convective Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Electric Equipment Convective Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Electric Equipment Latent Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Electric Equipment Latent Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Electric Equipment Lost Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Electric Equipment Lost Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Electric Equipment Total Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Electric Equipment Total Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Electric Equipment Electric Power,hourly; !- Zone Average [W]
Output:Variable,*,Zone Electric Equipment Electric Consumption,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Electric Equipment Radiant Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Electric Equipment Radiant Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Electric Equipment Convective Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Electric Equipment Convective Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Electric Equipment Latent Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Electric Equipment Latent Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Electric Equipment Lost Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Electric Equipment Lost Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Electric Equipment Total Heat Gain,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Electric Equipment Total Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Zone Transmitted Solar,hourly; !- Zone Average [W]
Output:Variable,*,Zone Beam Solar from Exterior Windows,hourly; !- Zone Average [W]
Output:Variable,*,Zone Beam Solar from Interior Windows,hourly; !- Zone Average [W]
Output:Variable,*,Zone Diff Solar from Exterior Windows,hourly; !- Zone Average [W]
Output:Variable,*,Zone Diff Solar from Interior Windows,hourly; !- Zone Average [W]
Output:Variable,*,Zone Window Heat Gain,hourly; !- Zone Average [W]
Output:Variable,*,Zone Window Heat Loss,hourly; !- Zone Average [W]
Output:Variable,*,Zone Transmitted Solar Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Beam Solar from Exterior Windows Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Beam Solar from Interior Windows Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Diff Solar from Exterior Windows Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Diff Solar from Interior Windows Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Window Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Zone Window Heat Loss Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Surface Ext Sunlit Area,hourly; !- Zone Average [m2]
Output:Variable,*,Surface Ext Sunlit Fraction,hourly; !- Zone Average []
Output:Variable,*,Surface Ext Solar Incident,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Ext Solar Beam Incident,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Ext Solar Sky Diffuse Incident,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Ext Solar Ground Diffuse Incident,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Ext Solar Beam Cosine Of Incidence Angle,hourly; !- Zone Average []
Output:Variable,*,Surface Ext Solar From Sky Diffuse Refl From Ground,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Ext Solar From Sky Diffuse Refl From Obstructions,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Ext Beam Sol From Bm-To-Bm Refl From Obstructions,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Ext Diff Sol From Bm-To-Diff Refl From Obstructions,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Ext Solar From Bm-To-Diff Refl From Ground,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Anisotropic Sky Multiplier,hourly; !- Zone Average []
Output:Variable,*,BSDF Beam Direction Number,hourly; !- Zone Average []
Output:Variable,*,BSDF Beam Theta Angle,hourly; !- Zone Average [rad]
Output:Variable,*,BSDF Beam Phi Angle,hourly; !- Zone Average [rad]
Output:Variable,*,Window Solar Absorbed:All Glass Layers,hourly; !- Zone Average [W]
Output:Variable,*,Total Shortwave Absorbed:All Glass Layers,hourly; !- Zone Average [W]
Output:Variable,*,Window Transmitted Solar,hourly; !- Zone Average [W]
Output:Variable,*,Window Transmitted Beam Solar,hourly; !- Zone Average [W]
Output:Variable,*,Window Transmitted Beam-to-Beam Solar,hourly; !- Zone Average [W]
Output:Variable,*,Window Transmitted Beam-to-Diffuse Solar,hourly; !- Zone Average [W]
```

```
Output:Variable,*,Window Transmitted Diffuse Solar,hourly; !- Zone Average [W]
Output:Variable,*,Window Heat Gain,hourly; !- Zone Average [W]
Output:Variable,*,Window Heat Loss,hourly; !- Zone Average [W]
Output:Variable,*,Window Gap Convective Heat Flow,hourly; !- Zone Average [W]
Output:Variable,*,Window Solar Absorbed:Shading Device,hourly; !- Zone Average [W]
Output:Variable,*,Window Solar Absorbed:All Glass Layers Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window Transmitted Solar Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window Transmitted Beam Solar Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window Transmitted Beam-to-Beam Solar Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window Transmitted Beam-to-Diffuse Solar Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window Transmitted Diffuse Solar Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window Heat Loss Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window Gap Convective Heat Flow Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window Solar Absorbed:Shading Device Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Window System Solar Transmittance,hourly; !- Zone Average []
Output:Variable,*,Window System Solar Reflectance,hourly; !- Zone Average []
Output:Variable,*,Window System Solar Absorptance,hourly; !- Zone Average []
Output:Variable,*,Inside Glass Condensation Flag,hourly; !- Zone Average []
Output:Variable,*,Inside Frame Condensation Flag,hourly; !- Zone Average []
Output:Variable,*,Inside Divider Condensation Flag,hourly; !- Zone Average []
Output:Variable,*,Beam Solar Reflected by Outside Reveal Surfaces,hourly; !- Zone Average [W]
Output:Variable,*,Beam Solar Reflected by Outside Reveal Surfaces Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Solar Horizontal Profile Angle,hourly; !- Zone Average [deg]
Output:Variable,*,Solar Vertical Profile Angle,hourly; !- Zone Average [deg]
Output:Variable,*,Glass Beam-Beam Solar Transmittance,hourly; !- Zone Average []
Output:Variable,*,Glass Beam-Diffuse Solar Transmittance,hourly; !- Zone Average []
Output:Variable,*,Glass Diffuse-Diffuse Solar Transmittance,hourly; !- Zone Average []
Output:Variable,*,Window Calculation Iterations,hourly; !- Zone Average []
Output:Variable,*,Beam Sol Intensity from Ext Windows on Inside of Surface,hourly; !- Zone Average [W/m2]
Output:Variable,*,Beam Sol Amount from Ext Windows on Inside of Surface,hourly; !- Zone Average [W]
Output:Variable,*,Beam Sol Intensity from Int Windows on Inside of Surface,hourly; !- Zone Average [W/m2]
Output:Variable,*,Beam Sol Amount from Int Windows on Inside of Surface,hourly; !- Zone Average [W]
Output:Variable,*,Initial Transmitted Diffuse Solar Absorbed on Inside of Surface,hourly; !- Zone Average [W]
Output:Variable,*,Initial Transmitted Diffuse Solar Transmitted Out Through Inside of Window Surface,hourly; !- Zone
Average [W]
Output:Variable,*,Total Shortwave Radiation Absorbed on Inside of Surface,hourly; !- Zone Average [W]
Output:Variable,*,Beam Sol Amount from Ext Windows on Inside of Surface Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Beam Sol Amount from Int Windows on Inside of Surface Energy,hourly; !- Zone Sum [J]
Output:Variable,*,debug DifShdgRatioIsoSky,hourly; !- Zone Average []
Output:Variable,*,debug DifShdgRatioHoriz,hourly; !- Zone Average []
Output:Variable,*,debug WithShdgIsoSky,hourly; !- Zone Average []
Output:Variable,*,debug WoShdgIsoSky,hourly; !- Zone Average []
Output:Variable,*,Surface Inside Face Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Surface Outside Face Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Surface Inside Face Adjacent Air Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Surface Inside Face Convection Heat Transfer Coefficient,hourly; !- Zone Average [W/m2-K]
Output:Variable,*,Surface Inside Face Convection Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Surface Inside Face Convection Heat Gain Rate per Area,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Inside Face Convection Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Surface Inside Face Net Surface Thermal Radiation Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Surface Inside Face Net Surface Thermal Radiation Heat Gain Rate per Area,hourly; !- Zone Average
[W/m2]
Output:Variable,*,Surface Inside Face Net Surface Thermal Radiation Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Surface Inside Face Solar Radiation Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Surface Inside Face Solar Radiation Heat Gain Rate per Area,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Inside Face Solar Radiation Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Surface Inside Face Lights Radiation Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Surface Inside Face Lights Radiation Heat Gain Rate per Area,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Inside Face Lights Radiation Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Surface Inside Face Internal Gains Radiation Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Surface Inside Face Internal Gains Radiation Heat Gain Rate per Area,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Inside Face Internal Gains Radiation Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Surface Inside Face System Radiation Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Surface Inside Face System Radiation Heat Gain Rate per Area,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Inside Face System Radiation Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Surface Outside Face Outdoor Air Dry Bulb Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Surface Outside Face Outdoor Air Wet Bulb Temperature,hourly; !- Zone Average [C]
```

```
Output:Variable,*,Surface Outside Face Outdoor Wind Velocity,hourly; !- Zone Average [m/s]
Output:Variable,*,Surface Outside Face Convection Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Surface Outside Face Convection Heat Gain Rate per Area,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Outside Face Convection Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Surface Outside Face Convection Heat Transfer Coefficient,hourly; !- Zone Average [W/m2-K]
Output:Variable,*,Surface Outside Face Net Thermal Radiation Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Surface Outside Face Net Thermal Radiation Heat Gain Rate per Area,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Outside Face Net Thermal Radiation Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Surface Outside Face Thermal Radiation to Air Heat Transfer Coefficient,hourly; !- Zone Average [W/m2-
K]
Output:Variable,*,Surface Outside Face Thermal Radiation to Sky Heat Transfer Coefficient,hourly; !- Zone Average [W/m2-
K]
Output:Variable,*,Surface Outside Face Thermal Radiation to Ground Heat Transfer Coefficient,hourly; !- Zone Average
[W/m2-K]
Output:Variable,*,Surface Outside Face Solar Radiation Heat Gain Rate,hourly; !- Zone Average [W]
Output:Variable,*,Surface Outside Face Solar Radiation Heat Gain Rate per Area,hourly; !- Zone Average [W/m2]
Output:Variable,*,Surface Outside Face Solar Radiation Heat Gain Energy,hourly; !- Zone Sum [J]
Output:Variable,*,Opaque Surface Inside Face Beam Solar Absorbed,hourly; !- Zone Average [W]
Output:Variable,*,Fraction of Time Shading Device Is On,hourly; !- Zone Average []
Output:Variable,*,Storm Window On/Off Flag,hourly; !- Zone Average []
Output:Variable,*,Window Blind Slat Angle,hourly; !- Zone Average [deg]
Output:Variable,*,Zone Mean Radiant Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Zone Mean Air Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Zone Operative Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Zone Mean Air Dewpoint Temperature,hourly; !- Zone Average [C]
Output:Variable,*,Zone Mean Air Humidity Ratio,hourly; !- Zone Average [kgWater/kgDryAir]
Output:Variable,*,Zone Air Balance Internal Convective Gains Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone Air Balance Surface Convection Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone Air Balance Interzone Air Transfer Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone Air Balance Outdoor Air Transfer Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone Air Balance System Air Transfer Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone Air Balance System Convective Gains Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone Air Balance Air Energy Storage Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone Infiltration Sensible Heat Loss,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Infiltration Sensible Heat Gain,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Infiltration Latent Heat Loss,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Infiltration Latent Heat Gain,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Infiltration Total Heat Loss,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Infiltration Total Heat Gain,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Infiltration Volume Flow Rate Current Density,hourly; !- HVAC Average [m3/s]
Output:Variable,*,Zone Infiltration Volume Flow Rate Standard Density,hourly; !- HVAC Average [m3/s]
Output:Variable,*,Zone Infiltration Volume Current Density,hourly; !- HVAC Sum [m3]
Output:Variable,*,Zone Infiltration Volume Standard Density,hourly; !- HVAC Sum [m3]
Output:Variable,*,Zone Infiltration Mass,hourly; !- HVAC Sum [kg]
Output:Variable,*,Zone Infiltration Air Change Rate,hourly; !- HVAC Average [ach]
Output:Variable,*,Zone Ventilation Sensible Heat Loss,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Ventilation Sensible Heat Gain,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Ventilation Latent Heat Loss,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Ventilation Latent Heat Gain,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Ventilation Total Heat Loss,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Ventilation Total Heat Gain,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Ventilation Volume Flow Rate Current Density,hourly; !- HVAC Average [m3/s]
Output:Variable,*,Zone Ventilation Volume Flow Rate Standard Density,hourly; !- HVAC Average [m3/s]
Output:Variable,*,Zone Ventilation Volume Current Density,hourly; !- HVAC Sum [m3]
Output:Variable,*,Zone Ventilation Volume Standard Density,hourly; !- HVAC Sum [m3]
Output:Variable,*,Zone Ventilation Mass,hourly; !- HVAC Sum [kg]
Output:Variable,*,Zone Ventilation Air Change Rate,hourly; !- HVAC Average [ach]
Output:Variable,*,Zone Ventilation Fan Electric Consumption,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Ventilation Inlet Air Temperature,hourly; !- HVAC Average [C]
Output:Variable,*,Zone/Sys Sensible Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone/Sys Sensible Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone/Sys Sensible Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone/Sys Sensible Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone/Sys Air Temperature,hourly; !- HVAC Average [C]
Output:Variable,*,Zone/Sys Air Temperature at Thermostat,hourly; !- HVAC Average [C]
Output:Variable,*,Zone Air Humidity Ratio,hourly; !- HVAC Average []
Output:Variable,*,Zone Air Relative Humidity,hourly; !- HVAC Average [%]
Output:Variable,*,Zone/Sys Sensible Load Predicted,hourly; !- HVAC Average [W]
Output:Variable,*,Zone/Sys Sensible Load to Heating Setpoint Predicted,hourly; !- HVAC Average [W]
```

```
Output:Variable,*,Zone/Sys Sensible Load to Cooling Setpoint Predicted,hourly; !- HVAC Average [W]
Output:Variable,*,Zone/Sys Moisture Load Rate Predicted,hourly; !- HVAC Average [kgWater/s]
Output:Variable,*,Zone/Sys Moisture Load Rate Predicted to humidifying setpoint,hourly; !- HVAC Average [kgWater/s]
Output:Variable,*,Zone/Sys Moisture Load Rate Predicted to dehumidifying setpoint,hourly; !- HVAC Average [kgWater/s]
Output:Variable,*,Zone/Sys Thermostat Control Type,hourly; !- Zone Average []
Output:Variable,*,Zone/Sys Thermostat Heating Setpoint,hourly; !- Zone Average [C]
Output:Variable,*,Zone/Sys Thermostat Cooling Setpoint,hourly; !- Zone Average [C]
Output:Variable,*,Zone List Sensible Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone List Sensible Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone List Sensible Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Zone List Sensible Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,HVACManage Iterations,hourly; !- HVAC Sum []
Output:Variable,*,AirLoop-Zone Iterations,hourly; !- HVAC Sum []
Output:Variable,*,Ideal Loads Sensible Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Latent Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Total Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Sensible Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Latent Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Total Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Zone Sensible Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Zone Latent Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Zone Total Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Zone Sensible Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Zone Latent Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Zone Total Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Outdoor Air Sensible Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Outdoor Air Latent Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Outdoor Air Total Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Outdoor Air Sensible Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Outdoor Air Latent Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Outdoor Air Total Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Heat Recovery Sensible Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Heat Recovery Latent Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Heat Recovery Total Heating Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Heat Recovery Sensible Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Heat Recovery Latent Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Heat Recovery Total Cooling Energy,hourly; !- HVAC Sum [J]
Output:Variable,*,Ideal Loads Sensible Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Latent Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Total Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Sensible Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Latent Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Total Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Zone Sensible Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Zone Latent Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Zone Total Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Zone Sensible Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Zone Latent Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Zone Total Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Outdoor Air Sensible Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Outdoor Air Latent Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Outdoor Air Total Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Outdoor Air Sensible Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Outdoor Air Latent Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Outdoor Air Total Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Heat Recovery Sensible Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Heat Recovery Latent Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Heat Recovery Total Heating Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Heat Recovery Sensible Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Heat Recovery Latent Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Heat Recovery Total Cooling Rate,hourly; !- HVAC Average [W]
Output:Variable,*,Ideal Loads Time Economizer Active,hourly; !- HVAC Sum [hr]
Output:Variable,*,Ideal Loads Time Heat Recovery Active,hourly; !- HVAC Sum [hr]
Output:Variable,*,Ideal Loads Hybrid Ventilation Availability Status,hourly; !- HVAC Average []
Output:Variable,*,Max SimAir Iterations,hourly; !- HVAC Sum []
Output:Variable,*,Tot SimAir Iterations,hourly; !- HVAC Sum []
Output:Variable,*,Tot SimAirLoopComponents Calls,hourly; !- HVAC Sum []
Output:Variable,*,Total Electric Power Purchased,hourly; !- HVAC Average [W]
```

```
Output:Variable,*,Total Electric Energy Purchased,hourly; !- HVAC Sum [J]
Output:Variable,*,Total Electric Energy Surplus,hourly; !- HVAC Sum [J]
Output:Variable,*,Net Electric Power Purchased,hourly; !- HVAC Average [W]
Output:Variable,*,Net Electric Energy Purchased,hourly; !- HVAC Sum [J]
Output:Variable,*,Total Building Electric Demand,hourly; !- HVAC Average [W]
Output:Variable,*,Total HVAC Electric Demand,hourly; !- HVAC Average [W]
Output:Variable,*,Total Electric Demand,hourly; !- HVAC Average [W]
Output:Variable,*,Total Electric Power Produced,hourly; !- HVAC Average [W]
Output:Variable,*,Total Electric Energy Produced,hourly; !- HVAC Sum [J]
Output:Variable,*,Time Zone Temperature Oscillating,hourly; !- HVAC Sum [hr]
Output:Variable,*,Time Any Zone Temperature Oscillating,hourly; !- HVAC Sum [hr]
Output:Variable,*,Time Not Comfortable Summer Clothes,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Not Comfortable Winter Clothes,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Not Comfortable Summer Or Winter Clothes,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Not Comfortable Summer Clothes Any Zone,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Not Comfortable Winter Clothes Any Zone,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Not Comfortable Summer Or Winter Clothes Any Zone,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Heating Setpoint Not Met,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Heating Setpoint Not Met While Occupied,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Cooling Setpoint Not Met,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Cooling Setpoint Not Met While Occupied,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Heating Setpoint Not Met Any Zone,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Cooling Setpoint Not Met Any Zone,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Heating Setpoint Not Met While Occupied Any Zone,hourly; !- Zone Sum [hr]
Output:Variable,*,Time Cooling Setpoint Not Met While Occupied Any Zone,hourly; !- Zone Sum [hr]
Output:Variable,*,Schedule Value,hourly; !- Zone Average []
Output:Variable,*,System Node Temp,hourly; !- HVAC Average [C]
Output:Variable,*,System Node MassFlowRate,hourly; !- HVAC Average [kg/s]
Output:Variable,*,System Node Humidity Ratio,hourly; !- HVAC Average [kgWater/kgDryAir]
Output:Variable,*,System Node Setpoint Temp,hourly; !- HVAC Average [C]
Output:Variable,*,System Node Setpoint Temp Hi,hourly; !- HVAC Average [C]
Output:Variable,*,System Node Setpoint Temp Lo,hourly; !- HVAC Average [C]
Output:Variable,*,System Node Setpoint Humidity Ratio,hourly; !- HVAC Average [kgWater/kgDryAir]
Output:Variable,*,System Node Setpoint Humidity Ratio Min,hourly; !- HVAC Average [kgWater/kgDryAir]
Output:Variable,*,System Node Setpoint Humidity Ratio Max,hourly; !- HVAC Average [kgWater/kgDryAir]
Output:Variable,*,System Node Relative Humidity,hourly; !- HVAC Average [%]
Output:Variable,*,System Node Pressure,hourly; !- HVAC Average [Pa]
Output:Variable,*,System Node Volume Flow Rate Standard Density,hourly; !- HVAC Average [m3/s]
Output:Variable,*,System Node Volume Flow Rate Current Density,hourly; !- HVAC Average [m3/s]
Output:Variable,*,System Node Current Density,hourly; !- HVAC Average [kg/m3]
Output:Variable,*,System Node Enthalpy,hourly; !- HVAC Average [J/kg]
Output:Variable,*,System Node Wetbulb Temp,hourly; !- HVAC Average [C]
Output:Variable,*,System Node Dewpoint Temperature,hourly; !- HVAC Average [C]
Output:Variable,*,System Node Quality,hourly; !- HVAC Average []
Output:Variable,*,System Node Height,hourly; !- HVAC Average [m]
Output:Variable,*,Carbon Equivalent Pollution From NOx,hourly; !- HVAC Sum [kg]
Output:Variable,*,Carbon Equivalent Pollution From CH4,hourly; !- HVAC Sum [kg]
Output:Variable,*,Carbon Equivalent Pollution From CO2,hourly; !- HVAC Sum [kg]
Output:Variable,*,Zone Mechanical Ventilation No Load Heat Removal,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Mechanical Ventilation Cooling Load Increase,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Mech Ventilation Cooling Load Increase: OverHeating,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Mechanical Ventilation Cooling Load Decrease,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Mechanical Ventilation No Load Heat Addition,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Mechanical Ventilation Heating Load Increase,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Mech Ventilation Heating Load Increase: OverCooling,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Mechanical Ventilation Heating Load Decrease,hourly; !- HVAC Sum [J]
Output:Variable,*,Zone Mechanical Ventilation Mass Flow Rate,hourly; !- HVAC Average [kg/s]
Output:Variable,*,Zone Mechanical Ventilation Mass,hourly; !- HVAC Sum [kg]
Output:Variable,*,Zone Mechanical Ventilation Volume Flow Rate Standard Density,hourly; !- HVAC Average [m3/s]
Output:Variable,*,Zone Mechanical Ventilation Volume Standard Density,hourly; !- HVAC Sum [m3]
Output:Variable,*,Zone Mechanical Ventilation Volume Flow Rate Current Density,hourly; !- HVAC Average [m3/s]
Output:Variable,*,Zone Mechanical Ventilation Volume Current Density,hourly; !- HVAC Sum [m3]
Output:Variable,*,Zone Mechanical Ventilation Air Change Rate,hourly; !- HVAC Average [ach]
```

Report data dictionary containing requested variables

```
! Program Version,EnergyPlus-Windows-OMP-64 7.2.0.006, YMD=2014.12.19 11:58,IDD_Version 7.2.0.006
! Output:Meter Objects (applicable to this run)
```

```
Output:Meter,Electricity:Facility,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Facility,hourly; !- [J]
Output:Meter,Electricity:Building,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Building,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter,InteriorLights:Electricity,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter,General:InteriorLights:Electricity,hourly; !- [J]
Output:Meter:Cumulative,General:InteriorLights:Electricity,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 5 W,hourly; !- [J]
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Output:Meter,Electricity:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter,Electricity:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter:Cumulative,Electricity:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter,InteriorLights:Electricity:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter:Cumulative,InteriorLights:Electricity:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter,General:InteriorEquipment:Electricity,hourly; !- [J]
Output:Meter:Cumulative,General:InteriorEquipment:Electricity,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMALZONE 0 W-CORNER_HALL,hourly;!-[J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 W,hourly; !- [J]
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Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter:Cumulative,InteriorEquipment:Electricity:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter,Fans:Electricity,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter,Ventilation (simple):Fans:Electricity,hourly; !- [J]
Output:Meter:Cumulative,Ventilation (simple):Fans:Electricity,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 9 S,hourly; !- [J]
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Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter,Fans:Electricity:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter:Cumulative,Fans:Electricity:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter,EnergyTransfer:Facility,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Facility,hourly; !- [J]
Output:Meter,EnergyTransfer:Building,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Building,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE -1 BASEMENT,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0 E-CORNER,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0 N-HALL,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0 S,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 0 W-CORNER_HALL,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 1,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 2,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 3,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 4,hourly; !- [J]
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Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 4,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 E,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 N-HALL,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 S,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 W,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 5 W-CORNER,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 6,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 7,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 8,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9 E,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9 E,hourly; !- [J]
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Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9 N-HALL,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9 S,hourly; !- [J]
Output:Meter,EnergyTransfer:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter:Cumulative,EnergyTransfer:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter,Heating:EnergyTransfer:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter:Cumulative,Heating:EnergyTransfer:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter:Cumulative,Cooling:EnergyTransfer:Zone:THERMAL ZONE 9 W,hourly; !- [J]
Output:Meter,DistrictHeating:Facility,hourly; !- [J]
Output:Meter:Cumulative,DistrictHeating:Facility,hourly; !- [J]
Output:Meter,DistrictHeating:HVAC,hourly; !- [J]
Output:Meter:Cumulative,DistrictHeating:HVAC,hourly; !- [J]
Output:Meter,Heating:DistrictHeating,hourly; !- [J]
Output:Meter:Cumulative,Heating:DistrictHeating,hourly; !- [J]
Output:Meter,DistrictCooling:Facility,hourly; !- [J]
Output:Meter:Cumulative,DistrictCooling:Facility,hourly; !- [J]
Output:Meter,DistrictCooling:HVAC,hourly; !- [J]
Output:Meter:Cumulative,DistrictCooling:HVAC,hourly; !- [J]
Output:Meter,Cooling:DistrictCooling,hourly; !- [J]
Output:Meter:Cumulative,Cooling:DistrictCooling,hourly; !- [J]
Output:Meter,ElectricityPurchased:Facility,hourly; !- [J]
Output:Meter:Cumulative,ElectricityPurchased:Facility,hourly; !- [J]
Output:Meter,ElectricityPurchased:Plant,hourly; !- [J]
Output:Meter:Cumulative,ElectricityPurchased:Plant,hourly; !- [J]
Output:Meter,Cogeneration:ElectricityPurchased,hourly; !- [J]
Output:Meter:Cumulative,Cogeneration:ElectricityPurchased,hourly; !- [J]
Output:Meter,ElectricitySurplusSold:Facility,hourly; !- [J]
Output:Meter:Cumulative,ElectricitySurplusSold:Facility,hourly; !- [J]
Output:Meter,ElectricitySurplusSold:Plant,hourly; !- [J]
Output:Meter:Cumulative,ElectricitySurplusSold:Plant,hourly; !- [J]
Output:Meter,Cogeneration:ElectricitySurplusSold,hourly; !- [J]
Output:Meter:Cumulative,Cogeneration:ElectricitySurplusSold,hourly; !- [J]
Output:Meter,ElectricityNet:Facility,hourly; !- [J]
Output:Meter:Cumulative,ElectricityNet:Facility,hourly; !- [J]
Output:Meter,ElectricityNet:Plant,hourly; !- [J]
Output:Meter:Cumulative,ElectricityNet:Plant,hourly; !- [J]
Output:Meter,Cogeneration:ElectricityNet,hourly; !- [J]
Output:Meter:Cumulative,Cogeneration:ElectricityNet,hourly; !- [J]
Output:Meter,Carbon Equivalent:Facility,hourly; !- [kg]
Output:Meter:Cumulative,Carbon Equivalent:Facility,hourly; !- [kg]
Output:Meter,CarbonEquivalentEmissions:Carbon Equivalent,hourly; !- [kg]
Output:Meter:Cumulative,CarbonEquivalentEmissions:Carbon Equivalent,hourly; !- [kg]
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APPENDIX F
Ground level - Corner office, East orientation

Date/Time [h]	Air Temperature [˚C]	Mean Radiant Temperature [˚C]	Relative Air Velocity [m/s]	Relative Humidity [%]	Clothing [clo]	Metabolic Rate [met]	PMV [-]	PPD [%]	Category [-]	
01/01 01:00:00	20.80020188	21.36947327	0.1	42.11107933	1.00	1.2	-0.15	5.5		
01/01 02:00:00	20.80235016	21.32648767	0.1	41.86863789	1.00	1.2	-0.16	5.5		
01/01 03:00:00	20.72096100	21.28259836	0.1	41.65560522	1.00	1.2	-0.17	5.6		
01/01 04:00:00	20.67738584	21.23363511	0.1	41.38994539	1.00	1.2	-0.18	5.7		
01/01 05:00:00	20.62211215	21.18565539	0.1	40.44154280	1.00	1.2	-0.20	5.8		
01/01 06:00:00	20.57213108	21.13906468	0.1	39.88294419	1.00	1.2	-0.21	6.0		
01/01 07:00:00	21.25148118	21.09715869	0.1	38.59531357	1.00	1.2	-0.15	5.5		
01/01 08:00:00	21.73911015	21.13089784	0.1	37.81699798	1.00	1.2	-0.09	5.2	I	Thu
01/01 09:00:00	22.46061848	21.21513696	0.1	37.86971751	1.00	1.2	0.00	5.0	I	
01/01 10:00:00	22.42200272	21.34552323	0.1	40.01220524	1.00	1.2	0.02	5.0	I	
01/01 11:00:00	22.55609931	21.40121316	0.1	41.90671824	1.00	1.2	0.05	5.1	I	
01/01 12:00:00	22.60302656	21.47198436	0.1	40.61490798	1.00	1.2	0.06	5.1	I	I
01/01 13:00:00	22.99457067	21.51706606	0.1	39.22843952	1.00	1.2	0.10	5.2	I	
01/01 14:00:00	22.67259190	21.63198075	0.1	39.70473653	1.00	1.2	0.07	5.1	I	
01/01 15:00:00	22.77951710	21.64324946	0.1	39.27850154	1.00	1.2	0.09	5.2	I	
01/01 16:00:00	22.76007129	21.69228121	0.1	41.46490182	1.00	1.2	0.10	5.2	I	
01/01 17:00:00	22.30730453	21.72786614	0.1	43.29796461	1.00	1.2	0.06	5.1	I	
01/01 18:00:00	22.24439562	21.68411685	0.1	43.60108462	1.00	1.2	0.05	5.1	I	
01/01 19:00:00	21.99884148	21.66977477	0.1	43.95061379	1.00	1.2	0.03	5.0		
01/01 20:00:00	21.72656094	21.63385355	0.1	44.14872089	1.00	1.2	-0.01	5.0		
01/01 21:00:00	21.67872756	21.59161384	0.1	43.64665763	1.00	1.2	-0.02	5.0		
01/01 22:00:00	21.64350831	21.56342022	0.1	43.12798846	1.00	1.2	-0.03	5.0		
01/01 23:00:00	20.61551037	21.53697715	0.1	44.51327413	1.00	1.2	-0.14	5.4		
01/01 24:00:00	20.79833264	21.37376223	0.1	42.31277234	1.00	1.2	-0.15	5.5		
01/02 01:00:00	20.65345390	21.34461002	0.1	41.17358499	1.00	1.2	-0.18	5.7		
01/02 02:00:00	20.59068240	21.27967659	0.1	39.66283413	1.00	1.2	-0.20	5.8		
01/02 03:00:00	20.50111024	21.21973375	0.1	38.80845487	1.00	1.2	-0.22	6.0		
01/02 04:00:00	20.43586704	21.15797508	0.1	38.06813717	1.00	1.2	-0.24	6.2		
01/02 05:00:00	20.35629775	21.09803779	0.1	37.40366166	1.00	1.2	-0.25	6.4		
01/02 06:00:00	20.29791349	21.03799371	0.1	37.00084831	1.00	1.2	-0.27	6.5		
01/02 07:00:00	21.02344536	20.98287925	0.1	35.48630655	1.00	1.2	-0.20	5.9		
01/02 08:00:00	21.48707874	21.01815164	0.1	34.86891696	1.00	1.2	-0.15	5.5	I	Fri
01/02 09:00:00	22.07491530	21.11058286	0.1	36.06548801	1.00	1.2	-0.07	5.1	I	
01/02 10:00:00	22.15050712	21.22689707	0.1	38.54876508	1.00	1.2	-0.03	5.0	I	
01/02 11:00:00	22.33021610	21.31119156	0.1	39.71033856	1.00	1.2	0.00	5.0	I	
01/02 12:00:00	22.41445632	21.38822690	0.1	38.75608232	1.00	1.2	0.01	5.0	I	I
01/02 13:00:00	22.83641330	21.42497916	0.1	37.39429807	1.00	1.2	0.06	5.1	I	
01/02 14:00:00	22.44334716	21.53700339	0.1	37.90768295	1.00	1.2	0.03	5.0	I	
01/02 15:00:00	22.51863985	21.52909506	0.1	37.86803100	1.00	1.2	0.04	5.0	I	
01/02 16:00:00	22.47250712	21.56210558	0.1	38.17406290	1.00	1.2	0.04	5.0	I	
01/02 17:00:00	21.94035108	21.57387933	0.1	39.46085898	1.00	1.2	-0.02	5.0	I	
01/02 18:00:00	21.92764189	21.51299618	0.1	39.39132611	1.00	1.2	-0.02	5.0	I	
01/02 19:00:00	21.70743306	21.49320646	0.1	39.01949662	1.00	1.2	-0.05	5.1		
01/02 20:00:00	21.44877716	21.45349934	0.1	39.07953064	1.00	1.2	-0.09	5.2		
01/02 21:00:00	21.40195167	21.40881032	0.1	38.53394950	1.00	1.2	-0.10	5.2		
01/02 22:00:00	21.34630438	21.37616984	0.1	38.31237480	1.00	1.2	-0.11	5.3		
01/02 23:00:00	20.23133134	21.34182410	0.1	39.81961157	1.00	1.2	-0.23	6.1		
01/02 24:00:00	20.37026870	21.15057970	0.1	37.79727395	1.00	1.2	-0.25	6.3		
01/03 01:00:00	20.22826058	21.10540152	0.1	37.04657109	1.00	1.2	-0.27	6.5		
01/03 02:00:00	20.15619143	21.02772629	0.1	36.34495460	1.00	1.2	-0.29	6.8		
01/03 03:00:00	20.06152825	20.95398099	0.1	35.62514319	1.00	1.2	-0.31	7.0		
01/03 04:00:00	19.98224120	20.87944358	0.1	35.11622992	1.00	1.2	-0.33	7.3		
01/03 05:00:00	19.90770115	20.80673530	0.1	34.73386813	1.00	1.2	-0.35	7.5		
01/03 06:00:00	19.83351692	20.73548952	0.1	34.23223162	1.00	1.2	-0.37	7.8		
01/03 07:00:00	20.63662056	20.66513592	0.1	32.53039666	1.00	1.2	-0.29	6.8		
01/03 08:00:00	20.89564770	20.70734840	0.1	32.30440204	1.00	1.2	-0.26	6.4		
01/03 09:00:00	21.31033664	20.77773634	0.1	33.52011796	1.00	1.2	-0.20	5.9	I	Sat
01/03 10:00:00	21.62505234	20.87321682	0.1	36.54934855	1.00	1.2	-0.14	5.4	I	I
01/03 11:00:00	22.07749012	21.15945537	0.1	37.68340481	1.00	1.2	-0.05	5.1	I	
01/03 12:00:00	22.59519814	21.60978672	0.1	38.12565111	1.00	1.2	0.05	5.1	I	
01/03 13:00:00	22.65548299	22.06447683	0.1	38.38957456	1.00	1.2	0.11	5.2		
01/03 14:00:00	23.08544233	22.42935768	0.1	37.50525726	1.00	1.2	0.19	5.7		
01/05 06:00:00	18.50793556	19.59716271	0.1	25.51490904	1.00	1.2	-0.67	14.4		
01/05 07:00:00	19.35266760	19.52092032	0.1	24.34516161	1.00	1.2	-0.59	12.3		
01/05 08:00:00	20.99652946	19.57061415	0.1	25.29835226	1.00	1.2	-0.40	8.4	II	Mon

01/05 09:00:00	21.00000000	19.79527178	0.1	31.20911488	1.00	1.2	-0.35	7.5	II	
01/05 10:00:00	21.00000000	19.89104033	0.1	32.46395573	1.00	1.2	-0.33	7.3	II	
01/05 11:00:00	21.00000000	19.96977568	0.1	32.85589242	1.00	1.2	-0.32	7.1	II	
01/05 12:00:00	21.00000000	20.05593779	0.1	32.90920048	1.00	1.2	-0.31	7.0	II	II
01/05 13:00:00	21.23423862	20.11415216	0.1	31.58237805	1.00	1.2	-0.29	6.7	II	
01/05 14:00:00	21.00042019	20.21895302	0.1	31.94758726	1.00	1.2	-0.30	6.9	II	
01/05 15:00:00	21.00000000	20.33656664	0.1	31.50123445	1.00	1.2	-0.29	6.8	II	
01/05 16:00:00	21.00000000	20.38832255	0.1	31.28434828	1.00	1.2	-0.29	6.7	II	
01/05 17:00:00	21.00000000	20.24022501	0.1	32.16710285	1.00	1.2	-0.30	6.8	II	
01/05 18:00:00	20.32130102	20.22303404	0.1	32.69552386	1.00	1.2	-0.37	7.9	II	
01/05 19:00:00	20.11990864	20.12660093	0.1	31.41568371	1.00	1.2	-0.41	8.5		
01/05 20:00:00	19.91642563	20.07370688	0.1	30.81424386	1.00	1.2	-0.44	9.1		
01/05 21:00:00	19.87380841	20.01924158	0.1	29.90690531	1.00	1.2	-0.46	9.4		
01/05 22:00:00	19.80914578	19.97579971	0.1	29.29100480	1.00	1.2	-0.47	9.7		
01/05 23:00:00	18.50502184	19.93141630	0.1	30.17351139	1.00	1.2	-0.61	12.9		
01/05 24:00:00	18.72449165	19.68107462	0.1	27.49678022	1.00	1.2	-0.63	13.3		
01/06 01:00:00	18.56770543	19.63478092	0.1	26.47474262	1.00	1.2	-0.65	14.0		
01/06 02:00:00	18.49369965	19.53987098	0.1	25.51287237	1.00	1.2	-0.67	14.6		
01/06 03:00:00	18.38135646	19.45247071	0.1	24.91508712	1.00	1.2	-0.70	15.3		
01/06 04:00:00	18.27442664	19.36182511	0.1	24.55786141	1.00	1.2	-0.72	16.0		
01/06 05:00:00	18.21330490	19.27422822	0.1	24.42071609	1.00	1.2	-0.74	16.5		
01/06 06:00:00	18.12040176	19.19168735	0.1	24.34145657	1.00	1.2	-0.76	17.2		
01/06 07:00:00	18.95653179	19.11122033	0.1	23.27811682	1.00	1.2	-0.68	14.7		
01/06 08:00:00	20.99472045	19.15491047	0.1	24.69019681	1.00	1.2	-0.45	9.2	II	Tue
01/06 09:00:00	21.00000000	19.42723880	0.1	31.92561861	1.00	1.2	-0.38	8.0	II	
01/06 10:00:00	21.00000000	19.52403334	0.1	33.19890470	1.00	1.2	-0.36	7.7	II	
01/06 11:00:00	21.00000000	19.59728650	0.1	33.52941041	1.00	1.2	-0.35	7.6	II	
01/06 12:00:00	21.00000000	19.65938731	0.1	33.52701412	1.00	1.2	-0.35	7.5	II	II
01/06 13:00:00	21.00000000	19.69607812	0.1	32.86272597	1.00	1.2	-0.35	7.5	II	
01/06 14:00:00	21.00000000	19.74351171	0.1	32.93454841	1.00	1.2	-0.34	7.4	II	
01/06 15:00:00	21.00000000	19.77742374	0.1	32.29206427	1.00	1.2	-0.34	7.5	II	
01/06 16:00:00	21.00000000	19.80341848	0.1	31.64574904	1.00	1.2	-0.34	7.5	II	
01/06 17:00:00	21.00000000	19.82705057	0.1	32.47552363	1.00	1.2	-0.34	7.4	II	
01/06 18:00:00	19.81591021	19.83917766	0.1	33.41893966	1.00	1.2	-0.46	9.5	II	
01/06 19:00:00	19.56974090	19.68782343	0.1	31.80135815	1.00	1.2	-0.51	10.5		
01/06 20:00:00	19.39400170	19.61847485	0.1	30.80443450	1.00	1.2	-0.54	11.2		
01/06 21:00:00	19.35269758	19.55420464	0.1	29.94671830	1.00	1.2	-0.56	11.6		
01/06 22:00:00	19.28529468	19.50032734	0.1	29.23389128	1.00	1.2	-0.57	11.9		
01/06 23:00:00	17.90207530	19.44651196	0.1	30.16600551	1.00	1.2	-0.73	16.5		
01/06 24:00:00	18.11901175	19.17375548	0.1	27.21760927	1.00	1.2	-0.75	16.8		
01/07 01:00:00	17.95082240	19.11474047	0.1	25.65093505	1.00	1.2	-0.78	17.9		
01/07 02:00:00	17.86405768	19.00743313	0.1	24.15967876	1.00	1.2	-0.81	18.8		
01/07 03:00:00	17.73219626	18.90777697	0.1	23.26254834	1.00	1.2	-0.84	19.9		
01/07 04:00:00	17.63828923	18.80529072	0.1	22.59391044	1.00	1.2	-0.86	20.7		
01/07 05:00:00	17.52699577	18.70573422	0.1	21.42326587	1.00	1.2	-0.89	21.8		
01/07 06:00:00	17.43124808	18.60736687	0.1	20.59481491	1.00	1.2	-0.91	22.7		
01/07 07:00:00	18.30327442	18.51532344	0.1	19.53425357	1.00	1.2	-0.82	19.4		
01/07 08:00:00	20.99088010	18.56813637	0.1	22.78315612	1.00	1.2	-0.51	10.6	III	Wed
01/07 09:00:00	21.00000000	18.99308903	0.1	31.73301635	1.00	1.2	-0.42	8.7	II	
01/07 10:00:00	21.00000000	19.15216026	0.1	33.04370281	1.00	1.2	-0.40	8.3	II	
01/07 11:00:00	21.00000000	19.36478372	0.1	33.18496975	1.00	1.2	-0.38	8.0	II	
01/07 12:00:00	21.00000000	19.49789471	0.1	33.05302140	1.00	1.2	-0.37	7.8	II	II
01/07 13:00:00	21.00000000	19.50030278	0.1	32.85736763	1.00	1.2	-0.37	7.8	II	
01/07 14:00:00	21.00000000	20.12856042	0.1	31.63866013	1.00	1.2	-0.31	7.0	II	
01/07 15:00:00	21.00000000	19.90573732	0.1	31.21440363	1.00	1.2	-0.34	7.4	II	
01/07 16:00:00	21.00000000	19.74930253	0.1	31.63247643	1.00	1.2	-0.35	7.5	II	
01/07 17:00:00	21.00000000	19.75754095	0.1	33.28875375	1.00	1.2	-0.34	7.4	II	
01/07 18:00:00	19.83621708	19.76886140	0.1	34.28470543	1.00	1.2	-0.46	9.5	II	
01/07 19:00:00	19.55350822	19.61850343	0.1	32.57885116	1.00	1.2	-0.52	10.6		
01/07 20:00:00	19.36373759	19.54895360	0.1	31.99950457	1.00	1.2	-0.55	11.3		
01/07 21:00:00	19.32438404	19.48532550	0.1	31.11960533	1.00	1.2	-0.56	11.6		
01/07 22:00:00	19.25834279	19.43330549	0.1	30.39119170	1.00	1.2	-0.58	12.0		
01/07 23:00:00	17.95448898	19.38128016	0.1	31.26685721	1.00	1.2	-0.73	16.3		
01/07 24:00:00	18.11592208	19.12936796	0.1	28.41401009	1.00	1.2	-0.75	16.8		
01/08 01:00:00	17.94498169	19.06573379	0.1	26.76055410	1.00	1.2	-0.78	17.9		
01/08 02:00:00	17.88335827	18.96210998	0.1	25.53996150	1.00	1.2	-0.80	18.7		
01/08 03:00:00	17.75807600	18.86840076	0.1	24.91441943	1.00	1.2	-0.83	19.6		
01/08 04:00:00	17.67000502	18.77167101	0.1	24.34401805	1.00	1.2	-0.85	20.4		
01/08 05:00:00	17.56575709	18.67884975	0.1	24.05859479	1.00	1.2	-0.87	21.3		
01/08 06:00:00	17.47615319	18.58701011	0.1	24.22997140	1.00	1.2	-0.89	22.0		
01/08 07:00:00	18.32943487	18.50128385	0.1	23.21596121	1.00	1.2	-0.80	18.7		
01/08 08:00:00	20.99111631	18.54374853	0.1	25.22891687	1.00	1.2	-0.50	10.3	III	Thu
01/08 09:00:00	21.00000000	18.92582874	0.1	34.08637247	1.00	1.2	-0.42	8.6	II	
01/08 10:00:00	21.00000000	19.06281673	0.1	35.26483707	1.00	1.2	-0.40	8.3	II	

01/08 11:00:00	21.00000000	19.17066210	0.1	35.33633716	1.00	1.2	-0.38	8.1	II	
01/08 12:00:00	21.00000000	19.26342998	0.1	35.26867056	1.00	1.2	-0.38	8.0	II	II
01/08 13:00:00	21.00000000	19.32822747	0.1	34.93040805	1.00	1.2	-0.37	7.9	II	
01/08 14:00:00	21.00000000	19.39772794	0.1	35.05753225	1.00	1.2	-0.36	7.8	II	
01/08 15:00:00	21.00000000	19.44539571	0.1	34.60661021	1.00	1.2	-0.36	7.7	II	
01/08 16:00:00	21.00000000	19.49393698	0.1	34.12710022	1.00	1.2	-0.36	7.7	II	
01/08 17:00:00	21.00000000	19.51983813	0.1	34.86775714	1.00	1.2	-0.35	7.6	II	
01/08 18:00:00	19.54577456	19.54336009	0.1	35.97719140	1.00	1.2	-0.51	10.4	III	
01/08 19:00:00	19.22706984	19.35567400	0.1	33.49053640	1.00	1.2	-0.57	11.9		
01/08 20:00:00	19.05198808	19.27289101	0.1	31.95487483	1.00	1.2	-0.61	12.8		
01/08 21:00:00	19.00157308	19.20217642	0.1	30.85051033	1.00	1.2	-0.63	13.3		
01/08 22:00:00	18.92469138	19.14174727	0.1	29.96130390	1.00	1.2	-0.64	13.8		
01/08 23:00:00	17.56648663	19.08291942	0.1	30.74793581	1.00	1.2	-0.81	18.9		
01/08 24:00:00	17.74266825	18.81692246	0.1	27.52786701	1.00	1.2	-0.82	19.4		
01/09 01:00:00	17.56641325	18.74588428	0.1	25.95734807	1.00	1.2	-0.86	20.7		
01/09 02:00:00	17.48178413	18.63485674	0.1	25.02520996	1.00	1.2	-0.88	21.6		
01/09 03:00:00	17.36295502	18.53280133	0.1	24.43210473	1.00	1.2	-0.91	22.7		
01/09 04:00:00	17.26421278	18.43018847	0.1	23.98932213	1.00	1.2	-0.94	23.6		
01/09 05:00:00	17.16268390	18.33119457	0.1	23.67536679	1.00	1.2	-0.96	24.5		
01/09 06:00:00	17.06462129	18.23376169	0.1	23.44095622	1.00	1.2	-0.98	25.4		
01/09 07:00:00	17.93728160	18.14123935	0.1	22.31733274	1.00	1.2	-0.89	21.7		
01/09 08:00:00	20.98923359	18.18435021	0.1	25.08500839	1.00	1.2	-0.54	11.1	III	Fri
01/09 09:00:00	21.00000000	18.63218877	0.1	34.70402844	1.00	1.2	-0.44	9.1	II	
01/09 10:00:00	21.00000000	18.78638411	0.1	35.65417246	1.00	1.2	-0.42	8.7	II	
01/09 11:00:00	21.00000000	18.90815168	0.1	35.87961930	1.00	1.2	-0.41	8.5	II	
01/09 12:00:00	21.00000000	19.00987304	0.1	35.28554025	1.00	1.2	-0.40	8.4	II	II
01/09 13:00:00	21.00000000	19.08305382	0.1	34.90870718	1.00	1.2	-0.40	8.3	II	
01/09 14:00:00	21.00000000	19.16353488	0.1	34.32163607	1.00	1.2	-0.39	8.2	II	
01/09 15:00:00	21.00000000	19.22304478	0.1	33.78030076	1.00	1.2	-0.39	8.2	II	
01/09 16:00:00	21.00000000	19.27615613	0.1	33.90946418	1.00	1.2	-0.38	8.1	II	
01/09 17:00:00	21.00000000	19.32208742	0.1	34.80973652	1.00	1.2	-0.37	7.9	II	
01/09 18:00:00	19.26463450	19.35374633	0.1	35.98874294	1.00	1.2	-0.56	11.5	III	
01/09 19:00:00	18.93028350	19.12950089	0.1	32.43392716	1.00	1.2	-0.63	13.5		
01/09 20:00:00	18.77104722	19.03582160	0.1	31.42918965	1.00	1.2	-0.66	14.4		
01/09 21:00:00	18.72706567	18.95940513	0.1	30.36633329	1.00	1.2	-0.68	14.9		
01/09 22:00:00	18.65087023	18.89487463	0.1	29.50668472	1.00	1.2	-0.70	15.4		
01/09 23:00:00	17.28021799	18.83173112	0.1	30.25258555	1.00	1.2	-0.87	21.1		
01/09 24:00:00	17.43299421	18.55748699	0.1	27.01796589	1.00	1.2	-0.89	21.8		
01/10 01:00:00	17.28291634	18.47967698	0.1	25.28973016	1.00	1.2	-0.92	23.1		
01/10 02:00:00	17.20049976	18.36728861	0.1	24.40254578	1.00	1.2	-0.95	24.1		
01/10 03:00:00	17.09449789	18.26445450	0.1	23.87122157	1.00	1.2	-0.97	25.1		
01/10 04:00:00	16.99881089	18.16219345	0.1	23.54188478	1.00	1.2	-0.99	26.0		
01/10 05:00:00	16.90215197	18.06209753	0.1	23.36273295	1.00	1.2	-1.02	26.9		
01/10 06:00:00	16.80904477	17.96420030	0.1	23.28038858	1.00	1.2	-1.04	27.8		
01/10 07:00:00	17.74266238	17.86961033	0.1	21.92167037	1.00	1.2	-0.93	23.6		
01/10 08:00:00	17.86247645	17.91623342	0.1	21.87138575	1.00	1.2	-0.92	22.9		
01/10 09:00:00	20.98829883	17.92746684	0.1	25.78132599	1.00	1.2	-0.56	11.6	III	Sat
01/10 10:00:00	21.00000000	18.40082685	0.1	36.82755053	1.00	1.2	-0.45	9.3	II	II
01/10 11:00:00	21.00000000	18.57235527	0.1	38.95559926	1.00	1.2	-0.42	8.8	II	
01/10 12:00:00	21.00000000	18.70248693	0.1	39.37172003	1.00	1.2	-0.41	8.5	II	
01/10 13:00:00	21.00000000	18.79929253	0.1	41.42307288	1.00	1.2	-0.39	8.1		
01/10 14:00:00	19.19035564	18.88139200	0.1	44.55601725	1.00	1.2	-0.57	11.9		
01/10 15:00:00	18.65376478	18.64477777	0.1	43.05444171	1.00	1.2	-0.66	14.2		
01/10 16:00:00	18.46710781	18.54792580	0.1	41.12668961	1.00	1.2	-0.70	15.4		
01/10 17:00:00	18.40182740	18.47524998	0.1	39.56024525	1.00	1.2	-0.72	16.0		
01/10 18:00:00	18.33934068	18.41959746	0.1	38.14301788	1.00	1.2	-0.74	16.6		
01/10 19:00:00	16.97416184	18.36855263	0.1	38.21060887	1.00	1.2	-0.92	22.8		
01/10 20:00:00	17.12547985	18.11362312	0.1	32.81759639	1.00	1.2	-0.94	23.9		
01/10 21:00:00	16.89609954	18.05183096	0.1	29.89907828	1.00	1.2	-0.99	25.8		
01/10 22:00:00	16.83250866	17.94201857	0.1	28.14937212	1.00	1.2	-1.02	26.9		
01/10 23:00:00	16.71220214	17.84553347	0.1	26.56557881	1.00	1.2	-1.05	28.2		
01/10 24:00:00	16.60987139	17.74558248	0.1	25.15421525	1.00	1.2	-1.07	29.5		
01/19 06:00:00	15.60000038	16.30359517	0.1	29.71763299	1.00	1.2	-1.31	41.0		
01/19 07:00:00	16.17182664	16.25503966	0.1	28.56474356	1.00	1.2	-1.25	37.8		
01/19 08:00:00	20.97832426	16.28447861	0.1	29.30235074	1.00	1.2	-0.70	15.4	IV	Mon
01/19 09:00:00	21.00000000	17.16536887	0.1	39.95277724	1.00	1.2	-0.55	11.5	III	
01/19 10:00:00	21.00000000	17.48061519	0.1	40.11681046	1.00	1.2	-0.52	10.8	III	
01/19 11:00:00	21.00000000	17.85943822	0.1	39.40016167	1.00	1.2	-0.49	10.0	II	
01/19 12:00:00	21.00000000	18.32273366	0.1	38.39496627	1.00	1.2	-0.45	9.3	II	II
01/19 13:00:00	21.00000000	18.75717476	0.1	37.87663306	1.00	1.2	-0.41	8.5	II	
01/19 14:00:00	21.00000000	19.14427418	0.1	35.59492101	1.00	1.2	-0.39	8.1	II	
01/19 15:00:00	21.00000000	19.28754058	0.1	34.77832596	1.00	1.2	-0.38	8.0	II	
01/19 16:00:00	21.00000000	19.29649421	0.1	34.14871606	1.00	1.2	-0.38	8.0	II	
01/19 17:00:00	21.00000000	19.02974576	0.1	35.45775372	1.00	1.2	-0.40	8.3	II	

01/19 18:00:00	19.46703760	19.05350101	0.1	37.21591791	1.00	1.2	-0.56	11.6	III	
01/19 19:00:00	19.04000238	18.82736972	0.1	35.54898563	1.00	1.2	-0.64	13.5		
01/19 20:00:00	18.68420437	18.73550313	0.1	35.06855966	1.00	1.2	-0.69	15.0		
01/21 06:00:00	17.26373693	18.12993723	0.1	33.58740189	1.00	1.2	-0.92	23.0		
01/21 07:00:00	18.03855478	18.05629919	0.1	32.27603135	1.00	1.2	-0.84	19.9		
01/21 08:00:00	20.99020760	18.08961681	0.1	31.29758086	1.00	1.2	-0.51	10.5	III	Wed
01/21 09:00:00	21.00000000	18.57278579	0.1	39.58385180	1.00	1.2	-0.42	8.7	II	
01/21 10:00:00	21.00000000	18.77128619	0.1	41.36850483	1.00	1.2	-0.39	8.2	II	
01/21 11:00:00	21.00000000	18.96048736	0.1	41.81021490	1.00	1.2	-0.37	7.9	II	
01/21 12:00:00	21.00000000	19.13840805	0.1	40.88097776	1.00	1.2	-0.36	7.7	II	II
01/21 13:00:00	21.00000000	19.27782141	0.1	40.65395598	1.00	1.2	-0.34	7.5	II	
01/21 14:00:00	21.00000000	19.34703457	0.1	40.45645155	1.00	1.2	-0.34	7.4	II	
01/21 15:00:00	21.00000000	19.41629258	0.1	40.60452242	1.00	1.2	-0.33	7.3	II	
01/21 16:00:00	21.00000000	19.48404249	0.1	40.17877159	1.00	1.2	-0.33	7.2	II	
01/21 17:00:00	21.00000000	19.44538493	0.1	40.15006319	1.00	1.2	-0.33	7.3	II	
01/21 18:00:00	20.00190331	19.47327522	0.1	41.77343473	1.00	1.2	-0.43	9.0	II	
01/21 19:00:00	19.70163115	19.33499254	0.1	41.27568164	1.00	1.2	-0.48	9.9		
01/21 20:00:00	19.35868394	19.27712061	0.1	41.44950320	1.00	1.2	-0.53	10.8		
02/18 06:00:00	17.45524955	18.53369996	0.1	28.80416006	1.00	1.2	-0.88	21.5		
02/18 07:00:00	18.28112181	18.43285688	0.1	27.35378083	1.00	1.2	-0.80	18.5		
02/18 08:00:00	20.99152657	18.46151336	0.1	27.72950307	1.00	1.2	-0.50	10.2	III	Wed
02/18 09:00:00	21.00000000	18.84239351	0.1	35.34227345	1.00	1.2	-0.42	8.6	II	
02/18 10:00:00	21.00000000	18.98201989	0.1	36.69316484	1.00	1.2	-0.40	8.3	II	
02/18 11:00:00	21.00000000	19.12693767	0.1	37.55581208	1.00	1.2	-0.38	8.0	II	
02/18 12:00:00	21.00000000	19.24727472	0.1	38.00991386	1.00	1.2	-0.36	7.8	II	II
02/18 13:00:00	21.00000000	19.28536296	0.1	37.76018853	1.00	1.2	-0.36	7.7	II	
02/18 14:00:00	21.00000000	19.89826463	0.1	36.20341396	1.00	1.2	-0.31	7.0	II	
02/18 15:00:00	21.00000000	20.42738406	0.1	33.40764827	1.00	1.2	-0.27	6.5	II	
02/18 16:00:00	21.37007762	20.76117472	0.1	31.32251365	1.00	1.2	-0.21	5.9	I	
02/18 17:00:00	21.00196834	20.70151349	0.1	32.00074878	1.00	1.2	-0.25	6.3	II	
02/18 18:00:00	20.23390407	20.09720374	0.1	32.67497275	1.00	1.2	-0.39	8.3	II	
02/18 19:00:00	19.93819844	19.90550139	0.1	31.47842633	1.00	1.2	-0.45	9.3		
02/18 20:00:00	19.67434375	19.80149784	0.1	31.33782771	1.00	1.2	-0.49	10.1		
03/18 06:00:00	22.24376825	22.23368573	0.1	32.78967181	0.70	1.2	-0.41	8.6		
03/18 07:00:00	22.84419546	22.28003484	0.1	31.86099129	0.70	1.2	-0.34	7.4		
03/18 08:00:00	23.53262921	22.39531269	0.1	31.55451741	0.70	1.2	-0.23	6.1	~ I	Wed
03/18 09:00:00	24.18533764	22.53622598	0.1	32.66611957	0.70	1.2	-0.12	5.3	I	
03/18 10:00:00	25.00000000	22.66364084	0.1	31.84787297	0.70	1.2	-0.01	5.0	I	
03/18 11:00:00	25.00000000	22.84403068	0.1	31.30653050	0.70	1.2	0.01	5.0	I	
03/18 12:00:00	25.00000000	23.31974933	0.1	29.52407166	0.70	1.2	0.06	5.1	I	I
03/18 13:00:00	25.00000000	23.93266430	0.1	28.23256467	0.70	1.2	0.12	5.3	I	
03/18 14:00:00	25.00000000	24.51259561	0.1	27.79095294	0.70	1.2	0.19	5.8	I	
03/18 15:00:00	25.00000000	25.00545828	0.1	27.94522032	0.70	1.2	0.25	6.3	II	
03/18 16:00:00	25.00000000	25.33222612	0.1	28.93636063	0.70	1.2	0.30	6.9	II	
03/18 17:00:00	25.00000000	25.16110693	0.1	29.85844677	0.70	1.2	0.28	6.7	II	
03/18 18:00:00	25.11162458	24.59664455	0.1	30.86005980	0.70	1.2	0.24	6.2	II	
03/18 19:00:00	24.62742994	24.40567313	0.1	31.16673190	0.70	1.2	0.15	5.5		
03/18 20:00:00	24.48381663	24.28684461	0.1	31.03099522	0.70	1.2	0.12	5.3		
04/22 06:00:00	24.08616588	24.13817502	0.1	25.57573695	0.38	1.2	-0.59	12.5		
04/22 07:00:00	24.77714106	24.22210677	0.1	25.77340676	0.38	1.2	-0.47	9.7		
04/22 08:00:00	24.99950591	24.34663151	0.1	28.84627966	0.38	1.2	-0.40	8.3	II	Wed
04/22 09:00:00	25.00000000	24.41702351	0.1	32.79152149	0.38	1.2	-0.36	7.7	II	
04/22 10:00:00	25.00000000	24.45928738	0.1	33.44213579	0.38	1.2	-0.35	7.5	II	
04/22 11:00:00	25.00000000	24.55320677	0.1	36.96339421	0.38	1.2	-0.31	7.0	II	
04/22 12:00:00	25.00000000	24.62589551	0.1	36.14892133	0.38	1.2	-0.30	6.9	II	II
04/22 13:00:00	25.00000000	24.79215146	0.1	35.26469133	0.38	1.2	-0.28	6.7	II	
04/22 14:00:00	25.00000000	25.10442011	0.1	34.66692134	0.38	1.2	-0.24	6.2	II	
04/22 15:00:00	25.00000000	25.48530150	0.1	34.14732602	0.38	1.2	-0.18	5.7	I	
04/22 16:00:00	25.00000000	25.64897194	0.1	33.33025935	0.38	1.2	-0.16	5.5	I	
04/22 17:00:00	26.57842920	25.77148440	0.1	29.72715801	0.38	1.2	0.09	5.2	I	
04/22 18:00:00	26.23995752	25.80802109	0.1	29.71810320	0.38	1.2	0.04	5.0	I	
04/22 19:00:00	25.55924916	25.34671511	0.1	30.34193213	0.38	1.2	-0.14	5.4		
04/22 20:00:00	25.39025727	25.20129415	0.1	30.24007937	0.38	1.2	-0.19	5.8		
05/20 06:00:00	25.90509311	25.53028115	0.1	50.45166458	0.38	1.2	0.09	5.2		
05/20 07:00:00	25.00870065	25.64379673	0.1	52.68602584	0.38	1.2	-0.02	5.0		
05/20 08:00:00	25.00000000	25.65038001	0.1	50.57499168	0.38	1.2	-0.04	5.0	I	Wed
05/20 09:00:00	25.00000000	25.69180788	0.1	49.89043895	0.38	1.2	-0.04	5.0	I	
05/20 10:00:00	25.00000000	25.72822477	0.1	48.13628078	0.38	1.2	-0.04	5.0	I	
05/20 11:00:00	25.00000000	25.78586991	0.1	48.80214647	0.38	1.2	-0.03	5.0	I	
05/20 12:00:00	25.00000000	25.92436282	0.1	47.47584823	0.38	1.2	-0.02	5.0	I	I
05/20 13:00:00	25.00000000	26.16677062	0.1	48.20793083	0.38	1.2	0.02	5.0	I	
05/20 14:00:00	25.00000000	26.36643857	0.1	48.66219914	0.38	1.2	0.06	5.1	I	
05/20 15:00:00	25.00000000	26.51162518	0.1	48.63853613	0.38	1.2	0.08	5.1	I	
05/20 16:00:00	25.00000000	26.56042415	0.1	48.69496436	0.38	1.2	0.09	5.2	I	

05/20 17:00:00	26.69571973	26.55330142	0.1	44.67654899	0.38	1.2	0.34	7.5	II	
05/20 18:00:00	26.69983141	26.63986515	0.1	44.85957791	0.38	1.2	0.36	7.7	II	
05/20 19:00:00	26.69999897	26.33504207	0.1	44.98787961	0.38	1.2	0.31	7.0		
05/20 20:00:00	26.70000076	26.29742207	0.1	45.75848617	0.38	1.2	0.31	7.0		
06/17 06:00:00	26.66241306	26.59762488	0.1	42.35629233	0.38	1.2	0.33	7.2		
06/17 07:00:00	25.03043122	26.68838081	0.1	47.71876772	0.38	1.2	0.11	5.2		
06/17 08:00:00	25.00000029	26.57145206	0.1	49.81599136	0.38	1.2	0.10	5.2	I	Wed
06/17 09:00:00	25.00000006	26.55558256	0.1	49.90164148	0.38	1.2	0.10	5.2	I	
06/17 10:00:00	25.00000001	26.52653793	0.1	49.10315217	0.38	1.2	0.09	5.2	I	
06/17 11:00:00	25.00000000	26.52361956	0.1	49.35296625	0.38	1.2	0.09	5.2	I	
06/17 12:00:00	25.00000000	26.58026261	0.1	48.11587059	0.38	1.2	0.09	5.2	I	I
06/17 13:00:00	25.00000000	26.71367339	0.1	49.17187427	0.38	1.2	0.12	5.3	I	
06/17 14:00:00	25.00000000	26.83599514	0.1	48.97923307	0.38	1.2	0.14	5.4	I	
06/17 15:00:00	25.00000000	26.88546388	0.1	48.51583262	0.38	1.2	0.14	5.4	I	
06/17 16:00:00	25.00000000	26.84720472	0.1	49.91520250	0.38	1.2	0.14	5.4	I	
06/17 17:00:00	26.69609729	26.81342003	0.1	45.87104865	0.38	1.2	0.39	8.3	II	
06/17 18:00:00	26.70000076	26.86546327	0.1	46.15559207	0.38	1.2	0.41	8.4	II	
06/17 19:00:00	26.70000076	26.80348281	0.1	45.94082867	0.38	1.2	0.39	8.3		
06/17 20:00:00	26.70000076	26.68198997	0.1	45.75185371	0.38	1.2	0.37	7.9		
07/15 06:00:00	26.52404856	26.46259110	0.1	39.78582918	0.38	1.2	0.26	6.4		
07/15 07:00:00	25.02499470	26.57274463	0.1	44.25250364	0.38	1.2	0.07	5.1		
07/15 08:00:00	25.00000014	26.48118362	0.1	46.15718959	0.38	1.2	0.06	5.1	I	Wed
07/15 09:00:00	25.00000003	26.45708541	0.1	46.14173085	0.38	1.2	0.06	5.1	I	
07/15 10:00:00	25.00000000	26.44586256	0.1	46.02806500	0.38	1.2	0.05	5.1	I	
07/15 11:00:00	25.00000000	26.44998069	0.1	46.52052225	0.38	1.2	0.06	5.1	I	
07/15 12:00:00	25.00000000	26.47206571	0.1	45.79528078	0.38	1.2	0.06	5.1	I	I
07/15 13:00:00	25.00000000	26.56077456	0.1	46.11014438	0.38	1.2	0.07	5.1	I	
07/15 14:00:00	25.00000000	26.60208457	0.1	45.54037804	0.38	1.2	0.08	5.1	I	
07/15 15:00:00	25.00000000	26.59845068	0.1	45.29570643	0.38	1.2	0.07	5.1	I	
07/15 16:00:00	25.00000000	26.56840129	0.1	45.16566317	0.38	1.2	0.07	5.1	I	
07/15 17:00:00	26.66191969	26.49708493	0.1	41.09330990	0.38	1.2	0.30	6.9	II	
07/15 18:00:00	26.70000076	26.58272527	0.1	42.59641128	0.38	1.2	0.33	7.3	II	
07/15 19:00:00	26.70000076	26.56720057	0.1	42.20187158	0.38	1.2	0.33	7.2		
07/15 20:00:00	26.70000076	26.45758513	0.1	41.77211140	0.38	1.2	0.31	7.0		
08/19 06:00:00	26.70000076	26.91794937	0.1	62.08947658	0.38	1.2	0.54	11.1		
08/19 07:00:00	25.03798020	26.96883498	0.1	61.81076352	0.38	1.2	0.25	6.4		
08/19 08:00:00	25.00000153	26.81705747	0.1	58.81030458	0.38	1.2	0.20	5.9	I	Wed
08/19 09:00:00	25.00000039	26.78079585	0.1	58.45276957	0.38	1.2	0.19	5.8	I	
08/19 10:00:00	25.00000010	26.76481881	0.1	56.60435420	0.38	1.2	0.18	5.7	I	
08/19 11:00:00	25.00000003	26.75129867	0.1	54.98745476	0.38	1.2	0.17	5.6	I	
08/19 12:00:00	25.00000001	26.84994978	0.1	51.77012063	0.38	1.2	0.16	5.5	I	I
08/19 13:00:00	25.00000000	27.03201375	0.1	53.44615056	0.38	1.2	0.20	5.8	I	
08/19 14:00:00	25.00000000	27.16235665	0.1	53.30725413	0.38	1.2	0.22	6.0	I	
08/19 15:00:00	25.00000000	27.21210912	0.1	53.86332145	0.38	1.2	0.23	6.1	~ I	
08/19 16:00:00	25.00000000	27.20149381	0.1	54.51311749	0.38	1.2	0.23	6.1	~ I	
08/19 17:00:00	26.68853005	27.03887115	0.1	51.33016543	0.38	1.2	0.47	9.7	II	
08/19 18:00:00	26.70000076	27.10796502	0.1	52.32477005	0.38	1.2	0.49	10.1	~ II	
08/19 19:00:00	26.70000076	26.94175162	0.1	52.13393954	0.38	1.2	0.46	9.5		
08/19 20:00:00	26.70000076	26.92555809	0.1	52.66998145	0.38	1.2	0.47	9.6		
09/16 06:00:00	25.30160730	25.30995322	0.1	34.54600910	0.38	1.2	-0.16	5.5		
09/16 07:00:00	25.00161900	25.40201942	0.1	36.25465968	0.38	1.2	-0.18	5.7		
09/16 08:00:00	25.00000000	25.42789830	0.1	40.92715523	0.38	1.2	-0.14	5.4	I	Wed
09/16 09:00:00	25.00000000	25.46208444	0.1	44.48336167	0.38	1.2	-0.11	5.3	I	
09/16 10:00:00	25.00000000	25.49641548	0.1	45.22922769	0.38	1.2	-0.10	5.2	I	
09/16 11:00:00	25.00000000	25.57411515	0.1	46.57728157	0.38	1.2	-0.08	5.1	I	
09/16 12:00:00	25.00000000	25.87378075	0.1	46.19675547	0.38	1.2	-0.04	5.0	I	I
09/16 13:00:00	25.00000000	26.24872807	0.1	46.31184552	0.38	1.2	0.02	5.0	I	
09/16 14:00:00	25.00000000	26.57810137	0.1	45.90695110	0.38	1.2	0.07	5.1	I	
09/16 15:00:00	25.00000000	26.81874190	0.1	45.46144864	0.38	1.2	0.11	5.2	I	
09/16 16:00:00	25.00000000	26.92385453	0.1	45.11411378	0.38	1.2	0.12	5.3	I	
09/16 17:00:00	26.69903663	26.66108095	0.1	40.45384166	0.38	1.2	0.33	7.3	II	
09/16 18:00:00	26.69999712	26.27810125	0.1	39.99294721	0.38	1.2	0.26	6.5	II	
09/16 19:00:00	26.53177561	26.22597956	0.1	40.18837404	0.38	1.2	0.23	6.1		
09/16 20:00:00	26.46126238	26.17954177	0.1	40.23632724	0.38	1.2	0.21	5.9		
10/21 06:00:00	25.70368911	25.62296082	0.1	45.80492457	0.38	1.2	0.04	5.0		
10/21 07:00:00	26.30744270	25.65574405	0.1	44.79562238	0.38	1.2	0.14	5.4		
10/21 08:00:00	25.00000000	25.80295770	0.1	47.49549855	0.38	1.2	-0.04	5.0	I	Wed
10/21 09:00:00	25.00000000	25.91258013	0.1	51.21143627	0.38	1.2	0.01	5.0	I	
10/21 10:00:00	25.00000000	25.97749294	0.1	51.43074079	0.38	1.2	0.02	5.0	I	
10/21 11:00:00	25.00000000	26.10947335	0.1	50.71311062	0.38	1.2	0.03	5.0	I	
10/21 12:00:00	25.00000000	26.23459491	0.1	48.06637446	0.38	1.2	0.03	5.0	I	I
10/21 13:00:00	25.00000000	26.22475485	0.1	48.72154312	0.38	1.2	0.04	5.0	I	
10/21 14:00:00	25.00000000	26.25638823	0.1	49.44169980	0.38	1.2	0.05	5.0	I	
10/21 15:00:00	25.00000000	26.70709122	0.1	47.50261465	0.38	1.2	0.11	5.2	I	

10/21 16:00:00	25.00000000	26.56370753	0.1	47.81505749	0.38	1.2	0.09	5.2	I	
10/21 17:00:00	26.03663168	26.30433589	0.1	47.23490867	0.38	1.2	0.21	6.0	I	
10/21 18:00:00	26.37116833	26.26165117	0.1	46.47859387	0.38	1.2	0.26	6.4	II	
10/21 19:00:00	26.43854564	26.23791056	0.1	46.31433995	0.38	1.2	0.26	6.5		
10/21 20:00:00	26.37093440	26.18993599	0.1	45.51207872	0.38	1.2	0.24	6.2		
11/18 06:00:00	20.79221473	21.69878448	0.1	30.82737626	1.00	1.2	-0.18	5.7		
11/18 07:00:00	21.56897210	21.62630782	0.1	29.66656933	1.00	1.2	-0.11	5.3		
11/18 08:00:00	21.99430066	21.66345378	0.1	29.56594635	1.00	1.2	-0.06	5.1	I	Wed
11/18 09:00:00	22.36167817	21.74622179	0.1	31.82026341	1.00	1.2	0.00	5.0	I	
11/18 10:00:00	22.53939918	21.82553053	0.1	33.82797234	1.00	1.2	0.04	5.0	I	
11/18 11:00:00	22.82618834	21.96762727	0.1	34.43480825	1.00	1.2	0.09	5.2	I	
11/18 12:00:00	23.02496581	22.12775964	0.1	35.04189475	1.00	1.2	0.14	5.4	I	I
11/18 13:00:00	23.54780214	22.18174981	0.1	34.24920615	1.00	1.2	0.20	5.8	I	
11/18 14:00:00	22.97037826	22.20736850	0.1	36.49026478	1.00	1.2	0.15	5.4	I	
11/18 15:00:00	22.91977118	22.13437496	0.1	37.19684126	1.00	1.2	0.14	5.4	I	
11/18 16:00:00	22.80027850	22.13441942	0.1	37.89678118	1.00	1.2	0.13	5.3	I	
11/18 17:00:00	22.18917535	22.12803676	0.1	39.47113503	1.00	1.2	0.07	5.1	I	
11/18 18:00:00	22.33947285	22.05884925	0.1	39.36433665	1.00	1.2	0.08	5.1	I	
11/18 19:00:00	22.24237640	22.04295500	0.1	39.61310639	1.00	1.2	0.07	5.1		
11/18 20:00:00	22.02803720	22.00980046	0.1	39.89646778	1.00	1.2	0.04	5.0		
12/16 06:00:00	17.95914835	18.53943299	0.1	41.97709668	1.00	1.2	-0.76	17.1		
12/16 07:00:00	18.64402399	18.48653555	0.1	40.58777021	1.00	1.2	-0.69	15.0		
12/16 08:00:00	20.99259485	18.51312929	0.1	37.89116918	1.00	1.2	-0.44	9.0	II	Wed
12/16 09:00:00	21.00000000	18.91321084	0.1	42.94187612	1.00	1.2	-0.37	7.8	II	
12/16 10:00:00	21.00000000	19.06915090	0.1	44.08853313	1.00	1.2	-0.35	7.5	II	
12/16 11:00:00	21.00000000	19.27314300	0.1	44.56434179	1.00	1.2	-0.32	7.2	II	
12/16 12:00:00	21.00000000	19.39782071	0.1	44.30335240	1.00	1.2	-0.31	7.0	II	II
12/16 13:00:00	21.30160481	19.58187959	0.1	43.07812685	1.00	1.2	-0.27	6.5	II	
12/16 14:00:00	21.33654586	19.72454963	0.1	44.16325113	1.00	1.2	-0.24	6.2	II	
12/16 15:00:00	21.55915473	19.96540367	0.1	44.54557683	1.00	1.2	-0.19	5.8	I	
12/16 16:00:00	21.31366414	19.82184484	0.1	44.65724618	1.00	1.2	-0.23	6.1	~ I	
12/16 17:00:00	21.00054052	19.83659423	0.1	44.82004764	1.00	1.2	-0.27	6.5	II	
12/16 18:00:00	20.64051222	19.82017487	0.1	45.34099623	1.00	1.2	-0.31	7.0	II	
12/16 19:00:00	20.27538595	19.77363164	0.1	45.55723319	1.00	1.2	-0.35	7.6		
12/16 20:00:00	19.93154523	19.71990472	0.1	45.60412858	1.00	1.2	-0.40	8.3		

5th level - Office, South orientation

Date/Time [h]	Air Temperature [˚C]	Mean Radiant Temperature [˚C]	Relative Air Velocity [m/s]	Relative Humidity [%]	Clothing [clo]	Metabolic Rate [met]	PMV [-]	PPD [%]	Category [-]	
01/01 01:00:00	21.57001701	21.79723915	0.1	41.46852342	1.00	1.2	-0.03	5.0		
01/01 02:00:00	21.54409948	21.76296883	0.1	41.10909964	1.00	1.2	-0.03	5.0		
01/01 03:00:00	21.48662416	21.72477103	0.1	40.75018884	1.00	1.2	-0.05	5.0		
01/01 04:00:00	21.44851300	21.68539476	0.1	40.39141712	1.00	1.2	-0.06	5.1		
01/01 05:00:00	21.40401671	21.64604490	0.1	39.61127073	1.00	1.2	-0.07	5.1		
01/01 06:00:00	21.36196609	21.60718591	0.1	39.05155092	1.00	1.2	-0.08	5.1		
01/01 07:00:00	21.85988423	21.57125932	0.1	38.15440174	1.00	1.2	-0.03	5.0		
01/01 08:00:00	22.15868207	21.58385403	0.1	37.78543198	1.00	1.2	0.00	5.0	I	Thu
01/01 09:00:00	22.73271335	21.62517261	0.1	37.99197343	1.00	1.2	0.07	5.1	I	
01/01 10:00:00	22.65903817	21.71524553	0.1	40.02843217	1.00	1.2	0.08	5.1	I	
01/01 11:00:00	22.77055052	21.75233551	0.1	41.86156389	1.00	1.2	0.11	5.3	I	
01/01 12:00:00	22.80364733	21.80528929	0.1	40.68168483	1.00	1.2	0.11	5.3	I	I
01/01 13:00:00	23.16121982	21.84070833	0.1	39.45649418	1.00	1.2	0.15	5.5	I	
01/01 14:00:00	22.85008627	21.93254726	0.1	39.88799030	1.00	1.2	0.13	5.3	I	
01/01 15:00:00	22.95652331	21.94438014	0.1	39.41863353	1.00	1.2	0.14	5.4	I	
01/01 16:00:00	22.93914265	21.98726030	0.1	41.48624499	1.00	1.2	0.15	5.5	I	
01/01 17:00:00	22.54197706	22.01914568	0.1	43.15881384	1.00	1.2	0.12	5.3	I	
01/01 18:00:00	22.52898767	21.99056894	0.1	43.39836216	1.00	1.2	0.12	5.3	I	
01/01 19:00:00	22.34065916	21.98532914	0.1	43.73149578	1.00	1.2	0.10	5.2		
01/01 20:00:00	22.14808893	21.96090001	0.1	43.88624774	1.00	1.2	0.07	5.1		
01/01 21:00:00	22.12850352	21.93010131	0.1	43.49281017	1.00	1.2	0.06	5.1		
01/01 22:00:00	22.09791621	21.90930402	0.1	43.12569748	1.00	1.2	0.06	5.1		
01/01 23:00:00	21.51734514	21.88778213	0.1	43.63066901	1.00	1.2	-0.01	5.0		
01/01 24:00:00	21.50649515	21.81361606	0.1	42.20590418	1.00	1.2	-0.03	5.0		
01/02 01:00:00	21.46061782	21.77189451	0.1	40.91459589	1.00	1.2	-0.04	5.0		
01/02 02:00:00	21.38878412	21.72550587	0.1	39.66009549	1.00	1.2	-0.06	5.1		
01/02 03:00:00	21.32847165	21.67767860	0.1	38.71993699	1.00	1.2	-0.08	5.1		
01/02 04:00:00	21.27543174	21.63000305	0.1	37.88513416	1.00	1.2	-0.10	5.2		
01/02 05:00:00	21.21459163	21.58217045	0.1	37.11652609	1.00	1.2	-0.11	5.3		
01/02 06:00:00	21.16692253	21.53396642	0.1	36.53578847	1.00	1.2	-0.13	5.3		
01/02 07:00:00	21.64888972	21.48836704	0.1	35.53506693	1.00	1.2	-0.08	5.1		
01/02 08:00:00	21.98211037	21.49071288	0.1	35.10295684	1.00	1.2	-0.05	5.0	I	Fri
01/02 09:00:00	22.39386637	21.54144661	0.1	36.30809509	1.00	1.2	0.01	5.0	I	
01/02 10:00:00	22.43506047	21.61242147	0.1	38.54817445	1.00	1.2	0.04	5.0	I	
01/02 11:00:00	22.56606593	21.66359543	0.1	39.71354789	1.00	1.2	0.07	5.1	I	
01/02 12:00:00	22.62838378	21.71557332	0.1	38.84057416	1.00	1.2	0.07	5.1	I	I
01/02 13:00:00	23.01785908	21.74643926	0.1	37.61918729	1.00	1.2	0.11	5.3	I	
01/02 14:00:00	22.64236182	21.83766291	0.1	38.07719520	1.00	1.2	0.08	5.1	I	
01/02 15:00:00	22.72573191	21.83552833	0.1	37.95800833	1.00	1.2	0.09	5.2	I	
01/02 16:00:00	22.68365963	21.86361735	0.1	38.23245317	1.00	1.2	0.09	5.2	I	
01/02 17:00:00	22.22588065	21.88212167	0.1	39.33678055	1.00	1.2	0.05	5.0	I	
01/02 18:00:00	22.27055482	21.84038905	0.1	39.18616287	1.00	1.2	0.05	5.0	I	
01/02 19:00:00	22.11399135	21.83128692	0.1	38.90383525	1.00	1.2	0.03	5.0		
01/02 20:00:00	21.92881519	21.80309198	0.1	38.95177337	1.00	1.2	0.00	5.0		
01/02 21:00:00	21.90331898	21.76886886	0.1	38.53457814	1.00	1.2	-0.01	5.0		
01/02 22:00:00	21.85757015	21.74318732	0.1	38.37300577	1.00	1.2	-0.02	5.0		
01/02 23:00:00	21.08440487	21.71505878	0.1	39.31172980	1.00	1.2	-0.10	5.2		
01/02 24:00:00	21.18581770	21.60359937	0.1	37.62649949	1.00	1.2	-0.11	5.3		
01/03 01:00:00	21.11506502	21.56419518	0.1	36.66091457	1.00	1.2	-0.13	5.3		
01/03 02:00:00	21.05226447	21.50857883	0.1	35.91643427	1.00	1.2	-0.14	5.4		
01/03 03:00:00	20.98417226	21.45174204	0.1	35.15204483	1.00	1.2	-0.16	5.5		
01/03 04:00:00	20.92227514	21.39445143	0.1	34.53542287	1.00	1.2	-0.18	5.7		
01/03 05:00:00	20.86346982	21.33702982	0.1	34.01986529	1.00	1.2	-0.19	5.8		
01/03 06:00:00	20.80366589	21.27965739	0.1	33.45674251	1.00	1.2	-0.21	5.9		
01/03 07:00:00	21.33412082	21.22217016	0.1	32.31882171	1.00	1.2	-0.16	5.5		
01/03 08:00:00	21.52776268	21.22190373	0.1	32.14264315	1.00	1.2	-0.14	5.4		
01/03 09:00:00	21.76661542	21.25686317	0.1	33.48845341	1.00	1.2	-0.10	5.2	I	Sat
01/03 10:00:00	22.00291904	21.31011273	0.1	36.35900924	1.00	1.2	-0.05	5.1	I	I
01/03 11:00:00	22.19144622	21.37116886	0.1	37.98131428	1.00	1.2	-0.02	5.0	I	
01/03 12:00:00	22.32532858	21.43785874	0.1	39.24692971	1.00	1.2	0.01	5.0	I	
01/03 13:00:00	22.01458254	21.50110775	0.1	40.43148578	1.00	1.2	-0.01	5.0		
01/03 14:00:00	22.11422629	21.51839487	0.1	40.29937123	1.00	1.2	0.00	5.0		
01/05 06:00:00	19.45228836	20.04929435	0.1	24.73994782	1.00	1.2	-0.52	10.8		
01/05 07:00:00	19.97352657	19.99179287	0.1	24.09257991	1.00	1.2	-0.48	9.8		
01/05 08:00:00	20.99865977	19.99212935	0.1	24.64022833	1.00	1.2	-0.36	7.8	II	Mon

01/05	09:00:00	21.00000000	20.10834644	0.1	29.97488485	1.00	1.2	-0.32	7.2	II	
01/05	10:00:00	21.00000000	20.16289370	0.1	31.49375726	1.00	1.2	-0.31	7.0	II	
01/05	11:00:00	21.00000000	20.21034328	0.1	32.09113715	1.00	1.2	-0.30	6.9	II	
01/05	12:00:00	21.00000000	20.25715826	0.1	32.31394056	1.00	1.2	-0.29	6.8	II	II
01/05	13:00:00	21.35807970	20.28317740	0.1	31.06222020	1.00	1.2	-0.26	6.4	II	
01/05	14:00:00	21.00033416	20.36612264	0.1	31.84090193	1.00	1.2	-0.29	6.7	II	
01/05	15:00:00	21.00000000	20.36002767	0.1	31.57603615	1.00	1.2	-0.29	6.7	II	
01/05	16:00:00	21.00000000	20.36615702	0.1	31.57615269	1.00	1.2	-0.29	6.7	II	
01/05	17:00:00	21.00000000	20.37655793	0.1	32.26555701	1.00	1.2	-0.28	6.7	II	
01/05	18:00:00	20.53345268	20.38040123	0.1	32.50280800	1.00	1.2	-0.33	7.3	II	
01/05	19:00:00	20.51234881	20.32577509	0.1	31.22125473	1.00	1.2	-0.35	7.5		
01/05	20:00:00	20.32679854	20.30462263	0.1	30.86270672	1.00	1.2	-0.37	7.9		
01/05	21:00:00	20.28280940	20.26909458	0.1	30.23063462	1.00	1.2	-0.38	8.1		
01/05	22:00:00	20.24136063	20.23896727	0.1	29.75382931	1.00	1.2	-0.39	8.3		
01/05	23:00:00	19.35316187	20.20875521	0.1	30.25658290	1.00	1.2	-0.49	10.1		
01/05	24:00:00	19.53351219	20.06694396	0.1	28.05568497	1.00	1.2	-0.50	10.2		
01/06	01:00:00	19.45575776	20.03042402	0.1	26.91363924	1.00	1.2	-0.51	10.6		
01/06	02:00:00	19.39624604	19.96703653	0.1	25.82216937	1.00	1.2	-0.53	11.0		
01/06	03:00:00	19.31895170	19.90373714	0.1	25.08195751	1.00	1.2	-0.55	11.4		
01/06	04:00:00	19.24116742	19.83803439	0.1	24.52641257	1.00	1.2	-0.57	11.8		
01/06	05:00:00	19.19335910	19.77309512	0.1	24.14724371	1.00	1.2	-0.58	12.1		
01/06	06:00:00	19.12232243	19.70949067	0.1	23.85750825	1.00	1.2	-0.60	12.5		
01/06	07:00:00	19.63992218	19.64708330	0.1	23.24761778	1.00	1.2	-0.55	11.4		
01/06	08:00:00	20.99762510	19.64208454	0.1	24.27071633	1.00	1.2	-0.40	8.4	II	Tue
01/06	09:00:00	21.00000000	19.79098444	0.1	30.89542891	1.00	1.2	-0.35	7.5	II	
01/06	10:00:00	21.00000000	19.85006532	0.1	32.41918042	1.00	1.2	-0.33	7.3	II	
01/06	11:00:00	21.00000000	19.89997860	0.1	32.92288625	1.00	1.2	-0.33	7.2	II	
01/06	12:00:00	21.00000000	19.94515164	0.1	33.01661654	1.00	1.2	-0.32	7.2	II	II
01/06	13:00:00	21.00000000	19.97343774	0.1	32.22739632	1.00	1.2	-0.32	7.2	II	
01/06	14:00:00	21.00000000	20.01068998	0.1	32.33646621	1.00	1.2	-0.32	7.1	II	
01/06	15:00:00	21.00000000	20.03970627	0.1	31.79286435	1.00	1.2	-0.32	7.1	II	
01/06	16:00:00	21.00000000	20.06307823	0.1	31.15009027	1.00	1.2	-0.32	7.1	II	
01/06	17:00:00	21.00000000	20.08457713	0.1	32.03011426	1.00	1.2	-0.31	7.1	II	
01/06	18:00:00	20.12555818	20.09663367	0.1	32.62537711	1.00	1.2	-0.41	8.5	II	
01/06	19:00:00	20.03297813	20.00652672	0.1	31.21965415	1.00	1.2	-0.43	8.9		
01/06	20:00:00	19.89616625	19.96509222	0.1	30.55868765	1.00	1.2	-0.46	9.4		
01/06	21:00:00	19.88044308	19.92183344	0.1	29.93037742	1.00	1.2	-0.46	9.5		
01/06	22:00:00	19.82918117	19.88307357	0.1	29.41599748	1.00	1.2	-0.48	9.8		
01/06	23:00:00	18.94095845	19.84266106	0.1	29.85852765	1.00	1.2	-0.57	12.0		
01/06	24:00:00	19.07894821	19.69279837	0.1	27.58320245	1.00	1.2	-0.59	12.2		
01/07	01:00:00	19.00104307	19.63874848	0.1	26.08406967	1.00	1.2	-0.61	12.8		
01/07	02:00:00	18.92350375	19.56346271	0.1	24.62352523	1.00	1.2	-0.63	13.4		
01/07	03:00:00	18.83044976	19.48714826	0.1	23.63909128	1.00	1.2	-0.65	14.0		
01/07	04:00:00	18.75614255	19.40929228	0.1	22.82543544	1.00	1.2	-0.67	14.5		
01/07	05:00:00	18.67020614	19.33140045	0.1	21.73240376	1.00	1.2	-0.69	15.2		
01/07	06:00:00	18.59319732	19.25340779	0.1	20.84830509	1.00	1.2	-0.71	15.8		
01/07	07:00:00	19.11996820	19.17849359	0.1	20.16676783	1.00	1.2	-0.67	14.4		
01/07	08:00:00	20.99542704	19.17242408	0.1	22.50116876	1.00	1.2	-0.46	9.4	II	Wed
01/07	09:00:00	21.00000000	19.41960455	0.1	30.73236997	1.00	1.2	-0.39	8.1	II	
01/07	10:00:00	21.00000000	19.52012130	0.1	32.34269359	1.00	1.2	-0.37	7.8	II	
01/07	11:00:00	21.00000000	19.61320707	0.1	32.87617049	1.00	1.2	-0.35	7.6	II	
01/07	12:00:00	21.00000000	19.69449539	0.1	33.00573036	1.00	1.2	-0.35	7.5	II	II
01/07	13:00:00	21.00000000	19.74253987	0.1	32.74630282	1.00	1.2	-0.34	7.5	II	
01/07	14:00:00	21.00000000	19.81877559	0.1	32.53429013	1.00	1.2	-0.34	7.4	II	
01/07	15:00:00	21.00000000	19.86106194	0.1	32.47624843	1.00	1.2	-0.33	7.3	II	
01/07	16:00:00	21.00000000	19.88710545	0.1	32.32124583	1.00	1.2	-0.33	7.3	II	
01/07	17:00:00	21.00000000	19.92120552	0.1	33.58707915	1.00	1.2	-0.32	7.2	II	
01/07	18:00:00	20.06492116	19.94444591	0.1	34.27480443	1.00	1.2	-0.42	8.7	II	
01/07	19:00:00	19.93413803	19.85082343	0.1	32.62957068	1.00	1.2	-0.45	9.3		
01/07	20:00:00	19.75727890	19.81074028	0.1	32.28780880	1.00	1.2	-0.48	9.8		
01/07	21:00:00	19.75450778	19.76816318	0.1	31.57474586	1.00	1.2	-0.49	10.0		
01/07	22:00:00	19.70445745	19.73254485	0.1	31.00931840	1.00	1.2	-0.50	10.2		
01/07	23:00:00	18.84448190	19.69521149	0.1	31.42775502	1.00	1.2	-0.59	12.4		
01/07	24:00:00	18.97876324	19.55334331	0.1	29.06200687	1.00	1.2	-0.60	12.7		
01/08	01:00:00	18.89516586	19.50333249	0.1	27.45699352	1.00	1.2	-0.62	13.2		
01/08	02:00:00	18.84065785	19.43309481	0.1	26.10220072	1.00	1.2	-0.64	13.8		
01/08	03:00:00	18.75294928	19.36347166	0.1	25.27465688	1.00	1.2	-0.66	14.3		
01/08	04:00:00	18.68569158	19.29208262	0.1	24.52592126	1.00	1.2	-0.68	14.9		
01/08	05:00:00	18.60773738	19.22191654	0.1	23.99646342	1.00	1.2	-0.70	15.4		
01/08	06:00:00	18.53795501	19.15119926	0.1	23.80405013	1.00	1.2	-0.72	15.8		
01/08	07:00:00	19.06315062	19.08357046	0.1	23.22580764	1.00	1.2	-0.67	14.5		
01/08	08:00:00	20.99517071	19.07563797	0.1	25.05615293	1.00	1.2	-0.45	9.3	II	Thu
01/08	09:00:00	21.00000000	19.30899752	0.1	33.54842865	1.00	1.2	-0.38	8.0	II	
01/08	10:00:00	21.00000000	19.40328916	0.1	34.96932737	1.00	1.2	-0.36	7.8	II	

01/08 11:00:00	21.00000000	19.48523166	0.1	35.17405185	1.00	1.2	-0.35	7.6	II	
01/08 12:00:00	21.00000000	19.55932488	0.1	35.15859449	1.00	1.2	-0.35	7.5	II	II
01/08 13:00:00	21.00000000	19.61398499	0.1	34.76791725	1.00	1.2	-0.34	7.5	II	
01/08 14:00:00	21.00000000	19.67365706	0.1	34.91959551	1.00	1.2	-0.34	7.4	II	
01/08 15:00:00	21.00000000	19.71932516	0.1	34.46959995	1.00	1.2	-0.34	7.4	II	
01/08 16:00:00	21.00000000	19.75830340	0.1	33.98364655	1.00	1.2	-0.33	7.3	II	
01/08 17:00:00	21.00000000	19.79343087	0.1	34.71431282	1.00	1.2	-0.33	7.2	II	
01/08 18:00:00	19.86510475	19.81931740	0.1	35.40467288	1.00	1.2	-0.45	9.2	II	
01/08 19:00:00	19.71154545	19.70426936	0.1	33.13975087	1.00	1.2	-0.49	10.0		
01/08 20:00:00	19.58168205	19.65452383	0.1	32.01166093	1.00	1.2	-0.51	10.5		
01/08 21:00:00	19.55524304	19.60686525	0.1	31.17317476	1.00	1.2	-0.52	10.8		
01/08 22:00:00	19.49766765	19.56294542	0.1	30.48975513	1.00	1.2	-0.54	11.1		
01/08 23:00:00	18.61080348	19.51802535	0.1	30.81427310	1.00	1.2	-0.64	13.6		
01/08 24:00:00	18.74473725	19.36628403	0.1	28.16312365	1.00	1.2	-0.65	14.0		
01/09 01:00:00	18.65863551	19.30678538	0.1	26.49387360	1.00	1.2	-0.67	14.6		
01/09 02:00:00	18.58285127	19.22820769	0.1	25.45440245	1.00	1.2	-0.70	15.2		
01/09 03:00:00	18.49608129	19.14913547	0.1	24.64400815	1.00	1.2	-0.72	15.9		
01/09 04:00:00	18.41765813	19.06983504	0.1	23.97923302	1.00	1.2	-0.74	16.5		
01/09 05:00:00	18.33727166	18.99130300	0.1	23.44288685	1.00	1.2	-0.75	17.1		
01/09 06:00:00	18.25790667	18.91291494	0.1	23.00344389	1.00	1.2	-0.77	17.7		
01/09 07:00:00	18.78626962	18.83702342	0.1	22.34756389	1.00	1.2	-0.73	16.2		
01/09 08:00:00	20.99415608	18.82418520	0.1	24.74714905	1.00	1.2	-0.48	9.8	II	Fri
01/09 09:00:00	21.00000000	19.09360905	0.1	34.02769234	1.00	1.2	-0.40	8.4	II	
01/09 10:00:00	21.00000000	19.19834770	0.1	35.28369929	1.00	1.2	-0.38	8.1	II	
01/09 11:00:00	21.00000000	19.29002734	0.1	35.64719812	1.00	1.2	-0.37	7.9	II	
01/09 12:00:00	21.00000000	19.37081629	0.1	35.11528276	1.00	1.2	-0.37	7.8	II	II
01/09 13:00:00	21.00000000	19.43292259	0.1	34.67158527	1.00	1.2	-0.36	7.8	II	
01/09 14:00:00	21.00000000	19.50094854	0.1	34.11380945	1.00	1.2	-0.36	7.7	II	
01/09 15:00:00	21.00000000	19.55461032	0.1	33.55403662	1.00	1.2	-0.36	7.7	II	
01/09 16:00:00	21.00000000	19.60297075	0.1	33.64048118	1.00	1.2	-0.35	7.6	II	
01/09 17:00:00	21.00000000	19.64657202	0.1	34.56515676	1.00	1.2	-0.34	7.5	II	
01/09 18:00:00	19.64098798	19.67847351	0.1	35.25031698	1.00	1.2	-0.49	10.0	II	
01/09 19:00:00	19.48419534	19.54078746	0.1	32.08993232	1.00	1.2	-0.53	11.0		
01/09 20:00:00	19.37694518	19.48371617	0.1	31.35926613	1.00	1.2	-0.55	11.5		
01/09 21:00:00	19.34946480	19.43177551	0.1	30.56589929	1.00	1.2	-0.57	11.8		
01/09 22:00:00	19.29251587	19.38322750	0.1	29.90766963	1.00	1.2	-0.58	12.1		
01/09 23:00:00	18.39730715	19.33418512	0.1	30.20957309	1.00	1.2	-0.68	14.9		
01/09 24:00:00	18.51894290	19.17558555	0.1	27.54932066	1.00	1.2	-0.70	15.3		
01/10 01:00:00	18.45059340	19.11034245	0.1	25.78376954	1.00	1.2	-0.72	16.0		
01/10 02:00:00	18.37335724	19.02861095	0.1	24.77254131	1.00	1.2	-0.74	16.6		
01/10 03:00:00	18.29371730	18.94712569	0.1	24.00252971	1.00	1.2	-0.76	17.3		
01/10 04:00:00	18.21508925	18.86596982	0.1	23.41782412	1.00	1.2	-0.78	17.9		
01/10 05:00:00	18.13573655	18.78469132	0.1	22.98109786	1.00	1.2	-0.80	18.5		
01/10 06:00:00	18.05766320	18.70409363	0.1	22.65859476	1.00	1.2	-0.82	19.2		
01/10 07:00:00	18.66223026	18.62455937	0.1	21.76170529	1.00	1.2	-0.76	17.4		
01/10 08:00:00	18.75356286	18.61476856	0.1	21.70470371	1.00	1.2	-0.75	17.1		
01/10 09:00:00	20.99368451	18.60192645	0.1	25.06609108	1.00	1.2	-0.50	10.2	III	Sat
01/10 10:00:00	21.00000000	18.89184112	0.1	35.96549987	1.00	1.2	-0.41	8.5	II	II
01/10 11:00:00	21.00000000	19.01079845	0.1	38.57469585	1.00	1.2	-0.38	8.1	II	
01/10 12:00:00	21.00000000	19.11114135	0.1	39.27407329	1.00	1.2	-0.37	7.9	II	
01/10 13:00:00	21.00000000	19.19051690	0.1	41.52224063	1.00	1.2	-0.35	7.5		
01/10 14:00:00	19.56990269	19.26092030	0.1	44.05090177	1.00	1.2	-0.49	10.1		
01/10 15:00:00	19.33564602	19.11147329	0.1	42.63929742	1.00	1.2	-0.54	11.2		
01/10 16:00:00	19.14901156	19.06115829	0.1	41.54392795	1.00	1.2	-0.57	11.9		
01/10 17:00:00	19.10047149	19.00880843	0.1	40.48683859	1.00	1.2	-0.59	12.3		
01/10 18:00:00	19.04997682	18.96560237	0.1	39.50305613	1.00	1.2	-0.60	12.6		
01/10 19:00:00	18.02675309	18.92319412	0.1	39.63528119	1.00	1.2	-0.72	16.1		
01/10 20:00:00	18.24159387	18.75444041	0.1	34.96266080	1.00	1.2	-0.73	16.4		
01/10 21:00:00	18.05209513	18.71124842	0.1	32.06025472	1.00	1.2	-0.77	17.7		
01/10 22:00:00	18.01330175	18.62810136	0.1	30.04848777	1.00	1.2	-0.80	18.4		
01/10 23:00:00	17.91611165	18.55179218	0.1	28.25957276	1.00	1.2	-0.82	19.4		
01/10 24:00:00	17.83515101	18.47144649	0.1	26.62765744	1.00	1.2	-0.85	20.3		
01/19 06:00:00	16.25095822	16.78691608	0.1	25.14293687	1.00	1.2	-1.20	35.6		
01/19 07:00:00	16.78359765	16.73412859	0.1	24.57184776	1.00	1.2	-1.15	32.8		
01/19 08:00:00	20.98310464	16.73959373	0.1	27.38440454	1.00	1.2	-0.67	14.4	III	Mon
01/19 09:00:00	21.00000000	17.42296604	0.1	40.54800114	1.00	1.2	-0.53	10.8	III	
01/19 10:00:00	21.00000000	17.70441868	0.1	41.09547226	1.00	1.2	-0.50	10.2	III	
01/19 11:00:00	21.00000000	17.95384624	0.1	40.66632333	1.00	1.2	-0.47	9.7	II	
01/19 12:00:00	21.00000000	18.17663151	0.1	40.13973727	1.00	1.2	-0.45	9.3	II	II
01/19 13:00:00	21.00000000	18.36256776	0.1	40.84043708	1.00	1.2	-0.43	8.9	II	
01/19 14:00:00	21.00000000	18.54131828	0.1	39.10623504	1.00	1.2	-0.43	8.8	II	
01/19 15:00:00	21.00000000	18.69187652	0.1	38.59281755	1.00	1.2	-0.41	8.6	II	
01/19 16:00:00	21.00000000	18.81681326	0.1	37.79115088	1.00	1.2	-0.41	8.5	II	
01/19 17:00:00	21.00000000	18.92210185	0.1	37.94008791	1.00	1.2	-0.39	8.3	II	

01/19 18:00:00	19.43175820	19.01680806	0.1	39.76003550	1.00	1.2	-0.55	11.5	III	
01/19 19:00:00	19.20261205	18.86003100	0.1	37.47372415	1.00	1.2	-0.61	12.8		
01/19 20:00:00	18.91363674	18.82242581	0.1	36.99214898	1.00	1.2	-0.64	13.7		
01/21 06:00:00	18.24737585	18.69199932	0.1	32.16370014	1.00	1.2	-0.75	17.0		
01/21 07:00:00	18.77122371	18.63459390	0.1	31.38290297	1.00	1.2	-0.70	15.5		
01/21 08:00:00	20.99415575	18.63462251	0.1	31.59980288	1.00	1.2	-0.46	9.4	II	Wed
01/21 09:00:00	21.00000000	18.95134817	0.1	39.65481139	1.00	1.2	-0.38	8.1	II	
01/21 10:00:00	21.00000000	19.09626314	0.1	41.48380353	1.00	1.2	-0.36	7.7	II	
01/21 11:00:00	21.00000000	19.22410654	0.1	42.03454715	1.00	1.2	-0.34	7.5	II	
01/21 12:00:00	21.00000000	19.33500897	0.1	41.26069664	1.00	1.2	-0.34	7.4	II	II
01/21 13:00:00	21.00000000	19.42139598	0.1	41.19995524	1.00	1.2	-0.33	7.3	II	
01/21 14:00:00	21.00000000	19.50583424	0.1	41.01560155	1.00	1.2	-0.32	7.2	II	
01/21 15:00:00	21.00000000	19.57206471	0.1	41.10309776	1.00	1.2	-0.31	7.1	II	
01/21 16:00:00	21.00000000	19.62262113	0.1	40.67846112	1.00	1.2	-0.31	7.0	II	
01/21 17:00:00	21.00000000	19.66673072	0.1	40.52754208	1.00	1.2	-0.31	7.0	II	
01/21 18:00:00	20.19151961	19.70769109	0.1	41.75954567	1.00	1.2	-0.39	8.2	II	
01/21 19:00:00	20.01793603	19.62865325	0.1	41.16282413	1.00	1.2	-0.42	8.7		
01/21 20:00:00	19.77134968	19.59978046	0.1	41.27704809	1.00	1.2	-0.45	9.3		
02/18 06:00:00	18.27926530	18.85837818	0.1	29.36930538	1.00	1.2	-0.75	16.8		
02/18 07:00:00	18.80871798	18.79472205	0.1	28.34741675	1.00	1.2	-0.70	15.4		
02/18 08:00:00	20.99433955	18.79352630	0.1	28.61790140	1.00	1.2	-0.46	9.4	II	Wed
02/18 09:00:00	21.00000000	19.06992445	0.1	35.82550604	1.00	1.2	-0.39	8.2	II	
02/18 10:00:00	21.00000000	19.18663196	0.1	37.18581271	1.00	1.2	-0.37	7.9	II	
02/18 11:00:00	21.00000000	19.30703878	0.1	38.05125176	1.00	1.2	-0.36	7.7	II	
02/18 12:00:00	21.00000000	19.40866429	0.1	38.50796338	1.00	1.2	-0.34	7.5	II	II
02/18 13:00:00	21.00000000	19.46354122	0.1	38.36183544	1.00	1.2	-0.34	7.4	II	
02/18 14:00:00	21.00000000	19.59282822	0.1	37.59597939	1.00	1.2	-0.33	7.3	II	
02/18 15:00:00	21.00000000	19.65434485	0.1	36.48874130	1.00	1.2	-0.33	7.3	II	
02/18 16:00:00	21.00000000	19.71425835	0.1	35.70955877	1.00	1.2	-0.33	7.3	I	
02/18 17:00:00	21.00000000	19.78491921	0.1	35.96438665	1.00	1.2	-0.32	7.2	II	
02/18 18:00:00	20.06112200	19.81185286	0.1	36.61329689	1.00	1.2	-0.42	8.7	II	
02/18 19:00:00	19.90601018	19.72253605	0.1	34.44543811	1.00	1.2	-0.46	9.4		
02/18 20:00:00	19.67919119	19.68932381	0.1	34.29142548	1.00	1.2	-0.49	10.0		
03/18 06:00:00	22.59530881	22.44098788	0.1	32.68811632	0.80	1.2	-0.18	5.6		
03/18 07:00:00	23.00326964	22.47872196	0.1	32.16551765	0.80	1.2	-0.12	5.3		
03/18 08:00:00	23.61006163	22.56771540	0.1	31.92357930	0.80	1.2	-0.04	5.0	I	Wed
03/18 09:00:00	23.82605563	22.70071150	0.1	33.08887961	0.80	1.2	0.01	5.0	I	
03/18 10:00:00	24.15009837	22.81757629	0.1	32.32925306	0.80	1.2	0.06	5.1	I	
03/18 11:00:00	24.38592988	22.95618425	0.1	31.88688746	0.80	1.2	0.10	5.2	I	
03/18 12:00:00	24.63988959	23.08762015	0.1	30.77484764	0.80	1.2	0.14	5.4	I	I
03/18 13:00:00	24.82547644	23.24355641	0.1	30.02016244	0.80	1.2	0.17	5.6	I	
03/18 14:00:00	24.99983241	23.38882071	0.1	29.97419290	0.80	1.2	0.21	5.9	I	
03/18 15:00:00	25.13279536	23.53751444	0.1	30.34945317	0.80	1.2	0.25	6.3	II	
03/18 16:00:00	24.84576093	23.68828308	0.1	31.33699579	0.80	1.2	0.24	6.2	II	
03/18 17:00:00	24.69308383	23.86020446	0.1	31.67558563	0.80	1.2	0.24	6.2	II	
03/18 18:00:00	24.32213885	23.81619934	0.1	32.03132391	0.80	1.2	0.19	5.8	I	
03/18 19:00:00	24.06696026	23.81759367	0.1	32.15605105	0.80	1.2	0.16	5.5		
03/18 20:00:00	24.06101598	23.81423675	0.1	31.95698156	0.80	1.2	0.16	5.5		
04/22 06:00:00	24.79285569	24.71682841	0.1	24.81435700	0.50	1.2	-0.17	5.6		
04/22 07:00:00	24.99914891	24.75605730	0.1	25.68607319	0.50	1.2	-0.12	5.3		
04/22 08:00:00	24.99999080	24.80344872	0.1	28.97248682	0.50	1.2	-0.09	5.2	I	Wed
04/22 09:00:00	25.00000000	24.83750762	0.1	32.75865417	0.50	1.2	-0.06	5.1	I	
04/22 10:00:00	25.00000000	24.86058830	0.1	33.53091207	0.50	1.2	-0.05	5.1	I	
04/22 11:00:00	25.00000000	24.91445755	0.1	36.85654066	0.50	1.2	-0.02	5.0	I	
04/22 12:00:00	25.00000000	24.94552934	0.1	36.28517064	0.50	1.2	-0.02	5.0	I	I
04/22 13:00:00	25.00000000	24.98695745	0.1	35.59181329	0.50	1.2	-0.02	5.0	I	
04/22 14:00:00	25.00000000	25.02189918	0.1	35.04342182	0.50	1.2	-0.02	5.0	I	
04/22 15:00:00	25.00000000	25.04257524	0.1	34.53786379	0.50	1.2	-0.02	5.0	I	
04/22 16:00:00	25.00000000	25.15454811	0.1	33.72442797	0.50	1.2	-0.01	5.0	I	
04/22 17:00:00	26.35029906	25.33999941	0.1	30.57801630	0.50	1.2	0.20	5.8	I	
04/22 18:00:00	26.00688560	25.59501077	0.1	30.74408948	0.50	1.2	0.18	5.7	I	
04/22 19:00:00	25.57712528	25.33290254	0.1	31.12457750	0.50	1.2	0.08	5.1		
04/22 20:00:00	25.53206221	25.28423061	0.1	30.92725638	0.50	1.2	0.07	5.1		
05/20 06:00:00	26.46231236	25.89980236	0.1	49.31059210	0.50	1.2	0.44	9.0		
05/20 07:00:00	25.01891685	26.00927231	0.1	51.95205330	0.50	1.2	0.24	6.2		
05/20 08:00:00	25.00000001	25.95092777	0.1	49.85400544	0.50	1.2	0.22	6.0	I	Wed
05/20 09:00:00	25.00000000	25.95892465	0.1	49.38510164	0.50	1.2	0.21	6.0	I	
05/20 10:00:00	25.00000000	25.96872065	0.1	47.87339087	0.50	1.2	0.21	5.9	I	
05/20 11:00:00	25.00000000	25.98245210	0.1	48.53584985	0.50	1.2	0.21	5.9	I	
05/20 12:00:00	25.00000000	25.97874779	0.1	47.32448616	0.50	1.2	0.20	5.9	I	I
05/20 13:00:00	25.00000000	25.98614904	0.1	48.21798804	0.50	1.2	0.21	5.9	I	
05/20 14:00:00	25.00000000	25.99252798	0.1	48.81219168	0.50	1.2	0.22	6.0	I	
05/20 15:00:00	25.00000000	26.02961733	0.1	48.88501273	0.50	1.2	0.22	6.0	I	
05/20 16:00:00	25.00000000	26.12716509	0.1	48.93868129	0.50	1.2	0.24	6.2	I	

05/20 17:00:00	26.69914191	26.22875689	0.1	45.08734365	0.50	1.2	0.49	10.0	II	
05/20 18:00:00	26.69997976	26.46272158	0.1	45.40926580	0.50	1.2	0.53	10.8	III	
05/20 19:00:00	26.70000073	26.25199844	0.1	45.67018060	0.50	1.2	0.50	10.2		
05/20 20:00:00	26.68513258	26.25138454	0.1	46.49178747	0.50	1.2	0.50	10.3		
06/17 06:00:00	26.69976514	26.70900400	0.1	42.27133515	0.50	1.2	0.54	11.0		
06/17 07:00:00	25.03153285	26.76794745	0.1	47.64057258	0.50	1.2	0.32	7.2		
06/17 08:00:00	25.00000021	26.64324539	0.1	49.39383851	0.50	1.2	0.31	7.1	II	Wed
06/17 09:00:00	25.00000004	26.61081409	0.1	49.46490843	0.50	1.2	0.31	7.0	II	
06/17 10:00:00	25.00000001	26.57156325	0.1	48.77300654	0.50	1.2	0.30	6.9	II	
06/17 11:00:00	25.00000000	26.54316439	0.1	49.04168266	0.50	1.2	0.30	6.8	II	
06/17 12:00:00	25.00000000	26.50353725	0.1	47.88118998	0.50	1.2	0.28	6.7	II	II
06/17 13:00:00	25.00000000	26.48688300	0.1	49.08822511	0.50	1.2	0.29	6.7	II	
06/17 14:00:00	25.00000000	26.46616577	0.1	49.04299533	0.50	1.2	0.29	6.7	II	
06/17 15:00:00	25.00000000	26.47641873	0.1	48.63243905	0.50	1.2	0.28	6.7	II	
06/17 16:00:00	25.00000000	26.50476131	0.1	49.98499898	0.50	1.2	0.30	6.9	II	
06/17 17:00:00	26.69829366	26.54185264	0.1	46.14081313	0.50	1.2	0.54	11.2	III	
06/17 18:00:00	26.70000076	26.67369157	0.1	46.45300851	0.50	1.2	0.56	11.7	III	
06/17 19:00:00	26.70000076	26.70634560	0.1	46.13607817	0.50	1.2	0.57	11.7		
06/17 20:00:00	26.70000076	26.58422430	0.1	45.96891881	0.50	1.2	0.55	11.3		
07/15 06:00:00	26.67181653	26.54565489	0.1	40.34849327	0.50	1.2	0.49	10.1		
07/15 07:00:00	25.03009282	26.61014178	0.1	45.13200908	0.50	1.2	0.28	6.7		
07/15 08:00:00	25.00000026	26.50250169	0.1	46.48547478	0.50	1.2	0.27	6.6	II	Wed
07/15 09:00:00	25.00000004	26.46512658	0.1	46.18574998	0.50	1.2	0.26	6.5	II	
07/15 10:00:00	25.00000001	26.43958092	0.1	46.05693874	0.50	1.2	0.26	6.4	II	
07/15 11:00:00	25.00000000	26.41902005	0.1	46.51260471	0.50	1.2	0.26	6.4	II	
07/15 12:00:00	25.00000000	26.38170920	0.1	45.83337086	0.50	1.2	0.25	6.3	II	II
07/15 13:00:00	25.00000000	26.36325532	0.1	46.17430380	0.50	1.2	0.25	6.3	II	
07/15 14:00:00	25.00000000	26.33777699	0.1	45.64712312	0.50	1.2	0.24	6.2	II	
07/15 15:00:00	25.00000000	26.33236617	0.1	45.41173177	0.50	1.2	0.24	6.2	II	
07/15 16:00:00	25.00000000	26.32860805	0.1	45.29765791	0.50	1.2	0.24	6.2	II	
07/15 17:00:00	26.65277573	26.31187327	0.1	41.31333875	0.50	1.2	0.46	9.5	II	
07/15 18:00:00	26.70000076	26.44270876	0.1	42.76156157	0.50	1.2	0.50	10.3	III	
07/15 19:00:00	26.70000076	26.50322585	0.1	42.50848760	0.50	1.2	0.51	10.4		
07/15 20:00:00	26.70000076	26.39692096	0.1	42.26863032	0.50	1.2	0.49	10.1		
08/19 06:00:00	26.70000076	26.74931890	0.1	61.01416935	0.50	1.2	0.69	15.0		
08/19 07:00:00	25.03586944	26.79898248	0.1	61.72124279	0.50	1.2	0.43	8.9		
08/19 08:00:00	25.00000078	26.67234050	0.1	58.24390646	0.50	1.2	0.38	8.0	II	Wed
08/19 09:00:00	25.00000018	26.63722036	0.1	57.87826232	0.50	1.2	0.37	7.9	II	
08/19 10:00:00	25.00000004	26.61518884	0.1	56.16252613	0.50	1.2	0.36	7.7	II	
08/19 11:00:00	25.00000001	26.58262541	0.1	54.29667620	0.50	1.2	0.34	7.4	II	
08/19 12:00:00	25.00000000	26.54818250	0.1	51.50297496	0.50	1.2	0.31	7.1	II	II
08/19 13:00:00	25.00000000	26.53116017	0.1	53.63286514	0.50	1.2	0.33	7.2	II	
08/19 14:00:00	25.00000000	26.51126113	0.1	53.79177764	0.50	1.2	0.33	7.2	II	
08/19 15:00:00	25.00000000	26.49877339	0.1	54.52010910	0.50	1.2	0.33	7.3	II	
08/19 16:00:00	25.00000000	26.52337477	0.1	55.25335910	0.50	1.2	0.34	7.4	II	
08/19 17:00:00	26.69425039	26.52146508	0.1	52.68623009	0.50	1.2	0.59	12.3	III	
08/19 18:00:00	26.70000076	26.65755965	0.1	54.30594962	0.50	1.2	0.62	13.2	III	
08/19 19:00:00	26.70000076	26.58000805	0.1	54.22831603	0.50	1.2	0.61	12.9		
08/19 20:00:00	26.70000076	26.59492222	0.1	54.67617816	0.50	1.2	0.62	13.0		
09/16 06:00:00	25.68847238	25.57621344	0.1	35.57085922	0.50	1.2	0.17	5.6		
09/16 07:00:00	25.00646143	25.63257415	0.1	37.86408831	0.50	1.2	0.09	5.2		
09/16 08:00:00	25.00000000	25.62125265	0.1	41.66866587	0.50	1.2	0.11	5.3	I	Wed
09/16 09:00:00	25.00000000	25.63671332	0.1	44.80682195	0.50	1.2	0.14	5.4	I	
09/16 10:00:00	25.00000000	25.65499944	0.1	45.52209172	0.50	1.2	0.14	5.4	I	
09/16 11:00:00	25.00000000	25.67091645	0.1	46.71267831	0.50	1.2	0.15	5.5	I	
09/16 12:00:00	25.00000000	25.67583630	0.1	46.32495680	0.50	1.2	0.15	5.5	I	I
09/16 13:00:00	25.00000000	25.68940794	0.1	46.51217247	0.50	1.2	0.16	5.5	I	
09/16 14:00:00	25.00000000	25.69654557	0.1	46.15011238	0.50	1.2	0.15	5.5	I	
09/16 15:00:00	25.00000000	25.69440566	0.1	45.65426794	0.50	1.2	0.15	5.5	I	
09/16 16:00:00	25.00000000	25.76853263	0.1	45.23102415	0.50	1.2	0.16	5.5	I	
09/16 17:00:00	26.62290740	25.86222114	0.1	40.86165524	0.50	1.2	0.39	8.2	II	
09/16 18:00:00	26.42417663	25.85613163	0.1	41.06260101	0.50	1.2	0.36	7.7	II	
09/16 19:00:00	26.16897000	25.86172407	0.1	41.59608065	0.50	1.2	0.33	7.2		
09/16 20:00:00	26.18144304	25.85841453	0.1	41.51927309	0.50	1.2	0.33	7.2		
10/21 06:00:00	25.84237926	26.04432085	0.1	45.64668742	0.50	1.2	0.33	7.3		
10/21 07:00:00	25.00464287	26.06321309	0.1	45.08752031	0.50	1.2	0.20	5.8		
10/21 08:00:00	25.00000000	26.15745353	0.1	47.91262033	0.50	1.2	0.23	6.1	II	Wed
10/21 09:00:00	25.00000000	26.21399745	0.1	50.62188383	0.50	1.2	0.26	6.4	II	
10/21 10:00:00	25.00000000	26.25332275	0.1	50.69549101	0.50	1.2	0.27	6.5	II	
10/21 11:00:00	25.00000000	26.31159058	0.1	50.13310064	0.50	1.2	0.27	6.5	II	
10/21 12:00:00	25.00000000	26.34811659	0.1	47.71953025	0.50	1.2	0.26	6.4	II	II
10/21 13:00:00	25.00000000	26.37252061	0.1	48.46572857	0.50	1.2	0.27	6.5	II	
10/21 14:00:00	25.00000000	26.38901820	0.1	49.19163033	0.50	1.2	0.28	6.6	II	
10/21 15:00:00	25.00000000	26.40710921	0.1	48.01733421	0.50	1.2	0.27	6.5	II	

10/21 16:00:00	25.00000000	26.42341177	0.1	48.30821190	0.50	1.2	0.27	6.6	II	
10/21 17:00:00	24.29003330	26.39335688	0.1	47.63825863	0.50	1.2	0.15	5.5	I	
10/21 18:00:00	24.12766252	26.38691556	0.1	46.80757767	0.50	1.2	0.12	5.3	I	
10/21 19:00:00	24.01689700	26.38102805	0.1	46.34237046	0.50	1.2	0.10	5.2		
10/21 20:00:00	24.01514430	26.36842447	0.1	45.74509088	0.50	1.2	0.10	5.2		
11/18 06:00:00	21.89796688	22.37703313	0.1	29.62800289	1.00	1.2	0.00	5.0		
11/18 07:00:00	22.40232025	22.32614942	0.1	28.97388150	1.00	1.2	0.05	5.0		
11/18 08:00:00	22.70316429	22.32895200	0.1	29.05587957	1.00	1.2	0.08	5.1	I	Wed
11/18 09:00:00	22.89680130	22.37646996	0.1	31.48013737	1.00	1.2	0.12	5.3	I	
11/18 10:00:00	23.03937350	22.42024850	0.1	33.47659988	1.00	1.2	0.16	5.5	I	
11/18 11:00:00	23.21740659	22.47932178	0.1	34.28665135	1.00	1.2	0.19	5.7	I	
11/18 12:00:00	23.33648348	22.53934060	0.1	35.01615390	1.00	1.2	0.21	5.9	I	I
11/18 13:00:00	23.81056250	22.57748211	0.1	34.34324547	1.00	1.2	0.27	6.5	II	
11/18 14:00:00	23.32281806	22.66209252	0.1	36.32775184	1.00	1.2	0.23	6.1	I	
11/18 15:00:00	23.32500363	22.63385276	0.1	36.90952186	1.00	1.2	0.23	6.1	I	
11/18 16:00:00	23.23499725	22.64828663	0.1	37.54967682	1.00	1.2	0.23	6.1	I	
11/18 17:00:00	22.70050462	22.65190835	0.1	38.93933557	1.00	1.2	0.18	5.6	I	
11/18 18:00:00	22.92588265	22.60330918	0.1	38.70290080	1.00	1.2	0.19	5.8	I	
11/18 19:00:00	22.84800889	22.60257687	0.1	39.00028385	1.00	1.2	0.19	5.7		
11/18 20:00:00	22.69938046	22.57969282	0.1	39.21496666	1.00	1.2	0.17	5.6		
12/16 06:00:00	18.73377978	18.98232066	0.1	40.87349505	1.00	1.2	-0.63	13.4		
12/16 07:00:00	19.20602916	18.94297265	0.1	39.98798460	1.00	1.2	-0.59	12.2		
12/16 08:00:00	20.99552133	18.95046196	0.1	38.29656566	1.00	1.2	-0.39	8.2	II	Wed
12/16 09:00:00	21.00000000	19.21863664	0.1	43.11475112	1.00	1.2	-0.34	7.4	II	
12/16 10:00:00	21.00000000	19.33700008	0.1	44.28670050	1.00	1.2	-0.32	7.1	II	
12/16 11:00:00	21.00000000	19.45365159	0.1	44.84078552	1.00	1.2	-0.30	6.9	II	
12/16 12:00:00	21.00000000	19.54827646	0.1	44.70611561	1.00	1.2	-0.30	6.8	II	II
12/16 13:00:00	21.14747951	19.62762458	0.1	43.95808436	1.00	1.2	-0.28	6.6	II	
12/16 14:00:00	21.17944908	19.72747159	0.1	44.91526141	1.00	1.2	-0.26	6.4	II	
12/16 15:00:00	21.24943637	19.80449450	0.1	45.64964042	1.00	1.2	-0.24	6.2	II	
12/16 16:00:00	21.22116974	19.86911648	0.1	45.12196071	1.00	1.2	-0.24	6.2	II	
12/16 17:00:00	21.00046997	19.93484097	0.1	45.12126846	1.00	1.2	-0.26	6.4	II	
12/16 18:00:00	20.68941740	19.95425592	0.1	45.60253141	1.00	1.2	-0.29	6.7	II	
12/16 19:00:00	20.41893584	19.93871453	0.1	45.75128285	1.00	1.2	-0.32	7.1		
12/16 20:00:00	20.15925969	19.91530648	0.1	45.81654989	1.00	1.2	-0.35	7.6		

9th level - Office, West orientation

Date/Time [h]	Air Temperature [˚C]	Mean Radiant Temperature [˚C]	Relative Air Velocity [m/s]	Relative Humidity [%]	Clothing [clo]	Metabolic Rate [met]	PMV [-]	PPD [%]	Category [-]	
01/01 01:00:00	18.80773761	19.45087267	0.1	46.67883178	1.00	1.2	-0.55	11.3		
01/01 02:00:00	18.79646950	19.39427008	0.1	46.76207874	1.00	1.2	-0.55	11.4		
01/01 03:00:00	18.69944985	19.33889858	0.1	46.66237400	1.00	1.2	-0.57	11.9		
01/01 04:00:00	18.64667204	19.28049617	0.1	46.46374085	1.00	1.2	-0.58	12.2		
01/01 05:00:00	18.58164021	19.22400058	0.1	45.13415710	1.00	1.2	-0.60	12.7		
01/01 06:00:00	18.52239056	19.16901928	0.1	44.55403035	1.00	1.2	-0.62	13.0		
01/01 07:00:00	19.23492324	19.11775922	0.1	43.03152855	1.00	1.2	-0.55	11.3		
01/01 08:00:00	20.99249737	19.13283118	0.1	40.27689222	1.00	1.2	-0.36	7.7	II	Thu
01/01 09:00:00	20.99993594	19.32760086	0.1	42.79242234	1.00	1.2	-0.33	7.3	II	
01/01 10:00:00	21.00000000	19.42600144	0.1	44.35886327	1.00	1.2	-0.31	7.0	II	
01/01 11:00:00	21.00000000	19.50578403	0.1	46.24488459	1.00	1.2	-0.29	6.8	II	
01/01 12:00:00	21.00000000	19.57505842	0.1	44.41346493	1.00	1.2	-0.29	6.8	II	II
01/01 13:00:00	21.00000000	19.62705448	0.1	43.71009358	1.00	1.2	-0.29	6.8	II	
01/01 14:00:00	21.00000000	19.68383006	0.1	43.09154418	1.00	1.2	-0.29	6.8	II	
01/01 15:00:00	21.00000000	19.73140428	0.1	42.81999091	1.00	1.2	-0.29	6.7	II	
01/01 16:00:00	21.00000000	19.77270211	0.1	45.14606574	1.00	1.2	-0.27	6.5	II	
01/01 17:00:00	21.00000000	19.81070569	0.1	46.01758094	1.00	1.2	-0.26	6.4	II	
01/01 18:00:00	20.25652679	19.83772814	0.1	48.16003916	1.00	1.2	-0.34	7.4	II	
01/01 19:00:00	20.01313514	19.77652078	0.1	48.24918077	1.00	1.2	-0.37	7.9		
01/01 20:00:00	19.69971049	19.73523194	0.1	48.38244927	1.00	1.2	-0.41	8.5		
01/01 21:00:00	19.69558208	19.68408836	0.1	47.53678345	1.00	1.2	-0.42	8.7		
01/01 22:00:00	19.63959800	19.65031434	0.1	46.87406742	1.00	1.2	-0.43	8.9		
01/01 23:00:00	18.67218721	19.61585849	0.1	48.03382082	1.00	1.2	-0.54	11.1		
01/01 24:00:00	18.81976711	19.48821166	0.1	45.93176772	1.00	1.2	-0.54	11.3		
01/02 01:00:00	18.64746919	19.43047629	0.1	45.03761930	1.00	1.2	-0.57	12.0		
01/02 02:00:00	18.56461355	19.35465885	0.1	43.32301751	1.00	1.2	-0.60	12.6		
01/02 03:00:00	18.46031555	19.28270806	0.1	42.63386988	1.00	1.2	-0.62	13.2		
01/02 04:00:00	18.38228645	19.21007542	0.1	42.04534686	1.00	1.2	-0.64	13.7		
01/02 05:00:00	18.28842490	19.13936702	0.1	41.47216171	1.00	1.2	-0.66	14.2		
01/02 06:00:00	18.21937263	19.06888621	0.1	41.26788873	1.00	1.2	-0.68	14.7		
01/02 07:00:00	19.00864947	19.00274962	0.1	39.35423994	1.00	1.2	-0.60	12.7		
01/02 08:00:00	20.99165941	19.01692800	0.1	37.18912622	1.00	1.2	-0.39	8.2	II	Fri
01/02 09:00:00	20.99989953	19.24204253	0.1	41.26719242	1.00	1.2	-0.34	7.5	II	
01/02 10:00:00	20.99999999	19.36088283	0.1	43.49567694	1.00	1.2	-0.32	7.2	II	
01/02 11:00:00	21.00000000	19.46033957	0.1	44.41868173	1.00	1.2	-0.31	7.0	II	
01/02 12:00:00	21.00000000	19.53776801	0.1	42.93563850	1.00	1.2	-0.31	7.0	II	II
01/02 13:00:00	21.00000000	19.59032335	0.1	42.27733842	1.00	1.2	-0.31	7.0	II	
01/02 14:00:00	21.00000000	19.64675875	0.1	41.47962005	1.00	1.2	-0.30	6.9	II	
01/02 15:00:00	21.00000000	19.69221086	0.1	41.58409439	1.00	1.2	-0.30	6.9	II	
01/02 16:00:00	21.00000000	19.72821051	0.1	41.74481040	1.00	1.2	-0.29	6.8	II	
01/02 17:00:00	21.00000000	19.76240398	0.1	42.20561561	1.00	1.2	-0.29	6.7	II	
01/02 18:00:00	20.08320988	19.78814293	0.1	44.22182549	1.00	1.2	-0.38	8.0	II	
01/02 19:00:00	19.81205994	19.70690036	0.1	43.07864830	1.00	1.2	-0.43	8.8		
01/02 20:00:00	19.49833478	19.65541180	0.1	43.01693504	1.00	1.2	-0.47	9.6		
01/02 21:00:00	19.53132899	19.59468687	0.1	41.92314066	1.00	1.2	-0.47	9.7		
01/02 22:00:00	19.44078249	19.55600135	0.1	41.65905757	1.00	1.2	-0.49	10.0		
01/02 23:00:00	18.27863995	19.51141026	0.1	43.21212420	1.00	1.2	-0.62	13.1		
01/02 24:00:00	18.45005947	19.34564973	0.1	40.91890447	1.00	1.2	-0.62	13.3		
01/03 01:00:00	18.25811123	19.27272094	0.1	40.59990570	1.00	1.2	-0.66	14.1		
01/03 02:00:00	18.17012079	19.17872401	0.1	40.01762012	1.00	1.2	-0.68	14.8		
01/03 03:00:00	18.05562092	19.08904318	0.1	39.31902548	1.00	1.2	-0.71	15.6		
01/03 04:00:00	17.95975127	18.99934785	0.1	38.93541271	1.00	1.2	-0.73	16.2		
01/03 05:00:00	17.86977853	18.91223456	0.1	38.68921032	1.00	1.2	-0.75	16.9		
01/03 06:00:00	17.78037122	18.82671834	0.1	38.18834240	1.00	1.2	-0.77	17.6		
01/03 07:00:00	18.65150069	18.74298167	0.1	36.13300777	1.00	1.2	-0.68	14.9		
01/03 08:00:00	18.80382643	18.75723297	0.1	36.11884616	1.00	1.2	-0.67	14.4		
01/03 09:00:00	20.99133741	18.78921986	0.1	35.94508752	1.00	1.2	-0.42	8.7	II	Sat
01/03 10:00:00	20.99977907	19.05486747	0.1	42.49168099	1.00	1.2	-0.36	7.7	II	II
01/03 11:00:00	20.99999553	19.19656964	0.1	45.00039446	1.00	1.2	-0.33	7.3	II	
01/03 12:00:00	20.99999993	19.30581816	0.1	45.98432552	1.00	1.2	-0.31	7.0	II	
01/03 13:00:00	21.00000000	19.39566110	0.1	46.60277351	1.00	1.2	-0.30	6.9		
01/03 14:00:00	19.90257868	19.47658608	0.1	49.41497029	1.00	1.2	-0.41	8.4		
01/05 06:00:00	15.85359304	17.10545883	0.1	29.74690915	1.00	1.2	-1.21	35.8		
01/05 07:00:00	16.82978718	17.04013016	0.1	28.03951212	1.00	1.2	-1.10	30.5		
01/05 08:00:00	20.97869664	17.08806129	0.1	30.30149443	1.00	1.2	-0.62	13.1	III	Mon

01/05 09:00:00	21.00000000	17.62024209	0.1	40.63803511	1.00	1.2	-0.51	10.4	III	
01/05 10:00:00	21.00000000	17.89470562	0.1	41.03285527	1.00	1.2	-0.48	9.8	II	
01/05 11:00:00	21.00000000	18.10958761	0.1	40.84783570	1.00	1.2	-0.46	9.4	II	
01/05 12:00:00	21.00000000	18.29775972	0.1	40.61958775	1.00	1.2	-0.44	9.1	II	II
01/05 13:00:00	21.00000000	18.44816819	0.1	40.74822540	1.00	1.2	-0.43	8.8	II	
01/05 14:00:00	21.00000000	18.58576259	0.1	40.23498873	1.00	1.2	-0.41	8.6	II	
01/05 15:00:00	21.00000000	18.69721294	0.1	39.36958615	1.00	1.2	-0.41	8.5	II	
01/05 16:00:00	21.00000000	18.78566035	0.1	39.09507532	1.00	1.2	-0.40	8.4	II	
01/05 17:00:00	21.00000000	18.86725845	0.1	39.01138377	1.00	1.2	-0.39	8.3	II	
01/05 18:00:00	19.02045795	18.93756770	0.1	40.90203705	1.00	1.2	-0.60	12.6	III	
01/05 19:00:00	18.64906843	18.76210671	0.1	37.38212707	1.00	1.2	-0.68	14.7		
01/05 20:00:00	18.44172708	18.67480235	0.1	35.65306251	1.00	1.2	-0.72	15.9		
01/05 21:00:00	18.38790782	18.59942077	0.1	33.72938442	1.00	1.2	-0.74	16.6		
01/05 22:00:00	18.30528921	18.53597206	0.1	32.49726214	1.00	1.2	-0.76	17.3		
01/05 23:00:00	16.94162935	18.47338005	0.1	32.75219388	1.00	1.2	-0.93	23.5		
01/05 24:00:00	17.12302580	18.25768435	0.1	29.12103622	1.00	1.2	-0.95	24.0		
01/06 01:00:00	16.90905066	18.15828361	0.1	28.14168956	1.00	1.2	-0.99	25.7		
01/06 02:00:00	16.80186116	18.03542035	0.1	27.33778006	1.00	1.2	-1.01	26.9		
01/06 03:00:00	16.66016143	17.92023976	0.1	26.84616193	1.00	1.2	-1.04	28.2		
01/06 04:00:00	16.52347981	17.80478904	0.1	26.68179055	1.00	1.2	-1.07	29.4		
01/06 05:00:00	16.44166077	17.69299409	0.1	26.79786214	1.00	1.2	-1.09	30.3		
01/06 06:00:00	16.32351512	17.58754329	0.1	26.88736391	1.00	1.2	-1.12	31.4		
01/06 07:00:00	17.28601484	17.48475065	0.1	25.45351197	1.00	1.2	-1.01	26.7		
01/06 08:00:00	20.98280771	17.49710873	0.1	28.57812700	1.00	1.2	-0.59	12.3	III	Tue
01/06 09:00:00	21.00000000	17.93203722	0.1	39.12607339	1.00	1.2	-0.48	9.9	II	
01/06 10:00:00	21.00000000	18.14306774	0.1	39.55522113	1.00	1.2	-0.46	9.5	II	
01/06 11:00:00	21.00000000	18.30585616	0.1	39.35147713	1.00	1.2	-0.45	9.2	II	
01/06 12:00:00	21.00000000	18.44593383	0.1	39.04015918	1.00	1.2	-0.43	9.0	II	II
01/06 13:00:00	21.00000000	18.55798274	0.1	39.41465113	1.00	1.2	-0.42	8.7	II	
01/06 14:00:00	21.00000000	18.66523908	0.1	38.77992462	1.00	1.2	-0.41	8.6	II	
01/06 15:00:00	21.00000000	18.75573606	0.1	37.52279792	1.00	1.2	-0.41	8.6	II	
01/06 16:00:00	21.00000000	18.83350118	0.1	36.78231621	1.00	1.2	-0.41	8.5	II	
01/06 17:00:00	21.00000000	18.90351561	0.1	37.08676351	1.00	1.2	-0.40	8.4	II	
01/06 18:00:00	18.89398111	18.96108243	0.1	39.09742898	1.00	1.2	-0.62	13.2	III	
01/06 19:00:00	18.54231211	18.76167561	0.1	35.66480176	1.00	1.2	-0.70	15.3		
01/06 20:00:00	18.35581129	18.65842239	0.1	33.57333571	1.00	1.2	-0.74	16.5		
01/06 21:00:00	18.28622792	18.56883046	0.1	32.10175556	1.00	1.2	-0.76	17.3		
01/06 22:00:00	18.19480947	18.48988379	0.1	30.91310934	1.00	1.2	-0.78	18.0		
01/06 23:00:00	16.68092445	18.41255362	0.1	31.45926549	1.00	1.2	-0.98	25.3		
01/06 24:00:00	16.90052434	18.16179127	0.1	27.74314595	1.00	1.2	-0.99	25.8		
01/07 01:00:00	16.65832538	18.04682856	0.1	26.16168016	1.00	1.2	-1.04	27.8		
01/07 02:00:00	16.53586708	17.90401790	0.1	24.81572364	1.00	1.2	-1.07	29.3		
01/07 03:00:00	16.36509373	17.76947948	0.1	24.07209517	1.00	1.2	-1.11	31.0		
01/07 04:00:00	16.23838531	17.63426714	0.1	23.61796990	1.00	1.2	-1.14	32.4		
01/07 05:00:00	16.09454132	17.50441201	0.1	22.28155577	1.00	1.2	-1.17	34.1		
01/07 06:00:00	15.96997660	17.37815516	0.1	21.52081297	1.00	1.2	-1.20	35.5		
01/07 07:00:00	16.99468011	17.25971657	0.1	20.21357243	1.00	1.2	-1.09	30.2		
01/07 08:00:00	20.97988531	17.27746552	0.1	26.62549293	1.00	1.2	-0.62	13.1	III	Wed
01/07 09:00:00	21.00000000	17.78209035	0.1	38.34801260	1.00	1.2	-0.50	10.3	III	
01/07 10:00:00	21.00000000	18.02083483	0.1	38.90312341	1.00	1.2	-0.48	9.8	II	
01/07 11:00:00	21.00000000	18.21254951	0.1	38.90495803	1.00	1.2	-0.46	9.4	II	
01/07 12:00:00	21.00000000	18.37462950	0.1	38.75313764	1.00	1.2	-0.44	9.1	II	II
01/07 13:00:00	21.00000000	18.49288363	0.1	39.48367007	1.00	1.2	-0.43	8.8	II	
01/07 14:00:00	21.00000000	18.62657279	0.1	38.71281831	1.00	1.2	-0.42	8.7	II	
01/07 15:00:00	21.00000000	18.71655563	0.1	37.95307730	1.00	1.2	-0.41	8.6	II	
01/07 16:00:00	21.00000000	18.78363441	0.1	37.49864030	1.00	1.2	-0.41	8.5	II	
01/07 17:00:00	21.00000000	18.85519922	0.1	38.05199971	1.00	1.2	-0.40	8.4	II	
01/07 18:00:00	18.91795780	18.91474050	0.1	40.14108526	1.00	1.2	-0.62	13.1	III	
01/07 19:00:00	18.54222859	18.71611028	0.1	36.28775077	1.00	1.2	-0.70	15.3		
01/07 20:00:00	18.34171489	18.61464051	0.1	34.94104123	1.00	1.2	-0.74	16.5		
01/07 21:00:00	18.27708990	18.52538624	0.1	33.42031194	1.00	1.2	-0.76	17.2		
01/07 22:00:00	18.18731202	18.44851385	0.1	32.20004743	1.00	1.2	-0.78	18.0		
01/07 23:00:00	16.76660222	18.37325720	0.1	32.65599563	1.00	1.2	-0.97	24.8		
01/07 24:00:00	16.92997444	18.13946852	0.1	29.01591919	1.00	1.2	-0.98	25.5		
01/08 01:00:00	16.68729444	18.02380147	0.1	27.28218944	1.00	1.2	-1.03	27.5		
01/08 02:00:00	16.59544634	17.88599464	0.1	26.37958730	1.00	1.2	-1.06	28.8		
01/08 03:00:00	16.43269849	17.75891790	0.1	25.99864901	1.00	1.2	-1.09	30.3		
01/08 04:00:00	16.31337062	17.63141909	0.1	25.61402991	1.00	1.2	-1.12	31.6		
01/08 05:00:00	16.17714569	17.50938958	0.1	25.57305722	1.00	1.2	-1.15	32.9		
01/08 06:00:00	16.05954222	17.39019923	0.1	26.13965697	1.00	1.2	-1.17	34.0		
01/08 07:00:00	17.05539873	17.27853394	0.1	24.81128361	1.00	1.2	-1.06	28.9		
01/08 08:00:00	20.98062949	17.28881034	0.1	28.74833319	1.00	1.2	-0.61	12.8	III	Thu
01/08 09:00:00	21.00000000	17.75728060	0.1	39.70060972	1.00	1.2	-0.50	10.2	III	
01/08 10:00:00	21.00000000	17.98255171	0.1	40.00435367	1.00	1.2	-0.47	9.7	II	

01/08 11:00:00	21.00000000	18.15805716	0.1	39.69172831	1.00	1.2	-0.46	9.4	II	
01/08 12:00:00	21.00000000	18.30889094	0.1	39.44906266	1.00	1.2	-0.45	9.2	II	II
01/08 13:00:00	21.00000000	18.43080180	0.1	40.14442980	1.00	1.2	-0.43	8.9	II	
01/08 14:00:00	21.00000000	18.54434961	0.1	39.26487843	1.00	1.2	-0.42	8.8	II	
01/08 15:00:00	21.00000000	18.63816681	0.1	38.52818780	1.00	1.2	-0.42	8.7	II	
01/08 16:00:00	21.00000000	18.71841800	0.1	37.98075099	1.00	1.2	-0.41	8.6	II	
01/08 17:00:00	21.00000000	18.78943386	0.1	38.29655680	1.00	1.2	-0.41	8.5	II	
01/08 18:00:00	18.77394082	18.84875760	0.1	40.37988820	1.00	1.2	-0.64	13.7	III	
01/08 19:00:00	18.40272939	18.63134588	0.1	36.15256576	1.00	1.2	-0.72	16.1		
01/08 20:00:00	18.20855898	18.52081331	0.1	33.56288867	1.00	1.2	-0.77	17.5		
01/08 21:00:00	18.13327450	18.42484675	0.1	31.89144753	1.00	1.2	-0.79	18.3		
01/08 22:00:00	18.03184082	18.33958661	0.1	30.59798489	1.00	1.2	-0.82	19.2		
01/08 23:00:00	16.49606402	18.25625946	0.1	31.17798843	1.00	1.2	-1.02	27.0		
01/08 24:00:00	16.71310097	17.99985881	0.1	27.39226130	1.00	1.2	-1.03	27.5		
01/09 01:00:00	16.46235433	17.87943767	0.1	26.14434552	1.00	1.2	-1.08	29.6		
01/09 02:00:00	16.34482444	17.73181879	0.1	25.49735653	1.00	1.2	-1.11	31.0		
01/09 03:00:00	16.18649005	17.59411071	0.1	25.21337168	1.00	1.2	-1.14	32.5		
01/09 04:00:00	16.05423621	17.45841581	0.1	25.03246807	1.00	1.2	-1.17	34.0		
01/09 05:00:00	15.92118507	17.32934040	0.1	24.93371412	1.00	1.2	-1.20	35.4		
01/09 06:00:00	15.79551949	17.20546312	0.1	24.86773365	1.00	1.2	-1.23	36.7		
01/09 07:00:00	16.82674139	17.08857015	0.1	23.41817225	1.00	1.2	-1.11	31.3		
01/09 08:00:00	20.97993424	17.10200900	0.1	28.56301375	1.00	1.2	-0.63	13.3	III	Fri
01/09 09:00:00	21.00000000	17.59999918	0.1	39.63670233	1.00	1.2	-0.51	10.5	III	
01/09 10:00:00	21.00000000	17.83503234	0.1	39.74039001	1.00	1.2	-0.49	10.1	~II	
01/09 11:00:00	21.00000000	18.01789602	0.1	39.61731001	1.00	1.2	-0.47	9.7	II	
01/09 12:00:00	21.00000000	18.17319101	0.1	38.91628240	1.00	1.2	-0.46	9.5	II	II
01/09 13:00:00	21.00000000	18.29989486	0.1	39.47421656	1.00	1.2	-0.45	9.2	II	
01/09 14:00:00	21.00000000	18.41996609	0.1	38.07253768	1.00	1.2	-0.44	9.1	II	
01/09 15:00:00	21.00000000	18.51954157	0.1	37.37700535	1.00	1.2	-0.44	9.0	II	
01/09 16:00:00	21.00000000	18.60715419	0.1	37.40240943	1.00	1.2	-0.43	8.9	II	
01/09 17:00:00	21.00000000	18.68458384	0.1	37.87251025	1.00	1.2	-0.42	8.7	II	
01/09 18:00:00	18.58511331	18.74786468	0.1	39.82461644	1.00	1.2	-0.67	14.6	III	
01/09 19:00:00	18.20062751	18.51213874	0.1	34.30107494	1.00	1.2	-0.77	17.4		
01/09 20:00:00	18.03314031	18.38989029	0.1	32.59184868	1.00	1.2	-0.80	18.7		
01/09 21:00:00	17.96013847	18.28899239	0.1	31.04102148	1.00	1.2	-0.83	19.6		
01/09 22:00:00	17.85892536	18.19889433	0.1	29.82724965	1.00	1.2	-0.85	20.5		
01/09 23:00:00	16.26217118	18.11136858	0.1	30.45324579	1.00	1.2	-1.06	29.0		
01/09 24:00:00	16.49947582	17.83980113	0.1	26.63476269	1.00	1.2	-1.07	29.4		
01/10 01:00:00	16.26645854	17.71737103	0.1	25.22231752	1.00	1.2	-1.12	31.6		
01/10 02:00:00	16.15729731	17.56758783	0.1	24.66845611	1.00	1.2	-1.15	32.9		
01/10 03:00:00	16.01241767	17.42959260	0.1	24.49350041	1.00	1.2	-1.18	34.4		
01/10 04:00:00	15.88557991	17.29531268	0.1	24.46926489	1.00	1.2	-1.21	35.8		
01/10 05:00:00	15.76036186	17.16708133	0.1	24.54222807	1.00	1.2	-1.24	37.1		
01/10 06:00:00	15.64245872	17.04464045	0.1	24.65986171	1.00	1.2	-1.26	38.4		
01/10 07:00:00	16.71540355	16.92847257	0.1	23.02234578	1.00	1.2	-1.14	32.7		
01/10 08:00:00	16.70657407	16.94479110	0.1	23.11889095	1.00	1.2	-1.14	32.6		
01/10 09:00:00	20.97844177	16.92885350	0.1	28.90257711	1.00	1.2	-0.64	13.7	III	Sat
01/10 10:00:00	21.00000000	17.44296053	0.1	41.73210739	1.00	1.2	-0.52	10.7	III	II
01/10 11:00:00	21.00000000	17.69083650	0.1	42.76950993	1.00	1.2	-0.49	10.0	II	
01/10 12:00:00	21.00000000	17.88051391	0.1	42.61092072	1.00	1.2	-0.47	9.6	II	
01/10 13:00:00	21.00000000	18.03383088	0.1	44.58975832	1.00	1.2	-0.44	9.1		
01/10 14:00:00	18.31411558	18.16522604	0.1	49.72689320	1.00	1.2	-0.71	15.8		
01/10 15:00:00	17.72952411	17.92535890	0.1	46.49462536	1.00	1.2	-0.82	19.3		
01/10 16:00:00	17.59912659	17.80621929	0.1	42.86871537	1.00	1.2	-0.87	20.9		
01/10 17:00:00	17.50150611	17.72134797	0.1	40.43918558	1.00	1.2	-0.90	22.1		
01/10 18:00:00	17.42637701	17.64622551	0.1	38.31442288	1.00	1.2	-0.92	23.1		
01/10 19:00:00	15.86558293	17.57458592	0.1	37.75077611	1.00	1.2	-1.13	32.2		
01/10 20:00:00	16.10881436	17.32740836	0.1	31.36941480	1.00	1.2	-1.15	33.0		
01/10 21:00:00	15.83415260	17.22814061	0.1	28.88518490	1.00	1.2	-1.20	35.6		
01/10 22:00:00	15.74498377	17.09511426	0.1	27.64037780	1.00	1.2	-1.23	36.9		
01/10 23:00:00	15.60000753	16.97436473	0.1	26.34625002	1.00	1.2	-1.27	38.7		
01/10 24:00:00	15.60000041	16.85459946	0.1	25.89127208	1.00	1.2	-1.28	39.3		
01/19 06:00:00	15.60000038	15.54779488	0.1	40.34251920	1.00	1.2	-1.34	42.3		
01/19 07:00:00	15.60000038	15.52639343	0.1	39.59298140	1.00	1.2	-1.34	42.6		
01/19 08:00:00	20.97253388	15.51193008	0.1	35.14973819	1.00	1.2	-0.74	16.6	IV	Mon
01/19 09:00:00	21.00000000	16.30283445	0.1	43.31490194	1.00	1.2	-0.62	13.1	III	
01/19 10:00:00	21.00000000	16.68165523	0.1	42.90901543	1.00	1.2	-0.58	12.2	III	
01/19 11:00:00	21.00000000	16.98797316	0.1	42.39928780	1.00	1.2	-0.56	11.6	III	
01/19 12:00:00	21.00000000	17.25192002	0.1	41.98325240	1.00	1.2	-0.54	11.0	III	III
01/19 13:00:00	21.00000000	17.47049096	0.1	42.95635460	1.00	1.2	-0.51	10.5	III	
01/19 14:00:00	21.00000000	17.67039243	0.1	41.14987159	1.00	1.2	-0.50	10.2	~II	
01/19 15:00:00	21.00000000	17.83713246	0.1	40.85374491	1.00	1.2	-0.48	9.9	II	
01/19 16:00:00	21.00000000	17.97325203	0.1	40.18991238	1.00	1.2	-0.47	9.7	II	
01/19 17:00:00	21.00000000	18.08646169	0.1	40.20863162	1.00	1.2	-0.46	9.5	II	

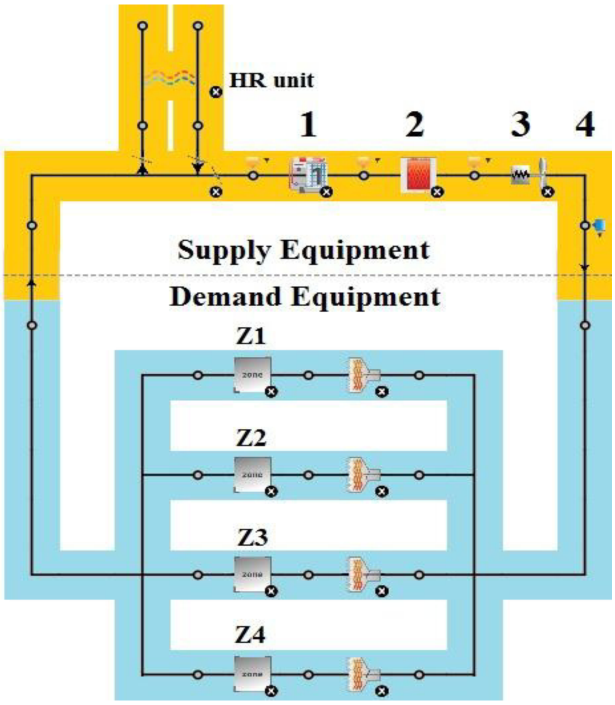
01/19 18:00:00	18.47589313	18.19078303	0.1	43.53001515	1.00	1.2	-0.72	16.1	IV	
01/19 19:00:00	17.92334383	17.94421272	0.1	39.98321361	1.00	1.2	-0.83	19.5		
01/19 20:00:00	17.65895462	17.81796460	0.1	38.33417492	1.00	1.2	-0.88	21.4		
01/21 06:00:00	15.98265975	17.01419608	0.1	36.41029399	1.00	1.2	-1.17	34.1		
01/21 07:00:00	16.86064602	16.91602845	0.1	34.71770273	1.00	1.2	-1.08	29.6		
01/21 08:00:00	20.98039430	16.92080131	0.1	34.80313120	1.00	1.2	-0.61	12.8	III	Wed
01/21 09:00:00	21.00000000	17.45985191	0.1	44.01386734	1.00	1.2	-0.50	10.4	III	
01/21 10:00:00	21.00000000	17.72952495	0.1	44.78538144	1.00	1.2	-0.47	9.7	II	
01/21 11:00:00	21.00000000	17.94348984	0.1	44.84463611	1.00	1.2	-0.45	9.3	II	
01/21 12:00:00	21.00000000	18.12365480	0.1	43.97766558	1.00	1.2	-0.44	9.0	II	II
01/21 13:00:00	21.00000000	18.26966883	0.1	44.47468433	1.00	1.2	-0.42	8.7	II	
01/21 14:00:00	21.00000000	18.40019694	0.1	44.04962873	1.00	1.2	-0.41	8.6	II	
01/21 15:00:00	21.00000000	18.50545134	0.1	43.92256466	1.00	1.2	-0.40	8.4	II	
01/21 16:00:00	21.00000000	18.58867848	0.1	43.39979903	1.00	1.2	-0.40	8.3	II	
01/21 17:00:00	21.00000000	18.66054046	0.1	43.03598718	1.00	1.2	-0.39	8.2	II	
01/21 18:00:00	19.07776844	18.72851965	0.1	46.42317573	1.00	1.2	-0.59	12.3	III	
01/21 19:00:00	18.65259623	18.54180418	0.1	44.96947683	1.00	1.2	-0.66	14.3		
01/21 20:00:00	18.35019511	18.44445085	0.1	44.47126876	1.00	1.2	-0.71	15.6		
02/18 06:00:00	15.90106775	17.16578177	0.1	30.53112459	1.00	1.2	-1.19	35.1		
02/18 07:00:00	16.87117366	17.05194041	0.1	28.73186943	1.00	1.2	-1.09	30.1		
02/18 08:00:00	20.98024441	17.05991165	0.1	31.59921574	1.00	1.2	-0.61	12.9	III	Wed
02/18 09:00:00	21.00000000	17.56111006	0.1	40.99409140	1.00	1.2	-0.51	10.5	III	
02/18 10:00:00	21.00000000	17.80293687	0.1	41.35304304	1.00	1.2	-0.48	9.9	II	
02/18 11:00:00	21.00000000	18.01048832	0.1	41.73120282	1.00	1.2	-0.46	9.5	II	
02/18 12:00:00	21.00000000	18.18409570	0.1	41.89966759	1.00	1.2	-0.44	9.2	II	II
02/18 13:00:00	21.00000000	18.29981072	0.1	42.45263603	1.00	1.2	-0.43	8.9	II	
02/18 14:00:00	21.00000000	18.48016787	0.1	41.09368152	1.00	1.2	-0.42	8.7	II	
02/18 15:00:00	21.00000000	18.58396976	0.1	40.05846702	1.00	1.2	-0.42	8.6	II	
02/18 16:00:00	21.00000000	18.67644547	0.1	39.43460169	1.00	1.2	-0.41	8.5	I	
02/18 17:00:00	21.00000000	18.75093624	0.1	39.62035135	1.00	1.2	-0.40	8.4	II	
02/18 18:00:00	18.93496154	18.81356019	0.1	41.79403978	1.00	1.2	-0.62	13.1	III	
02/18 19:00:00	18.50532774	18.61695310	0.1	37.59757392	1.00	1.2	-0.71	15.6		
02/18 20:00:00	18.28795862	18.51034557	0.1	36.59657932	1.00	1.2	-0.75	16.8		
03/18 06:00:00	19.76748151	19.73802784	0.1	37.73905728	0.80	1.2	-0.80	18.6		
03/18 07:00:00	20.99609212	20.03377512	0.1	35.79954909	0.80	1.2	-0.63	13.3		
03/18 08:00:00	21.19410495	20.22636310	0.1	35.82399905	0.80	1.2	-0.58	12.1	III	Wed
03/18 09:00:00	21.42160539	20.19985940	0.1	36.34323932	0.80	1.2	-0.55	11.4	III	
03/18 10:00:00	21.67533764	20.26268357	0.1	35.11687723	0.80	1.2	-0.52	10.7	III	
03/18 11:00:00	21.91114203	20.37420786	0.1	34.35074574	0.80	1.2	-0.48	9.9	II	
03/18 12:00:00	22.03380735	20.48927483	0.1	33.01744851	0.80	1.2	-0.46	9.5	II	II
03/18 13:00:00	22.34808953	20.61098916	0.1	31.76430101	0.80	1.2	-0.42	8.7	II	
03/18 14:00:00	22.46272181	20.74659100	0.1	31.89628993	0.80	1.2	-0.39	8.2	II	
03/18 15:00:00	22.58966252	20.87068828	0.1	32.39161715	0.80	1.2	-0.35	7.6	II	
03/18 16:00:00	22.28965369	20.98996083	0.1	33.50598508	0.80	1.2	-0.37	7.9	II	
03/18 17:00:00	21.92521069	21.05244890	0.1	34.20462021	0.80	1.2	-0.41	8.5	II	
03/18 18:00:00	21.51164835	21.04177808	0.1	34.40308641	0.80	1.2	-0.46	9.4	II	
03/18 19:00:00	21.15649402	21.02420919	0.1	34.57642329	0.80	1.2	-0.50	10.3		
03/18 20:00:00	21.10613514	20.99541619	0.1	34.47970476	0.80	1.2	-0.51	10.5		
04/22 06:00:00	22.83791509	22.95055303	0.1	27.48896770	0.50	1.2	-0.68	14.9		
04/22 07:00:00	23.33165637	23.04220024	0.1	27.99480259	0.50	1.2	-0.59	12.4		
04/22 08:00:00	23.91498953	23.11084594	0.1	30.27740099	0.50	1.2	-0.48	9.9	II	Wed
04/22 09:00:00	23.97324587	23.20914320	0.1	34.18746446	0.50	1.2	-0.44	9.0	II	
04/22 10:00:00	24.12500251	23.26903986	0.1	34.33845637	0.50	1.2	-0.40	8.4	II	
04/22 11:00:00	24.30459257	23.37067407	0.1	38.23430967	0.50	1.2	-0.34	7.4	II	
04/22 12:00:00	24.68900322	23.45845863	0.1	36.05969514	0.50	1.2	-0.28	6.6	II	II
04/22 13:00:00	24.58982696	23.58071228	0.1	35.09367885	0.50	1.2	-0.29	6.7	II	
04/22 14:00:00	24.84289960	23.65853313	0.1	33.90384346	0.50	1.2	-0.24	6.2	II	
04/22 15:00:00	24.95968218	23.73132314	0.1	33.17315311	0.50	1.2	-0.22	6.0	I	
04/22 16:00:00	24.65645643	23.80075678	0.1	32.94149242	0.50	1.2	-0.26	6.4	II	
04/22 17:00:00	24.50474114	23.80900714	0.1	32.49906192	0.50	1.2	-0.28	6.7	II	
04/22 18:00:00	24.20043101	23.81175967	0.1	32.15556691	0.50	1.2	-0.33	7.3	II	
04/22 19:00:00	23.87938645	23.78165508	0.1	31.85856697	0.50	1.2	-0.38	8.1		
04/22 20:00:00	23.78810794	23.75550609	0.1	31.54247827	0.50	1.2	-0.40	8.4		
05/20 06:00:00	25.57483279	25.27633199	0.1	51.19121647	0.50	1.2	0.22	6.0		
05/20 07:00:00	25.00479850	25.54318367	0.1	52.69981304	0.50	1.2	0.18	5.7		
05/20 08:00:00	25.00000000	25.55615412	0.1	50.49246821	0.50	1.2	0.17	5.6	I	Wed
05/20 09:00:00	25.00000000	25.48330136	0.1	49.95627591	0.50	1.2	0.15	5.5	I	
05/20 10:00:00	25.00000000	25.42511007	0.1	48.19396936	0.50	1.2	0.13	5.4	I	
05/20 11:00:00	25.00000000	25.44427302	0.1	48.94954117	0.50	1.2	0.14	5.4	I	
05/20 12:00:00	25.00000000	25.46110048	0.1	47.66714884	0.50	1.2	0.13	5.4	I	I
05/20 13:00:00	25.00000000	25.48836485	0.1	48.52673605	0.50	1.2	0.14	5.4	I	
05/20 14:00:00	25.00000000	25.51248791	0.1	49.21600342	0.50	1.2	0.15	5.5	I	
05/20 15:00:00	25.00000000	25.53259215	0.1	49.32941232	0.50	1.2	0.15	5.5	I	
05/20 16:00:00	25.00000000	25.54276878	0.1	49.50709954	0.50	1.2	0.16	5.5	I	

05/20 17:00:00	26.64130613	25.53171428	0.1	45.98361624	0.50	1.2	0.39	8.1	II		
05/20 18:00:00	26.37170830	25.65257185	0.1	47.91993102	0.50	1.2	0.38	8.0	II		
05/20 19:00:00	26.07782033	25.66821805	0.1	49.08034692	0.50	1.2	0.34	7.4			
05/20 20:00:00	26.09302814	25.66448608	0.1	49.79182991	0.50	1.2	0.35	7.5			
06/17 06:00:00	26.66599770	26.71142823	0.1	42.45194033	0.50	1.2	0.53	11.0			
06/17 07:00:00	25.03389296	26.90340595	0.1	47.72589966	0.50	1.2	0.34	7.5			
06/17 08:00:00	25.00000079	26.79578924	0.1	49.36279101	0.50	1.2	0.34	7.4	II	Wed	
06/17 09:00:00	25.00000015	26.66831681	0.1	49.51266434	0.50	1.2	0.32	7.1	II		
06/17 10:00:00	25.00000003	26.56137328	0.1	48.83302660	0.50	1.2	0.30	6.9	II		
06/17 11:00:00	25.00000001	26.52189711	0.1	49.15067210	0.50	1.2	0.29	6.8	II		
06/17 12:00:00	25.00000000	26.48991047	0.1	48.04133405	0.50	1.2	0.28	6.7	II		II
06/17 13:00:00	25.00000000	26.48240396	0.1	49.20037589	0.50	1.2	0.29	6.7	II		
06/17 14:00:00	25.00000000	26.46665283	0.1	49.12607386	0.50	1.2	0.29	6.7	II		
06/17 15:00:00	25.00000000	26.44818868	0.1	48.69875268	0.50	1.2	0.28	6.6	II		
06/17 16:00:00	25.00000000	26.42299551	0.1	50.23584127	0.50	1.2	0.29	6.7	II		
06/17 17:00:00	26.69215930	26.37631780	0.1	46.62397558	0.50	1.2	0.52	10.7	III		
06/17 18:00:00	26.70000076	26.46745077	0.1	47.42204708	0.50	1.2	0.54	11.2	III		
06/17 19:00:00	26.70000076	26.48646118	0.1	47.48825117	0.50	1.2	0.54	11.3			
06/17 20:00:00	26.70000076	26.49523300	0.1	47.32643761	0.50	1.2	0.54	11.3			
07/15 06:00:00	26.35147687	26.43788421	0.1	39.57034805	0.50	1.2	0.42	8.7			
07/15 07:00:00	25.02026451	26.58573404	0.1	43.66641133	0.50	1.2	0.27	6.5			
07/15 08:00:00	25.00000007	26.55628636	0.1	45.58072332	0.50	1.2	0.27	6.6	II	Wed	
07/15 09:00:00	25.00000001	26.50507904	0.1	45.90145770	0.50	1.2	0.27	6.5	II		
07/15 10:00:00	25.00000000	26.45560800	0.1	45.83314412	0.50	1.2	0.26	6.4	II		
07/15 11:00:00	25.00000000	26.43434989	0.1	46.35057298	0.50	1.2	0.26	6.4	II		
07/15 12:00:00	25.00000000	26.41108228	0.1	45.62988713	0.50	1.2	0.25	6.3	II		II
07/15 13:00:00	25.00000000	26.40526354	0.1	45.97641639	0.50	1.2	0.25	6.4	II		
07/15 14:00:00	25.00000000	26.38912633	0.1	45.38906327	0.50	1.2	0.25	6.3	II		
07/15 15:00:00	25.00000000	26.37461439	0.1	45.13379288	0.50	1.2	0.24	6.3	II		
07/15 16:00:00	25.00000000	26.34376965	0.1	44.97650571	0.50	1.2	0.24	6.2	II		
07/15 17:00:00	26.64022247	26.29823626	0.1	40.88264099	0.50	1.2	0.46	9.4	II		
07/15 18:00:00	26.70000076	26.37900985	0.1	42.56593190	0.50	1.2	0.49	10.1	III		
07/15 19:00:00	26.53379394	26.39550897	0.1	42.41944736	0.50	1.2	0.47	9.6			
07/15 20:00:00	26.48438164	26.39520475	0.1	41.86089190	0.50	1.2	0.45	9.3			
08/19 06:00:00	26.69627230	26.97402596	0.1	65.66212534	0.50	1.2	0.75	17.1			
08/19 07:00:00	25.04206775	27.16832279	0.1	62.61360634	0.50	1.2	0.49	10.0			
08/19 08:00:00	25.00000343	27.08017845	0.1	57.77287906	0.50	1.2	0.44	9.0	II	Wed	
08/19 09:00:00	25.00000082	26.94365329	0.1	57.66602451	0.50	1.2	0.41	8.6	II		
08/19 10:00:00	25.00000020	26.84138877	0.1	56.11116474	0.50	1.2	0.39	8.2	II		
08/19 11:00:00	25.00000005	26.78823820	0.1	54.25229373	0.50	1.2	0.37	7.8	II		
08/19 12:00:00	25.00000001	26.74866965	0.1	51.76530265	0.50	1.2	0.35	7.5	II		II
08/19 13:00:00	25.00000000	26.72789858	0.1	53.71181677	0.50	1.2	0.36	7.7	II		
08/19 14:00:00	25.00000000	26.70733075	0.1	53.84735187	0.50	1.2	0.35	7.6	II		
08/19 15:00:00	25.00000000	26.68054731	0.1	54.63031503	0.50	1.2	0.36	7.7	II		
08/19 16:00:00	25.00000000	26.64258881	0.1	55.46146460	0.50	1.2	0.36	7.7	II		
08/19 17:00:00	26.69289323	26.59511960	0.1	53.33240928	0.50	1.2	0.60	12.7	III		
08/19 18:00:00	26.70000076	26.68656046	0.1	55.79283664	0.50	1.2	0.64	13.6	III		
08/19 19:00:00	26.70000076	26.70946727	0.1	55.88801183	0.50	1.2	0.64	13.7			
08/19 20:00:00	26.70000076	26.73811116	0.1	56.80170646	0.50	1.2	0.65	14.0			
09/16 06:00:00	24.44954382	24.54317173	0.1	35.32486522	0.50	1.2	-0.17	5.6			
09/16 07:00:00	24.98685232	24.82571876	0.1	35.49189405	0.50	1.2	-0.05	5.0			
09/16 08:00:00	25.00000000	24.96953978	0.1	40.79924575	0.50	1.2	0.01	5.0	I	Wed	
09/16 09:00:00	25.00000000	24.90078180	0.1	44.68664087	0.50	1.2	0.03	5.0	I		
09/16 10:00:00	25.00000000	24.90407265	0.1	45.24435769	0.50	1.2	0.03	5.0	I		
09/16 11:00:00	25.00000000	24.94221837	0.1	46.57492609	0.50	1.2	0.05	5.1	I		
09/16 12:00:00	25.00000000	24.97492027	0.1	46.23449416	0.50	1.2	0.05	5.1	I		I
09/16 13:00:00	25.00000000	25.01263288	0.1	46.41766543	0.50	1.2	0.06	5.1	I		
09/16 14:00:00	25.00000000	25.04401075	0.1	45.97873065	0.50	1.2	0.06	5.1	I		
09/16 15:00:00	25.00000000	25.06966358	0.1	45.36420217	0.50	1.2	0.06	5.1	I		
09/16 16:00:00	25.00000000	25.08806816	0.1	44.78480631	0.50	1.2	0.06	5.1	I		
09/16 17:00:00	26.44888925	25.10081567	0.1	40.61404409	0.50	1.2	0.25	6.3	II		
09/16 18:00:00	25.67425830	25.23382047	0.1	41.77027864	0.50	1.2	0.16	5.6	I		
09/16 19:00:00	25.40839592	25.19690075	0.1	42.08478423	0.50	1.2	0.12	5.3			
09/16 20:00:00	25.34726086	25.17952204	0.1	42.02939793	0.50	1.2	0.10	5.2			
10/21 06:00:00	24.25800694	24.22258286	0.1	49.01669308	0.50	1.2	-0.15	5.5			
10/21 07:00:00	24.69442610	24.24853178	0.1	48.38042622	0.50	1.2	-0.08	5.1			
10/21 08:00:00	25.75837407	24.42261599	0.1	49.83338847	0.50	1.2	0.12	5.3	I	Wed	
10/21 09:00:00	25.73255374	24.54144250	0.1	56.26386723	0.50	1.2	0.18	5.7	I		
10/21 10:00:00	25.90133911	24.61644149	0.1	57.30823746	0.50	1.2	0.23	6.1	~I		
10/21 11:00:00	26.05316556	24.72962054	0.1	57.29622768	0.50	1.2	0.27	6.5	II		
10/21 12:00:00	26.24268622	24.82735722	0.1	56.03105665	0.50	1.2	0.30	6.9	II		II
10/21 13:00:00	26.23173366	24.91727120	0.1	56.02186149	0.50	1.2	0.31	7.0	II		
10/21 14:00:00	26.29938615	24.98167472	0.1	56.48396096	0.50	1.2	0.33	7.3	II		
10/21 15:00:00	26.36750953	25.04849889	0.1	54.71445027	0.50	1.2	0.34	7.4	II		

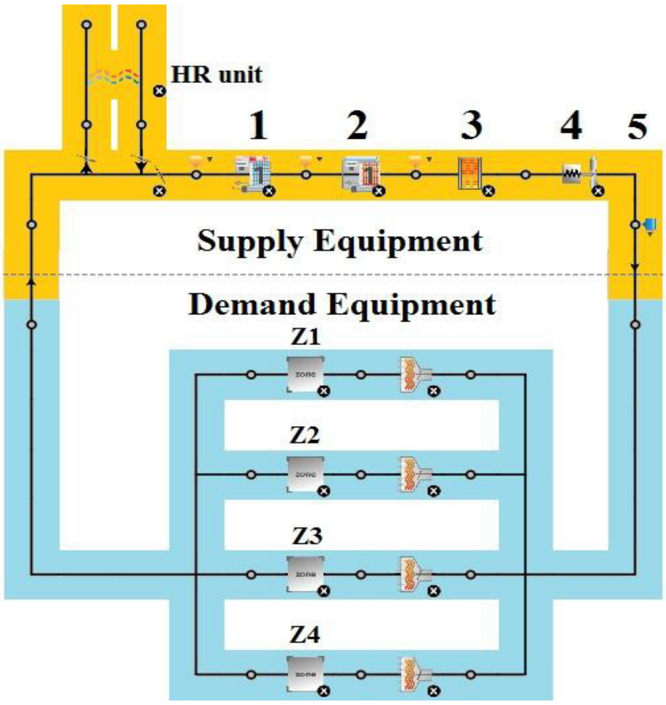
10/21 16:00:00	25.93415230	25.09262515	0.1	55.13026041	0.50	1.2	0.28	6.7	II	
10/21 17:00:00	25.67593707	25.06518038	0.1	54.05783963	0.50	1.2	0.23	6.1	~I	
10/21 18:00:00	25.35937729	25.04485533	0.1	53.01168631	0.50	1.2	0.17	5.6	I	
10/21 19:00:00	25.04751045	25.00975121	0.1	52.01964866	0.50	1.2	0.10	5.2		
10/21 20:00:00	24.97974815	24.96729623	0.1	50.20449078	0.50	1.2	0.08	5.1		
11/18 06:00:00	18.11184628	19.10399845	0.1	36.19607744	1.00	1.2	-0.71	15.7		
11/18 07:00:00	18.97545288	19.03159567	0.1	34.53398946	1.00	1.2	-0.63	13.3		
11/18 08:00:00	20.99112287	19.05368273	0.1	33.95405118	1.00	1.2	-0.40	8.4	II	Wed
11/18 09:00:00	20.99980952	19.28592209	0.1	38.91873287	1.00	1.2	-0.35	7.6	II	
11/18 10:00:00	20.99999950	19.41282289	0.1	40.60775078	1.00	1.2	-0.33	7.3	II	
11/18 11:00:00	20.99999999	19.52544058	0.1	40.81076651	1.00	1.2	-0.32	7.1	II	
11/18 12:00:00	21.00000000	19.61674318	0.1	40.90196289	1.00	1.2	-0.31	7.0	II	II
11/18 13:00:00	21.00000000	19.67631518	0.1	40.79758958	1.00	1.2	-0.30	6.9	II	
11/18 14:00:00	21.00000000	19.71730777	0.1	41.24960412	1.00	1.2	-0.30	6.9	II	
11/18 15:00:00	21.00000000	19.74914875	0.1	41.66657353	1.00	1.2	-0.29	6.8	II	
11/18 16:00:00	21.00000000	19.78585730	0.1	42.16199063	1.00	1.2	-0.29	6.7	II	
11/18 17:00:00	21.00000000	19.81959637	0.1	42.76196473	1.00	1.2	-0.28	6.6	II	
11/18 18:00:00	20.05854063	19.84642423	0.1	45.28026242	1.00	1.2	-0.37	7.9	II	
11/18 19:00:00	19.86694209	19.76841259	0.1	45.21491921	1.00	1.2	-0.40	8.4		
11/18 20:00:00	19.61558110	19.72510836	0.1	45.38619032	1.00	1.2	-0.43	8.9		
12/16 06:00:00	16.74287877	17.44845608	0.1	45.23985096	1.00	1.2	-1.00	26.2		
12/16 07:00:00	17.48451961	17.37503624	0.1	43.57538144	1.00	1.2	-0.92	22.9		
12/16 08:00:00	20.98335823	17.37858426	0.1	39.40191232	1.00	1.2	-0.54	11.1	III	Wed
12/16 09:00:00	21.00000000	17.84313194	0.1	45.97829079	1.00	1.2	-0.45	9.3	II	
12/16 10:00:00	21.00000000	18.06806382	0.1	46.67819123	1.00	1.2	-0.43	8.9	II	
12/16 11:00:00	21.00000000	18.25907144	0.1	46.96976240	1.00	1.2	-0.41	8.5	II	
12/16 12:00:00	21.00000000	18.41250254	0.1	46.57463613	1.00	1.2	-0.40	8.3	II	II
12/16 13:00:00	21.00000000	18.54145282	0.1	46.39062871	1.00	1.2	-0.38	8.1	II	
12/16 14:00:00	21.00000000	18.65566793	0.1	47.06212865	1.00	1.2	-0.37	7.9	II	
12/16 15:00:00	21.00000000	18.74913993	0.1	47.54567942	1.00	1.2	-0.36	7.7	II	
12/16 16:00:00	21.00000000	18.81747851	0.1	46.63767479	1.00	1.2	-0.36	7.7	II	
12/16 17:00:00	21.00000000	18.89489873	0.1	46.13099525	1.00	1.2	-0.35	7.6	II	
12/16 18:00:00	19.52774279	18.95627163	0.1	49.52536529	1.00	1.2	-0.50	10.3	III	
12/16 19:00:00	19.17857427	18.82064827	0.1	48.87872460	1.00	1.2	-0.56	11.5		
12/16 20:00:00	18.75847342	18.74505119	0.1	48.62427774	1.00	1.2	-0.61	12.9		

APPENDIX G
HVAC Systems

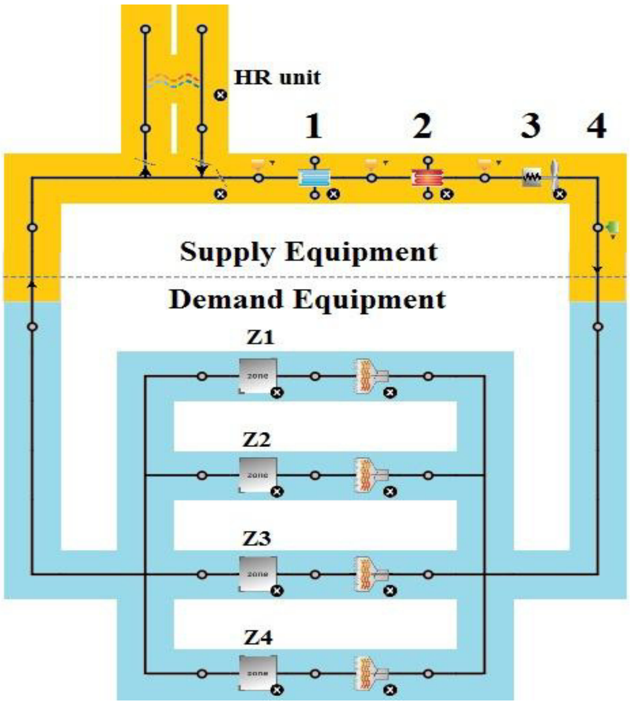
Scheme 1 – HVAC System 1 – Heat pump air to air



Scheme 2 – HVAC System 2 – Gas and electricity



Scheme 3 – HVAC System 3 – Electrical



Scheme 4 – HVAC System 4 – Fan coil