Design parameter guidelines for purely passive cooling buildings in Tropical regions

Fatima El Hadji

Master thesis
Delft University of Technology

Design parameter guidelines for purely passive cooling buildings in Tropical regions

by Fatima El Hadji

to obtain the degree of Master of Science
at the Delft University of Technology,
to be defended publicly on the 31st of October 2019

Student number:		4744896
Project duration:		November 1, 2018 – November 1, 2019
Thesis committee:	Dr. Alejandro Prieto Hoces,	TU Delft, supervisor
	Dr Michela Turrin,	TU Delft, supervisor
	ir Christien Janssen,	TU Delft, supervisor

TU Delft

Acknowledgements

I would like to express my sincere appreciation to all the people that I have met during this experience at TuDelft. First of all, I want to thank the graduation committee, Dr. Alejandro Prieto Hoces, Dr. Michela Turrin and it Christien Janssen for the supervision, the support and the guidance throughout this last year.

Many thanks to Esteco for the help and support during the optimization phase with ModeFrontier, to the experts at the VR lab of TuDelft and to Marianna for sharing the challenges of our master thesis together.

Special thanks to the people that started this experience with me, to the ones that left and to those that enjoyed till the end with me.

Finally, I am sincerely grateful to my mother for teaching me the patience, my sisters for teaching me the persistence and finally my brother for having enlightened the path to this opportunity.

Fatima El hadji
Delft, October 2019

Glossary

- *ZEB:* Zero Energy Building.
- *BPS:* Building Performance Simulation.
- *BPO:* Building Performance Optimization.
- *EUI:* Energy Intensity Use.
- *GH:* Grasshopper.
- *MF:* ModeFrontier.
- *DOE:* Design of Exploration.
- *GA:* Genetic algorithms.
- *wwr_n:* window-to-wall ratio north facade.
- *wwr_s:* window-to-wall ratio south facade.
- *wwr_e:* window-to-wall ratio east facade.
- *wwr_w:* window-to-wall ratio west facade.
- *shadingtype:* shading type.
- *depth:* depth of the louvres.
- *numshading:* number of louvres.
- *op_coolingload_normalized:* cooling demand.
- *sda*: spatial daylight autonomy.
- *op_optemp*: internal operative temperature.
- *op_solar_gains*: internal solar heat gains.
- *op_air_temp*: internal air temperature.
- *op_nat_vent_energy*: the heat loss due to natural ventilation.
- *op_lightingload_norm*: electric lighting load needed.
- *percent_comfort_time*: percentage of time for which at least 90% of the occupants are comfortable.

Contents

1

Introduction

1.1. Problem statement

Nowadays, the energy consumption has a significant role in the entire life cycle of a building. The energy consumed is influenced by both the design of the building it self and the climate conditions of the location. The energy demands keep rising due to growth in population, increasing demand for healthy, comfort and productive indoor environment, global climate changing, and so on [2]. In fact, as found from the International Energy Agency the energy consumption for cooling has tripled from 1990 till 2016 [7]. This rapid increase in energy use in buildings represents a major issue especially in regions with extreme climate conditions. For instance, in hot-humid climate the major reason for the high energy consumption for any type of building is the use of air conditioning [6]. In particular, in tropical regions where cooling buildings represent a necessity to assure a certain level of thermal comfort, over 50% of the building's energy consumption is used for cooling purposes [25]. A study conducted by Chan and S.Aun found out that the energy due to the use of air conditioning is equal to 64%, 59% and 51% of the total building's energy in Malaysia, Singapore and Thailand respectively [34]. Moreover, the Building and Construction Authority (BCA) of Singapore indicates that the percentage of electricity used for air conditioning in non-residential buildings reaches the 60% of the total electricity consumption [46].

The figure 1.1 shows the growth of the air conditioning use globally between 1990 and 2016. Also, it shows the comparison of the air conditioning use between the residential sector and the commercial sector, which is almost double of the first sector. Thus, this makes the focus on office buildings more reasonable for this research. Furthermore, when analyzing office buildings, the main reason behind this high energy consumption, is the design of fully glazed facade, which causes the overheating of the internal spaces and consequently the use of air-conditioners. Moreover, the economic growth in hot-arid and hot-humid regions, such as the Middle East and South-East Asia, has caused a boom in the construction of buildings designed through fully glazed facades to show modernity and prestige. (Carlos Ernesto Ochoa, 2008) In the case of tropical regions, which are characterized by intense radiation, high humidity, low wind speeds and a constant high air temperature throughout the year, the design strategies implemented plays a fundamental role in regards of two main factors: the energy consumption and indoor thermal comfort. In order to monitor and find a balance between these two variables, particularly when assessing office buildings in a tropical climate region, passive cooling strategies are explored and analyzed [32].

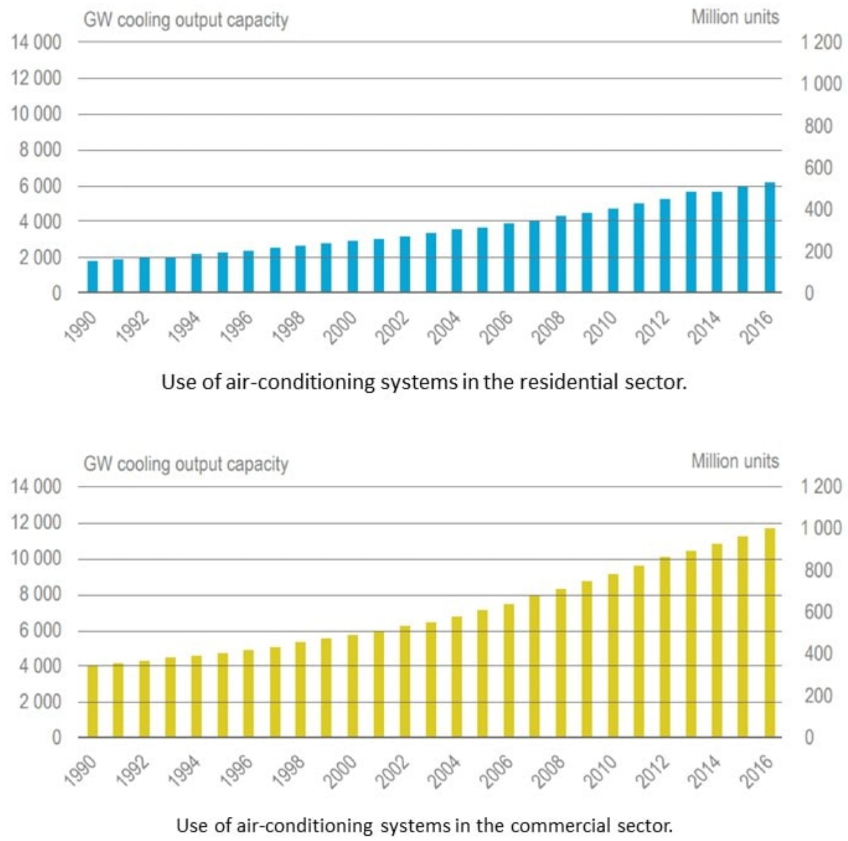

Figure 1.1: Use of air-conditioning systems in the residential sector (top) and in the commercial sector(bottom). IEA, 2018

Before the implementation of refrigeration technologies in the building industry and the increase of thermal comfort levels, designers in tropical climates used to tackle the climate conditions using natural methods to prevent the building from unwanted heat and to control the heat gains from the surrounding environment. This approach, known as vernacular architecture, has evolved over the years in the well-known bioclimatic approach. The latter has been deeply experimented and applied by its main pioneer: Ken Yeang. The Malaysian architect applied the bioclimatic strategies on several projects, especially on high rises. However, Ken Yeang's bioclimatic high rises are the outcome of the combination of passive cooling strategies and active cooling systems, which lead to high energy consumption levels.

Many passive solar strategies like the ones used in the bioclimatic architecture lead to the reduction of heating, cooling and lighting energy consumption. By applying these strategies individually, the energy demand can be reduced to a certain extent, but by implementing the optimal combination of different passive design strategies it is possible to reach even lower levels of energy consumption. The research of the optimal solution can be possible through the use of building energy simulations and building energy optimization tools in the early stage of the design [50].

Furthermore, another interesting factor is that out of 332 Zero Energy Buildings (ZEB) globally, only three ZEBs are built in the tropical climate. (2016 List of Zero NET Energy Buildings, 2019) In the last 2 decades a deep research has been carried out about passive house design, achieving significant improvements in terms of energy performance. The energy of the appliances to achieve indoor thermal comfort has been reduced drastically by means of design strategies. The result reached is the reduction of 90% of the energy heating demand compared to the existing building stock. On the other hand, the documentation and the examples available for tropical climates is far less even though cooling demand is one of the main factors for the rising energy demand in the countries of Southeast Asia. In fact, conventional modern constructions need between 200 and 400 kWh/m2 solely for the air conditioning systems. The main plausible reason for the limited design of passive buildings in tropical regions is the climatic conditions, intense radiation and high humidity, which make the design of a Zero Energy

Building a big challenge [56].

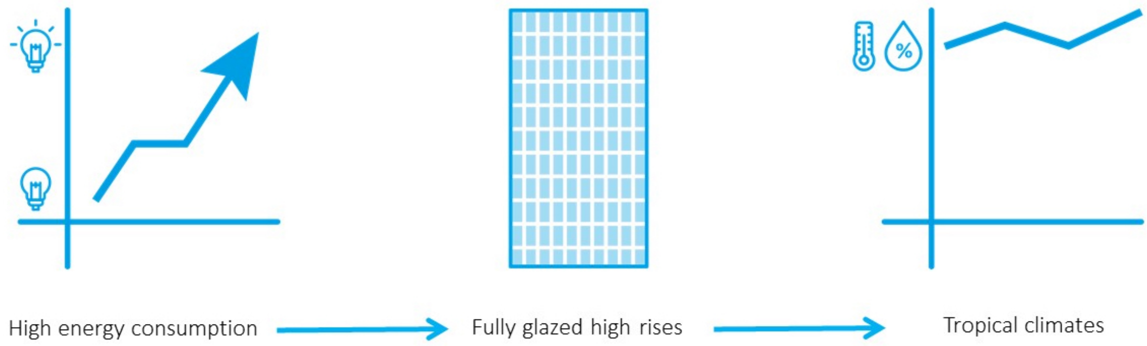

Figure 1.2: Problem statement.

The design of net zero-energy buildings is challenging the way buildings are designed and constructed, leading architects to address to detailed energy related decisions already at the conceptual stage of the design. Combining passive and active strategies already from the early design stage of a design requires not only an integrated collaboration between architects and engineers, but also a high level of expertise, and software packages such as the integration of building performance simulation (BPS) tools. A study revealed that architects and non-specialist users find it challenging to make use of BPS tool in order to achieve a design that meets aesthetic and energy related requirement , therefore a guideline that could simplify the design process for a nearly zero energy building through BPS tools is indeed helpful [10].

Thus, the aim of this research is to understand the feasibility of a purely passive building in tropical climates, combining the bioclimatic approach and passive cooling strategies. In particular, the design objective is to define the design parameters that guarantee a purely passive building and indoor thermal comfort. Also, it is the objective of this study to investigate the influence of the application of heat prevention and heat dissipation techniques on the design process of a purely passive building. Furthermore, since the adaptive thermal comfort model is regarded as a valuable concept to achieve a low consuming building, it is applied in this project. Finally, it is the aim of this study that the results and recommendations can be useful guidelines for designers that aim to design a purely passive building in a tropical region, such as Singapore, Indonesia, Uganda, Colombia or other countries, since the climate conditions are similar.

1.2. Main objective

The main objectives of this research are to investigate the possibility of the design of a purely passive building in tropical climate and to investigate to what extent it is possible to achieve a low energy building. Related to these main objectives, this research aims to identify the most impactful design parameters on the cooling consumption of a typical floor of an office building. Also, the research of the solutions of the most energy efficient buildings is carried out. Then with the results obtained, a guideline based on different aspects is drawn for future designers, architects and engineers willing to design a low energy building in hot-humid regions.

1.3. Research question

How can a purely passive office building be achieved in a tropical climate ensuring the indoor thermal comfort?

1.4. Sub questions

- What has been done in bioclimatic architecture to solve hot and humid climate issue in passive way?

- What are the applicable passive building strategies in a hot and humid climate?
- What is the most optimal combination of passive envelope strategies in order to reduce the cooling demands?
- What is the effect of the envelope design parameters on the cooling consumption?
- What is the effect of the combination of envelope parameters and indoor comfort parameters on the cooling consumption?

1.5. Approach and methodology

The main focus of this research is the application of passive cooling strategies on the design of the envelope of an office building in a tropical area, in particular in Singapore. The latter is chosen as starting point, since the country-state of Singapore offers different fully glazed high rises office buildings as case study, but the outcome of this study is intended to be applied in cities with similar climate conditions (such as Malaysia, Indonesia, or even Brazil). The original objective is to reduce the energy consumption for cooling, while keeping a focus on the indoor thermal comfort, throughout the application of the different passive strategies, and the following optimization of the latter. The development of this graduation project consists of the application of two methodologies in order to achieve the final goal: research for design and research through design.

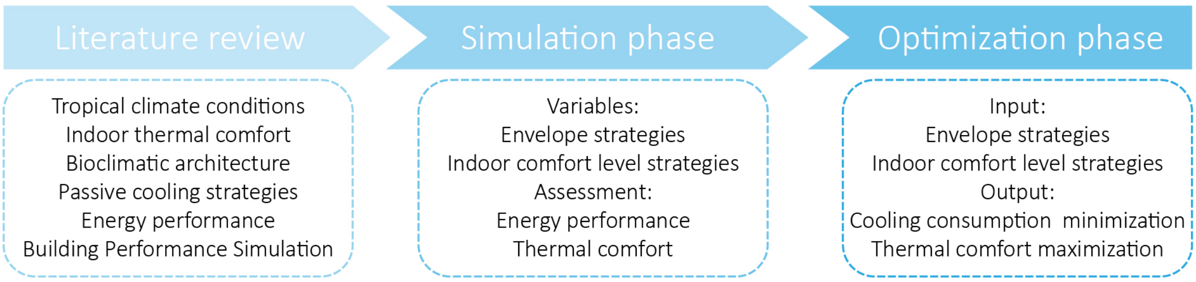

Figure 1.3: Approach followed

The first phase of this thesis is considered as research for design, through the literature review and the analysis of the scientific knowledge gathered about passive design strategies, indoor thermal comfort and computational design. The findings of the research will build the theoretical background which will lead the researcher to choose the most suitable design strategies according to the location of the case study. The chosen design strategies will be applied to a general case study and simulated through computer simulations during the second phase of the graduation project.

The second part involves research through design, meaning the research of design solutions through the computational application and simulation of design strategies, outcome of the previous phase of the thesis. In particular, this phase is based on an iterative design research, which has as main purpose the reduction at minimum of the energy consumption for cooling, while keeping track of the indoor thermal comfort.

Specifically, while the geometry of the building case study is maintained, other strategies are applied. These are divided in two groups of variables: envelope parameters and indoor comfort parameters. Thus, two rounds of optimization are run. The first optimization consists of the application of envelope parameters as variables, in order to investigate the most optimal combination of heat prevention techniques and to quantify the impact of a well thought envelope. In fact, once obtained the results of the first optimization an analysis of the impact of the envelope strategies is carried through the post-processing tools of the optimization software.
Then, a second optimization will be carried out implementing both envelope and indoor comfort variables, in order to assess to what extent it is possible to lower the cooling demands of an office buildings in tropical climate by implementing design strategies but also strategies linked to the users behaviour. This second optimization with respect to the first one, add new variables such as internal loads (occupancy and lighting density) and cooling set point temperature for the air conditioning system. Also, cross ventilation is implemented in order to assess the heat loss due to natural ventilation.

The impact of each variable on the cooling demand is analysed by observing the behaviour of the design solutions as a whole, but also specific unique cases are extracted from the design solutions to be discussed. Finally, in a last chapter specific design solutions are selected and proposed with respect to three different design goals: aesthetic goals (such as high transparency), internal constraints (occupancy density or a specific cooling set point temperature) and energy performance (low cooling consumption). This last discussion is done in order to help other designers to understand the impact of certain design decisions and to quantify the consequent range of energy consumption for cooling needed.
Since this study combines three different components, the design of the envelope, the indoor thermal comfort and the computational control of the first two, the research was carried out as follows. First, a research in literature was conducted. The research was performed using mainly article databases such as Web of Science, ResearchGate, Elsevier, ScienceDirect and Google Scholar. Initially, the strategy consisted on a first selection of publications based on various factors: relevance of the title in relation to the theme and then a narrower criteria which lead to the papers with major focus on the application of passive design strategies only in tropical climates.
Then, in order to refine the research, three groups of key words were established in relation with the three fields abovementioned:

- **Façade design**: purely passive building, passive design strategies, passive cooling, passive techniques, tropical climate, hot-humid area, tropical region, High rise, office building, envelope design, Solar control, Natural ventilation, Ventilation strategies, Building orientation, WWR, shading device, shading system, passive building, zero energy building ;

- **Climate design**: Thermal comfort, indoor thermal comfort, natural ventilation, ventilation strategies, adaptive approach, adaptive comfort;

- **Computational design**: Optimization, thermal simulation, energy efficient building, energy savings, energy consumption, cooling, thermal comfort, energy performance, Building energy performance optimization, Multi-objective optimization, computer simulation.

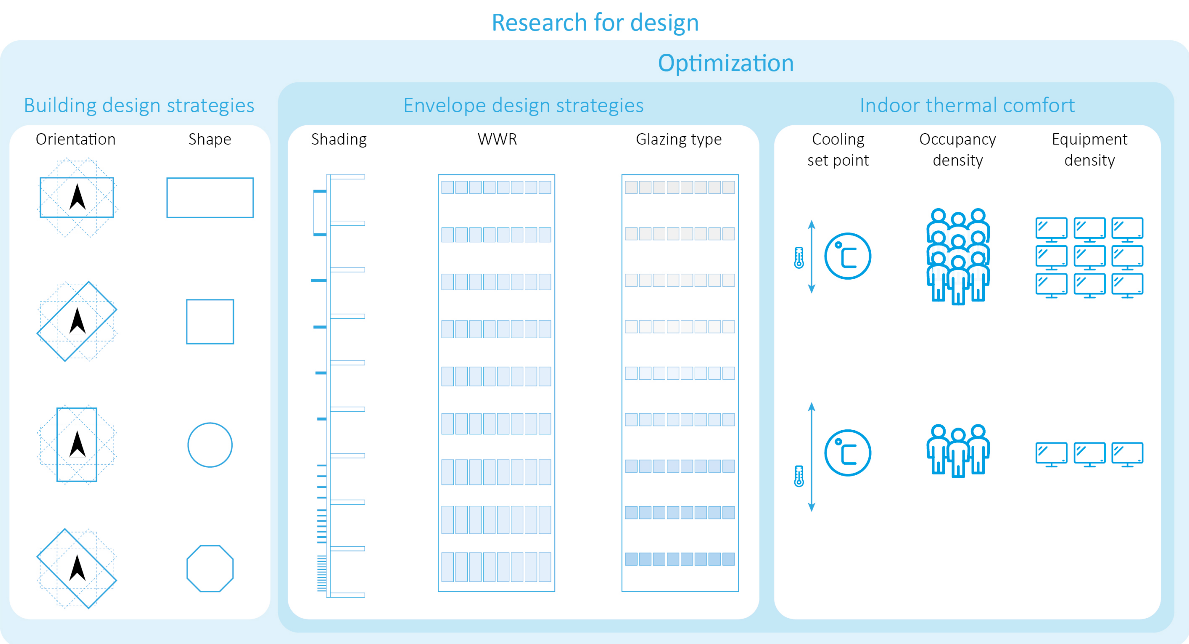

Figure 1.4: Optimization workflow implemented.

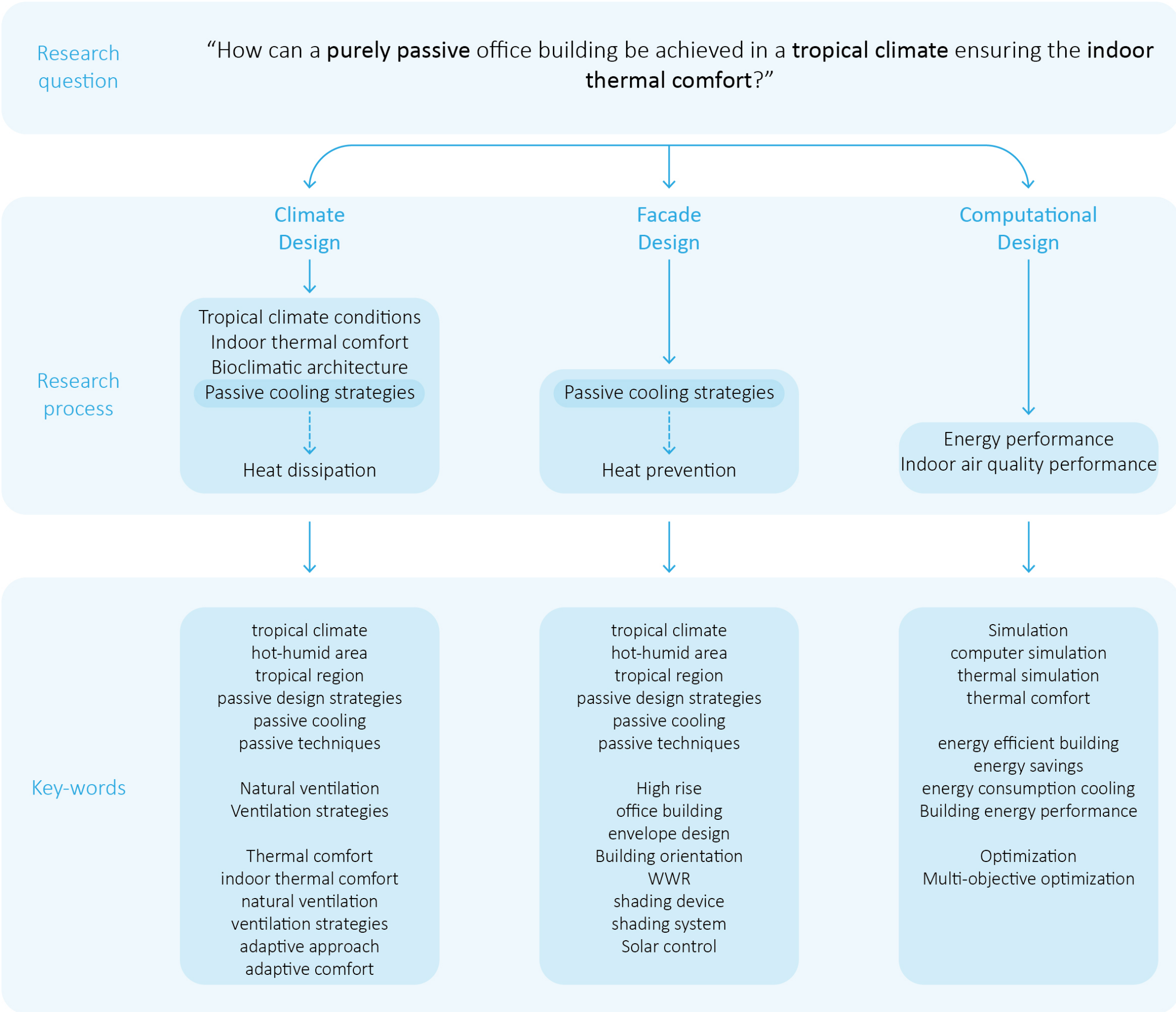

Figure 1.5: Literature review approach

1.6. Time planning

The following time planning scheme follows the methodology discussed above. The first phase of the graduation project will be dedicated entirely to the literature research. This will lead to the definition of a stronger background for the following phases. The next step, from the P2 assessment, will be focused on the final research on simulation and optimization process and on the definition of boundaries for the testing phase. The stage between P3 and P4 will be spent on the optimization phase, and the analysis of the results will follow in the period between P4 and P5. All the assessment periods until the P4 will be maintained as already planned, while the last session of P5 is not defined yet. The reason is the participation to the Solar Decathlon Europe competition, which will take place in the same period of the P5. Thus, the last assessment will be probably shifted exceptionally (date to be defined).

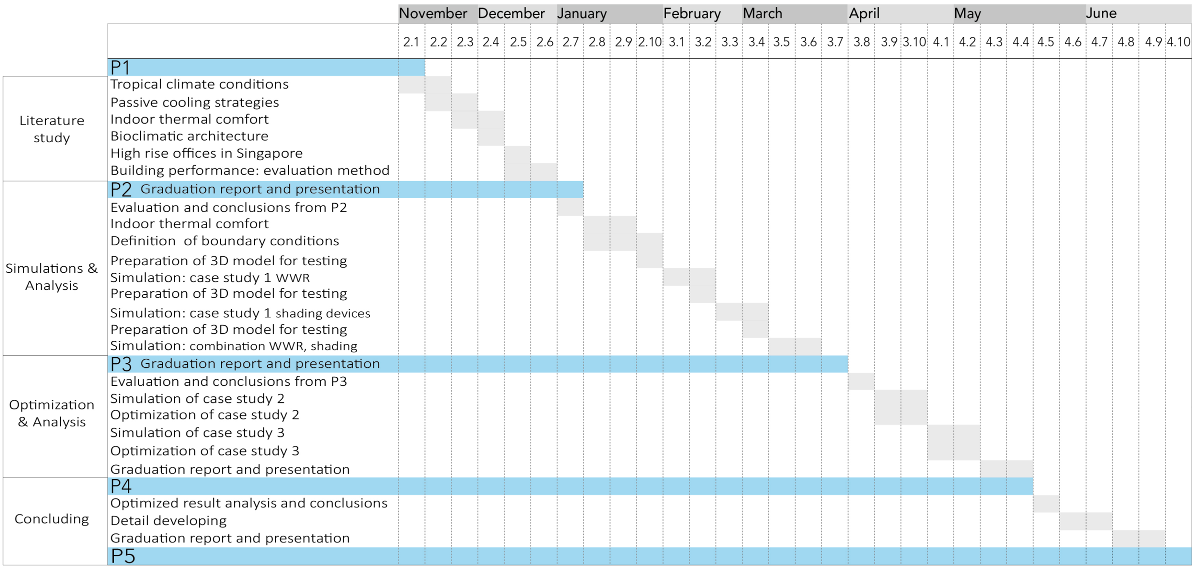

Figure 1.6: Time planning of the graduation project.

2

NET ZEB in Tropical climates

In this chapter Zero Energy Buildings in tropical climates will be presented and discussed. Although the scope of this research is the design of a purely passive building, it was not possible to find previous reference projects. Thus, it was considered to research on the definition of a zero energy building, which includes both passive and active strategies, and to investigate reference projects in tropical climates. As it is explained in the following paragraphs, the number of ZEBs in tropical regions is extremely low with respect to the number of ZEBs globally, proving the challenge of designing a low energy consuming building with extreme climate conditions.

2.1. Zero energy building definition

Zero-energy building, or also known as Zero Net Energy (ZNE) building, net-zero energy building (NZEB), net zero building or zero-carbon building refers to a building which consumes as much energy as it produces annually [55]. In the literature, Torcellini, et al. (2006) uses the general definition for ZEB given by The U.S. Department of Energy (DOE) Building Technologies Program: "A net zero energy building (ZEB) is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies."[30].

According to Torcellini, et al. (2006), a Net ZEB is a building with a very low energy consumption and a building which complement the already low energy demands by the use and generation of renewable energy on site. In order to be defined as Net ZEB it is necessary to focus on two main factors: firstly the reduction of the energy demands by implementing passive strategies and energy efficient systems and secondly the production of enough electricity by renewable energy systems in order to cover the previously reduced energy demands.

Passive design strategies are the first approach to implement in the design of Net ZEBs since they directly influence the heating, cooling, ventilation and lighting loads of the electrical systems, reducing the amount of renewable energy necessary to compensate the energy consumption of the building [20].

Between 2008 and 2013 the research program Solar Heating and Cooling Program (SHC) Task 40 / Energy in Buildings and Communities (EBC) Annex 52, within the framework "Towards Net Zero Energy Solar Buildings" carried out by the International Energy Agency, was followed and conducted by several researchers from different countries. The aim of the research was to analyse current net-zero, near net-zero and very low energy buildings and to elaborate a general outline of the entire concept. Also, other important objectives of this research project were to define design process tools, advanced building design and technology solutions and industry guidelines for future Net Zero Energy Buildings [55].

The overview of the Net ZEBs conducted in the framework of the IEA Task 40/Annex 52 has resulted in the acknowledgement of the need of the application of a bioclimatic approach with passive design strategies. In particular, the building envelope should not only rely on thermal insulation, but it should also become a multi-functional component that protect from outside environment while drawing from free sources of energy such as wind, sun, etc. The future effect of global warming on the climate for the upcoming decades must be took into account during the design of the building. The integrated system should be more energy efficient. Also, it was found that ceiling fans are fundamental to guarantee an indoor thermal comfort in locations where temperatures can achieve around 30°C [20].

In the abovementioned Task40/Annex52, the International Energy Agency focuses on a benchmark set of NZEBs globally and one of the outcomes of this research was the framing of a list of 30 zero energy buildings and projects. The latter were organized with regards to a list of required criteria in order to ensure high quality data about the buildings and their measured performance. The locations of those 30 Net-ZEBs are plotted in the figure 2.1 [20]. As it is showed in the map, the Net ZEB buildings in Tropical regions are only three: Ilet du Centre and Enerpos in La Reunion Island and BCA Academy in Singapore. A detailed description of the abovementioned projects and all the strategies implemented is addressed in the following paragraphs.

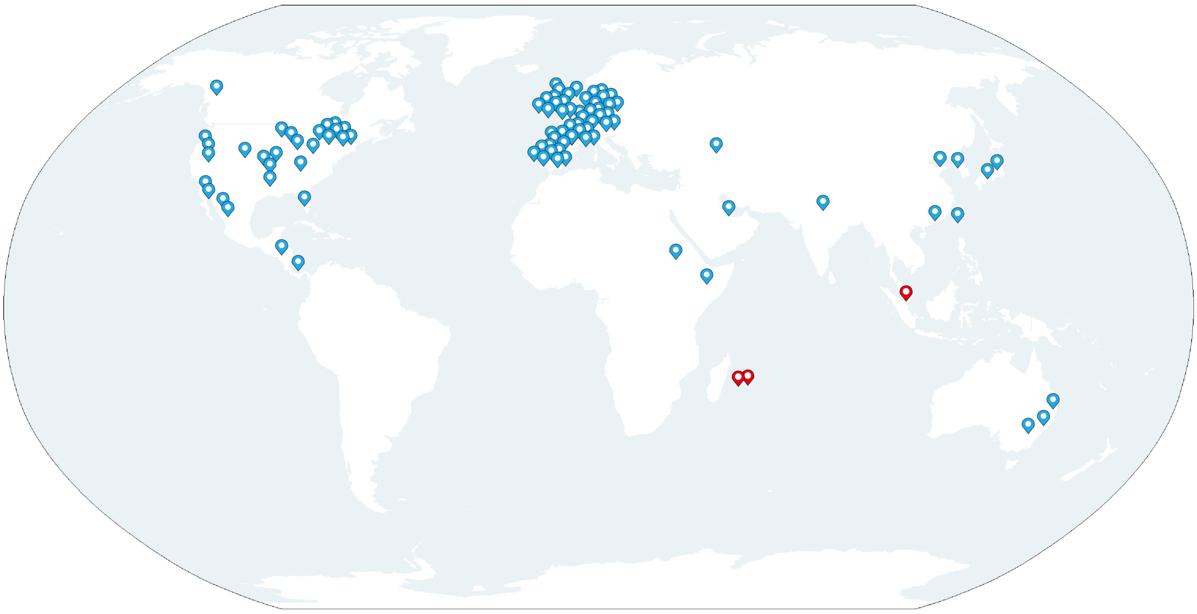

Figure 2.1: NET ZEB around the world. Source: https://www.researchgate.net

2.2. Zero energy building in the Tropics

2.2.1. BCA Academy, Singapore

The only Zero Energy Building in South East Asia is the BCA Academy in Singapore. This piece of architecture has been acclaimed as the nation's greenest building thanks to a smart usage and an efficient production of energy resulting from an optimal combination of passive design strategies, renewable energy sources and energy savings awareness campaign among the occupants. The current BCA Academy, 4,500 m^2 of classroom, office, research and public space, is the outcome of the retrofit of a former office building including classrooms and a resource center. Thanks to the integration of solar panels on the roof and of the façade, the energy produced sustains the daily needs of the building and, according to the BCA, the savings amount to roughly 84,000 Singapore dollars a year in energy costs compared to a typical office building in Singapore. The energy savings are achieved thanks to the application of passive measures, namely natural ventilation, solar shading devices, low-e glass, optimized daylighting and energy efficient lighting appliances. However, up to 40% of the cooling demands is saved due to the integration of technologically advanced chillers and personalized ventilation systems. Thus, both active and passive systems were applied, as shown in the figure 2.3.

Figure 2.2: Section of the BCA Academy (Source: http://www.hpbmagazine.org/Case-Studies/Zero-Energy-Building–BCA-Academy-Singapore/).

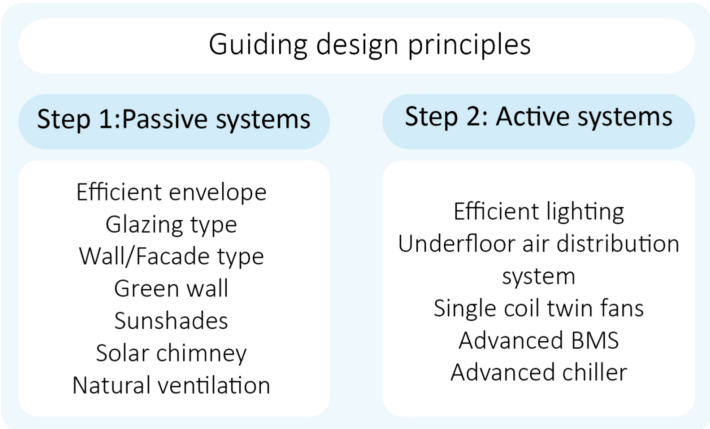

Figure 2.3: Guiding design principles of the BCA Academy.

This remarkable result is achieved thanks to the use of several active and passive strategies. First, an energy efficient envelope was designed to include both a low-e glass and shading systems allowing for a reduction of the transfer of solar radiation through glass, the decrease of the solar heat gain and the improvement of the quality of natural lighting, respectively. Second, a technologically advanced building management system allows to control, monitor and manage all the installations implemented in the building. The energy monitoring allows also to efficiently adapt and optimize the energy consumption adapting it to the occupants needs and habits. Other strategies which help to achieve a smart energy usage include the employment of technologically advanced chillers, variable speed drives, and personalised ventilation systems which lead to the reduction up to 40 % of the energy consumption relevant to the cooling system. Other than that, the energy use is further reduced by means of efficient equipment, such as energy efficient lamps, automatic switching via photosensors and daylighting. Third, solar radiation energy is obtained exploiting photovoltaic systems belonging to 1G,2G,3G generations and permit to produce electricity for the powering of all the appliances and ZEB lighting. Moreover, the stack effect drove by the solar photovoltaic leads to a better air circulation and ventilation in the classrooms. Also, the inside temperature is lowered not only by the natural ventilation but also by the vertical greenery. Last but not least, a careful attention was paid to the layout, aesthetics and design of the building with relation to the productivity and comfort of the users. For example, a green facade has been designed both to facilitate natural cooling and aesthetic purposes. Also, in the classrooms primarily natural light is allowed thanks to the integration of light tubes in the roof [60].

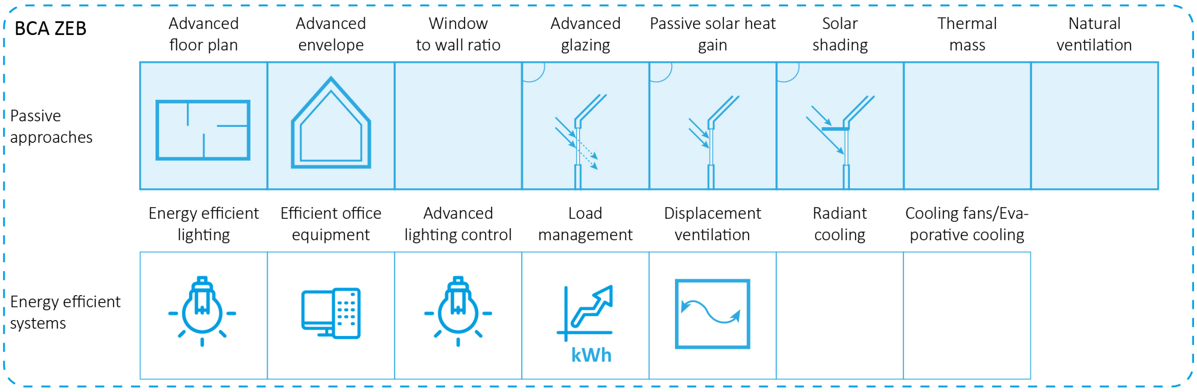

Figure 2.4: Passive and active measures applied in the design of the BCA ZEB

2.2.2. Ilet du Centre, Reunion Island

L'Ilet du Centre consists of housing and offices realized in 2008. The whole complex was designed following principles of bioclimatic architecture. Meaning the implementation of natural ventilation, and the design of external walkways as buffer zone area with a shading system. Regarding the heat prevention, external shutters are applied on the glazing and reflective metal cladding on the facade. While the generation of the energy is achieved through the positioning of solar panels on the roof [3].

Figure 2.5: Top view of the complex of the Ilet du Centre (Source: https://labreunion.fr/projets/ilet-du-centre/).

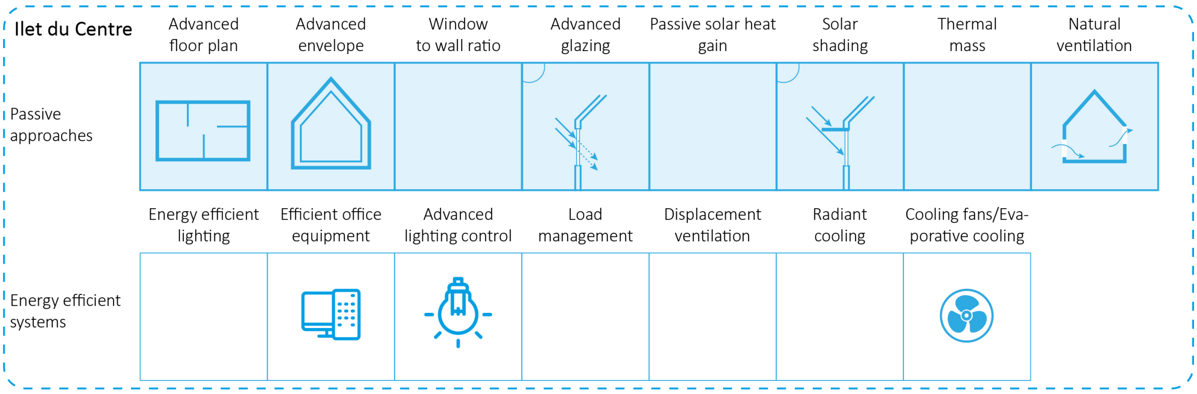

Figure 2.6: Passive and active measures applied in the design of the Ilet du Centre.

2.2.3. Enerpos, Reunion Island

The EnerPos building is the first educational zero energy building in the Tropics and it was inaugurated in 2008. The building reached both the goals set during the design phase: achieving a high energy efficient building while providing a comfortable environment for the users. In particular, the original objective was to cut the energy consumption due to the use of air conditioning system. In fact, the latter is used only in one-third of the building, in areas where computers and equipment lead to an increase of the temperature. While the rest of the building is cooled and naturally ventilated to create a comfortable place without the use of AC systems [55]. In particular, in order to boost the natural ventilation the building is designed as two small parallel buildings with a limited width and with interior louvers between the corridor and the offices on each side [3]. Regarding the heat prevention from the solar radiation, the first strategy was to do not place any glazing on the western and eastern facades, secondly external louvres and vertical shadings are positioned on the glazed areas [55]. Finally, concerning the energy production, solar panels are placed all over the surface area of the roof to balance the energy use of the building.

Figure 2.7: View of the two buildings that compose the EnerPos building (Source: http://www.hpbmagazine.org/Case-Studies/University-of-La-Reunions-ENERPOS-Saint-Pierre-La-Reunion-France/) .

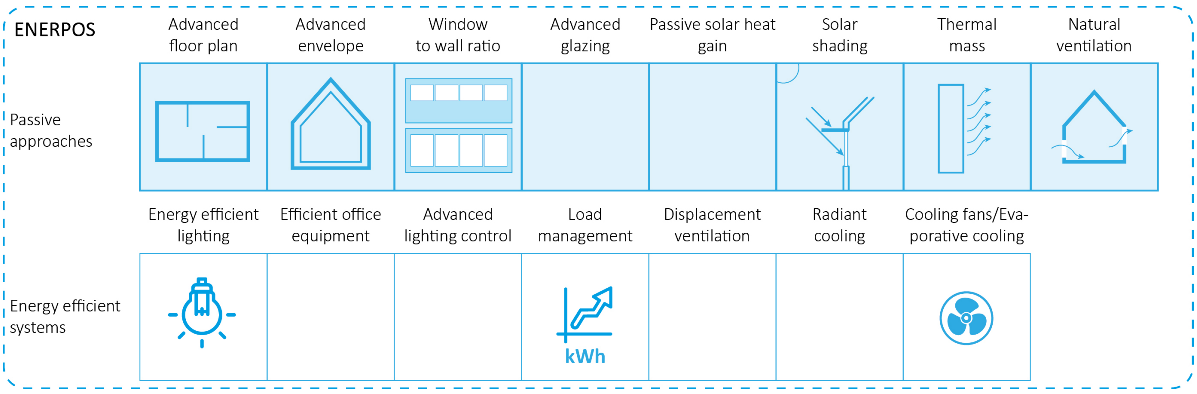

Figure 2.8: Passive and active measures applied in the design of Enerpos building.

2.3. Conclusions on ZEB in the Tropics

After the achievement of a zero energy building in Singapore, Professor Wittkopf stated that the main objective of the BCA Academy was not only to achieve the highest goals of a sustainable design but also to proof that the realization of a zero energy building is possible even in the extreme conditions of a tropical climate [12]. However, the achievement of a zero energy building in a tropical climate was made possible for a low building, while this research is applied on high rise buildings. In the figure 2.9 the comparison of the active and passive strategies implemented in the three zero energy buildings is showed.

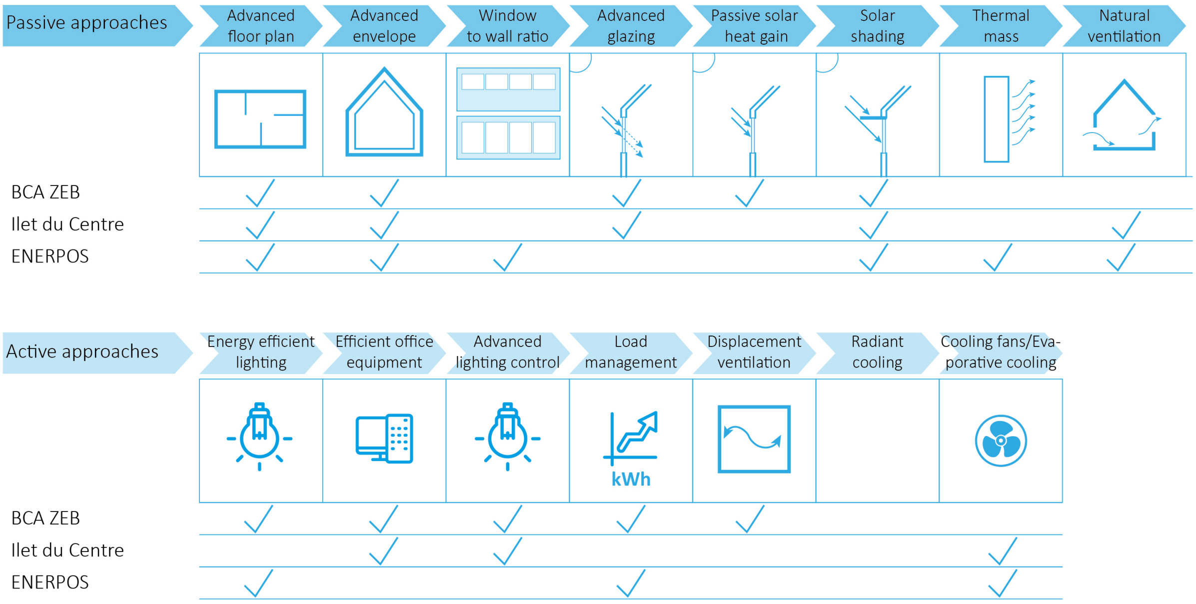

Figure 2.9: Comparison of the three ZEB buildings in terms of passive and active systems applied.

3

Background: Location

3.1. High rises offices in Singapore

The Singapore counts over 4,300 completed high-rises, the majority of it being Isituated in the city center. Singapore's history of skyscrapers began with the 1939 completion of the 17-storey Cathay Building, which was considered the tallest building in Southeast Asia, at that time.

Figure 3.1: Panorama of Singapore's skyline (Source: https://en.wikipedia.org)

Between 1970 and 1980 Singapore went through a remarkable development of the construction industry due to the city's rapid industrialization. During this period the tallest building in the city-state was the Overseas Union Bank Centre 280 m tall. Between 1990 and 2000 the skyscraper-building boom continued with the construction of 30 skyscraper of a minimum height of 140 m [55] Therefore, the economic development of countries of the South-East Asia, such as Singapore, has produced a construction boom characterized by prestige design and novelty to show prosperity and modernity [36]. Out of 216 high-rises, from a minimum height of 56 m to a maximum height of 290 m, 55% are residential buildings, 29% offices and the other 16% are hotels and mixed-use buildings [15].

3.2. Envelope design

Most of the high-rise offices in Singapore are designed with fully glazed curtain wall systems with high reflective glass. The buildings that integrate shading devices in the envelope are very limited. Also, façade with high window to wall ratio are preferred for aesthetical reasons and in order to guarantee a wide view of the skyline of the city. The highly sealed façades are a clear evidence of the dependence of electrical systems to control the indoor climate in the design of offices in Singapore. Moreover, the economic growth in hot-arid and hot-humid regions, such as the Middle East and South-East Asia, has caused a boom in the construction of high-rise buildings designed through fully glazed facades to show modernity and prestige [36]. In fact, the latter is seen as a metaphor of prosperity, creating a temperate western office climate within a tropical climate country [54].

Figure 3.2: Examples of high rise offices in Singapore. One Raffles Quay (Source: https://www.kpf.com/projects/one-raffles-quay) , Asia square tower 1 (Source:https://www.worldpropertyjournal.com/real-estate-news/singapore) and Frasers tower (Source:http://seac.tradelinkmedia.biz/publications/6/news/680) (from left to right).

3.3. The overall office building energy performance patterns in Singapore

Generally the energy consumption of an office building depends on "the air-conditioning system, lighting system, vertical transportation system, ventilation system, office equipment and other miscellaneous appliances". In the study carried out by Lee, on the analysis of the energy consumption of 12 sampled buildings in Singapore, the results showed that air-conditioning system reached the highest percentage of the total energy consumption with about 52%, followed by 25.3% of the energy consumed by the office equipment and other electrical appliances. Finally, the energy use of the lighting system, transportation system and ventilation system were found to be 11.73%, 7.30% and 3.80% of the total building energy consumption respectively [17].

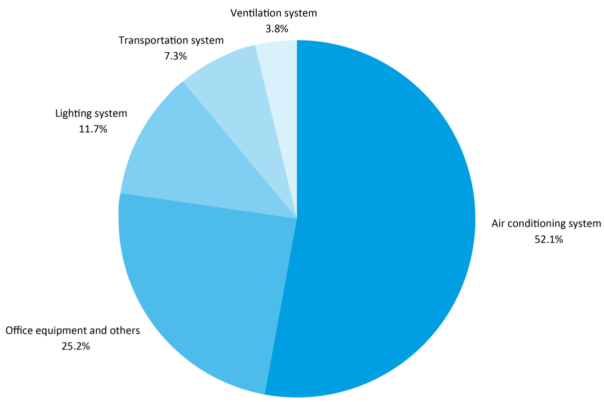

Figure 3.3: Percentage distribution of energy consumption of sampled office buildings in Singapore. Source: Qi, 2006.

Finally, the distribution of energy performance of office buildings in Singapore in terms of energy efficiency is in a very large range from 100 kWh/m2 /year to 469 kWh/m2 /year [17].

3.4. Benchmark in Singapore

The Building and Construction Authority (BCA) Green Mark Scheme was initiated in January 2005 with the objective of pushing the building design in Singapore to achieve more environment-friendly goals. The main purpose is to increase the awareness among developers, designers and builders of the impact of the construction industry on the environment by executing a standard benchmark and guideline system [48]. Also, the BCA Green Mark was designed specifically for the tropics, particularly for the city-state of Singapore, and in fact it is based on a different rating system with respect to the system used in the United States or in Europe, such as LEED or BREEAM [1]. Upon assessment, buildings are awarded a rating, so far 36% of Singapore's buildings have achieved Green Mark Certification [49] The regulations, the rating system and the criteria are updated every year through the publication of the reports. The criteria are structured in five sections, with 11 pre-requisite requirements to meet. The main five criteria that have been established to assess new and retrofitted buildings are the following:

- Sustainable Management
- Building Energy Performance
- Advanced Green Effort
- Resource Stewardship
- Smart and Healthy Buildings

The benchmark is not related solely on the design of a sustainable building, but it is mostly related to other factors, such as a green approach from the tenants, the occupants, the building developer, green leadership, the implementation of smart building operations and energy efficient systems or the sustainable management of the waste and of the water. Therefore, on a total of 165 points to achieve the maximum score only 40 points are spent for the Building Energy Performance. Furthermore, if the distribution of the 40 points dedicated for the Building Energy Performance is analysed, it turns out that the most significant part of these points is limited for the selection of an energy efficient air conditioning system and air distribution system (up to 17 points) while the least amount of points is dedicated to the façade performance (2 points).

Figure 3.4: Publications of the Building and Construction Authority (BCA) Green Mark Scheme

Figure 3.5: The main five criteria that have been established to assess new and retrofitted buildings.

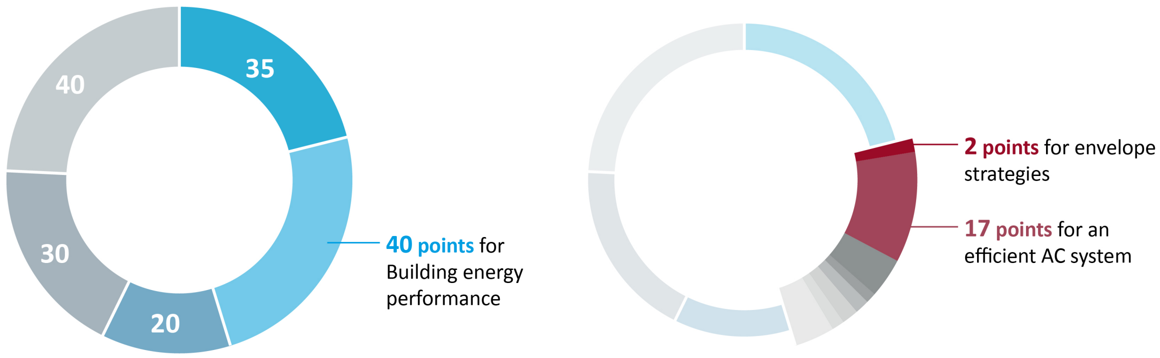

Figure 3.6: Division of the 165 points on the five criteria assessment.

It is clear that only two points out of 165 total points are not that influential on the final score, although the building and the envelope design in general are the first factors to be considered for a sustainable design. Thus, it is also evident that the Singaporean benchmark reward mostly the implementation of energy efficient and technological systems rather than the overall building design for the achievement of a sustainable design. Precisely, unlike other sustainable certifications the BCA Green Mark emphasizes markedly the installation of technologically advanced cooling units, claiming that reducing energy consumption is necessary in a tropical city where air-conditioning systems represent a considerable part of the total electricity demand [1].

Consequently, how can a building be defined more sustainable than another one, if the design of the building itself has a low influence on the rating system? Indeed, some experts question if this approach is encouraging towards an unsustainable addiction on air conditioning as an essential design component, regardless of the improvement in energy efficient models. Indeed, Deo Prasad, professor of architecture at the University of New South Wales in Australia and previous consultant of the BCA, during an interview stated that at the end the goal of these evaluation tools is to reduce the environmental footprint. The architect ended up the interview by questioning rhetorically:

'' is Singapore getting hooked into energy consumption being absolutely necessary for comfort? ''

Differently, other countries of the Southeast Asia, such as Malaysia and Indonesia, established rating tools promoting vernacular designs focused on passive technologies, such as the optimization of shading and natural ventilation [1].

3.5. BCA Green Mark buildings

The BCA defined ranges of numerical scores in accordance with the applicable criteria using the scoring methodology and the pre-requisite requirements established, in order to define the environmental performance of a specific design solution. Under this assessment, credit points are added if sustainable building features and practices are integrated in the overall design. Finally, a certification will be assigned to the buildings assessed depending on the level of the building performance and on the Green Mark Score. The possible certifications are the BCA Green Mark Certified, Gold, GoldPlus. Or Platinum and the corresponding score necessary is showed in the following table [12] :

Green Mark Rating	Green Mark score
Green Mark Platinum	70 points and above
Green Mark GoldPlus	60 to 70 points
Green Mark Gold	50 to 60 points
Green Mark Certified	Compliance with all pre requisite requirement

Figure 3.7: Green Mark rating score system.

The Awards will be given out for the following build types:

- Non-Residential Buildings (New & Existing)
- Residential Buildings (New & Existing)
- Schools
- Landed Houses
- Healthcare Facilities

Here are presented three of the existing office buildings that were awarded with the highest Green Mark award in 2018. The selection of the following three buildings over other 49 existing non-residential buildings is due to the intention to analyse the influential factors that led to the achievement of the highest rating in buildings with a medium-high height and with high window-to-wall ratio.

3.5.1. Revenue House, BCA Award Platinum

Strategies implemented are as follow:

- Installation of high-performance variable frequency chiller systems using environmentally friendly refrigerant, with an efficiency of less than 0.65kW/RT
- Installation of smart monitoring and leak detection for main and sub-water system
- Installation of CO2 monitoring and control system and electronic air cleaners for Air Handling Units
- Installation of LED Lighting for car parks and staircase
- Installation of Photocell sensors for all office levels and motion sensors in toilets
- Installation of Rainwater collection system for grey water usage and rain-sensor for autoirrigation system
- Recycling of plastic, aluminium electronic waste, cans, waste papers, toners, printer cartridges

3.5.2. Republic Plaza, BCA Award Platinum

Strategies implemented are as follow:

- Efficient water-cooled chiller plant system better than 0.60 kW/RT.
- Use of WELS-certified fittings and awarded as Water Efficient Building
- Use of LED lightings for car park and staircases
- Use of motion sensors for control of lightings at staircases and toilets
- All AHUs are equipped with high efficiency MERV 13 air filter
- Installation of auto tube cleaning system for the chiller plant

3.5.3. The Metropolis, BCA Award Platinum

Strategies implemented are as follow:

- Energy efficient chiller plant with a system efficiency of 0.578kW/RT
- Lifts and escalators are equipped with VVVF drive and sleep mode features
- 50.2 kWp solar panel to harness and generate clean energy
- Carbon monoxide (CO) sensors at car parks basement 1 to 3
- Water fittings certified under PUB “Excellent” and “Very Good” WELS rating
- Recycling chute for paper recycling

After the analysis of the reasons that led to the achievement of the highest Green Mark rating of the buildings abovementioned, it was possible to conclude that the main factors that influenced the final result were mainly the installation of energy efficient chillers, the installation of CO2 monitoring and control system, the use of LED lightings and the recycling of the waste produced in the building. Thus, it is again evident that the Green awarded buildings in Singapore are definitely not based on sustainable features related to the design of the building in order to solve the issues caused by the conditions of the site in a efficient and green way.

Figure 3.8: Examples of buildings rated with Platinum Award. Revenue House (Source: https://www.streetdirectory.com), Republic Plaza (Source: http://www.skyscrapercenter.com/building/republic-plaza/635) and The Metropolis (Source: http://www.servcorp.com.sg) (from left to right).

4 Background: Climate

This chapter will mainly discuss the main characteristic of a tropical climate and then focus in a second stage on the climate conditions of Singapore. Moreover, the indoor thermal comfort will be addressed in order to understand the standards and current comfort requirements for office buildings, making a comparison between indoor comfort levels in different climates.

4.1. Tropical climate

”A tropical climate in the Köppen climate classification is a non-arid climate in which all twelve months have mean temperatures of warmer than 18 °C (64 °F)”. This climate characterizes the regions along the equatorial belt with hot and humid weather. Tropical regions are marked by constant temperature throughout the year, with a slight difference of 2-3°C between the day and the night, high level relative humidity and high precipitation throughout the year. This particular climate is characterized by only two seasons, a dry and a wet season which differ in the amount of rainfall and cloudiness [31].

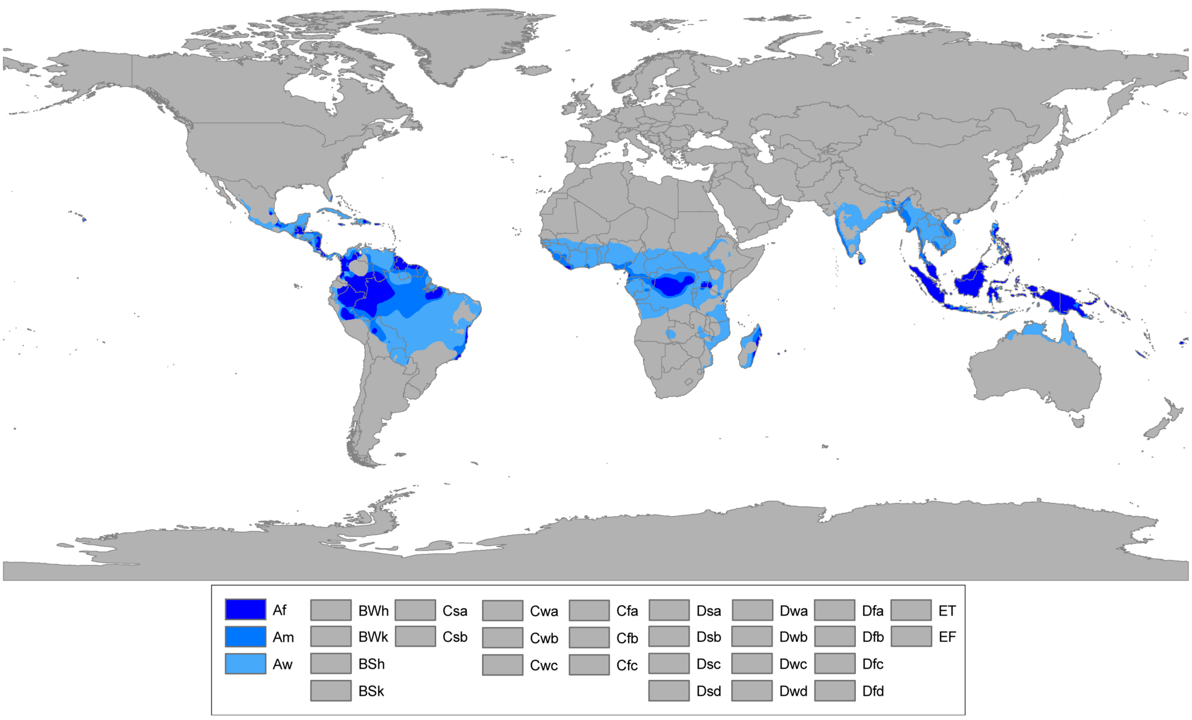

Figure 4.1: World map of Koppen-Geiger climate classification. Tropical climate extracted. (Source: www.wikipedia.org).

The Tropical Climate can be further classified according to the distribution of precipitation patterns such as: Tropical Fully Humid (Af), Tropical Monsoonal (Am) and Tropical Wet and Dry (Aw) [45]. This research will focus on the Tropical Fully Humid (Af) climate, which concerns locations such as Indonesia, Malaysia, Singapore, Eastern India, Eastern coast of Brazil, Eastern coast of Central America and the Amazon River Basin (South America) [45].

4.2. Singapore climate

Singapore is characterized by typical equatorial features: relatively uniform temperature, abundant rainfall, and high humidity. ”The average daily temperature is 26.9°C, with an average daily maximum of about 31°C and an average daily minimum of about 24.1°C. December and January are generally cooler months” [37].

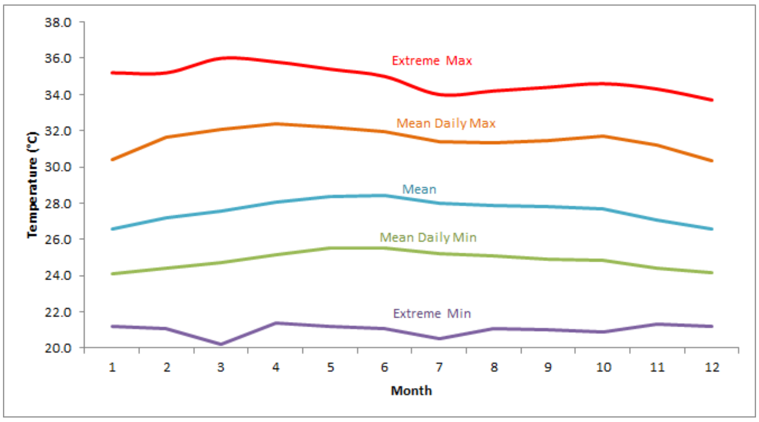

Figure 4.2: Mean monthly temperature variation (ºC) (1981-2010) (Source: http://www.weather.gov.sg/climate-climate-of-singapore/)

The average annual rainfall is equal to 2,352mm with rainfall throughout the whole year, with rain peaks in the months from November to January and dry periods in the months of July and February. February is usually the sunniest month while December is often the month with the least sunshine [37].

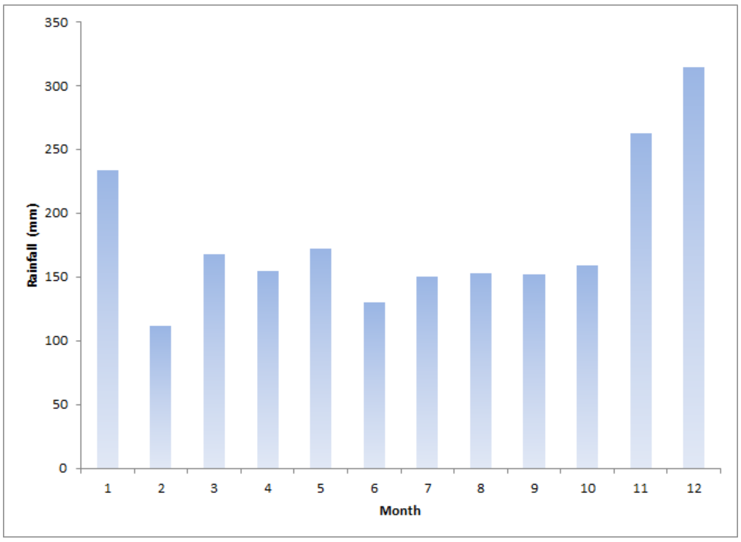

Figure 4.3: Monthly rainfall for Singapore (mm) (1981-2010) (Source: http://www.weather.gov.sg/climate-climate-of-singapore/)

The relative humidity is uniform throughout the year with very low variations from month to month. The variation of the relative humidity is mainly during the day, varying from 90% to around 60%, in the morning and in the afternoon respectively. The mean annual relative humidity is 83.9%. Relative humidity frequently reaches 100% during prolonged periods of rain [38].

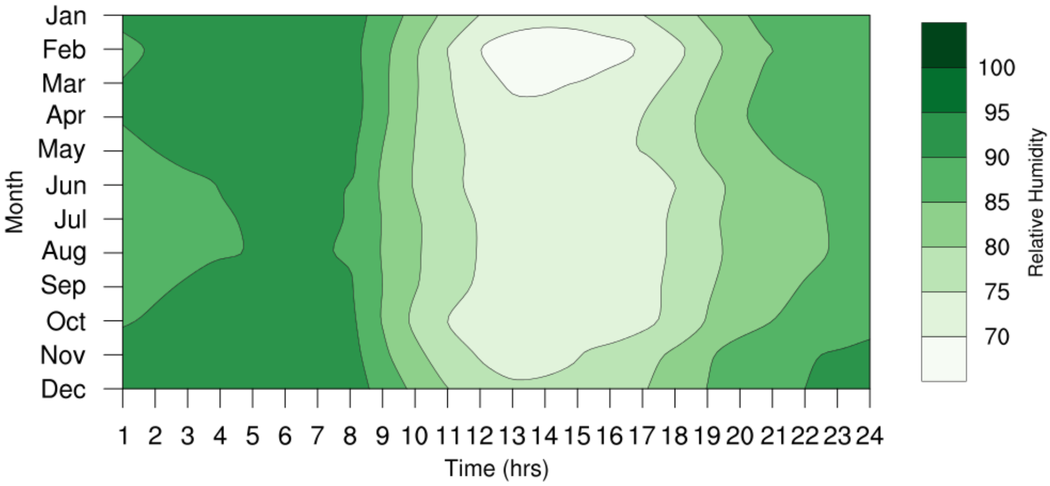

Figure 4.4: Hourly variation of relative humidity for each month (1981-2010) (Source: http://www.weather.gov.sg/climate-climate-of-singapore/)

Each type of climate results in a specific amount of solar radiation and a mean outside temperature that a building is exposed to. Therefore, from the climate depends also the amount of energy that is needed for heating, cooling and lighting. Cooling degree hours and days (CDD), heating degree hours and days (HDD) and solar excess hours and days (SED) for different tropical cities is shown in figure 4.5. A degree hour is the difference in temperature above or below the reference temperature (26°C for cooling and 18°C for heating) during the course of one hour and can be calculated if hourly temperature data are available.

	HDD	CDD	SED
Singapore	0	2627	1133
Kuala Lampur	0	2453	1019
Bangkok	1	2950	1275
Manila	0	2672	1052

Figure 4.5: HHD, CDD and SED of four cities in Tropical regions. (Source: Matthias Hasse, 2009)

Also, solar excess is defined as the amount of solar energy that is unwanted in the building, which causes overheating of the internal spaces. In order to establish the amount of solar excess which affect a specific location, solar excess degree hours are defined as the amount of degree hours where the sol-air temperature exceeds the outside air temperature. Solar excess degree hours cause an excess cooling load on the building due to incident solar radiation in the overheated period (summer). Regarding the behaviour of the wind, in Singapore the predominant winds come from the north to north-east and from the south to south-east. Thus, implementing high areas of openable windows on the north and south facades would enhance the indoor thermal conditions by means of wind driven natural ventilation.

4.3. Comparison between different climate's scenarios

In the following paragraph a comparison of the climate conditions of three different cities is made in order to test the applicability of the results of this thesis in other cities in tropical regions.The comparison is made between the city of Medellin, Uganda and Singapore. Firstly, the maximum average temperature is 27°C for Medellin and 31°C for Jakarta and Singapore.Regarding the minimum average temperature, the city of Medellin records the lowest value, with 15°C, followed by Kampala with 16°C and Singapore with 23°C.

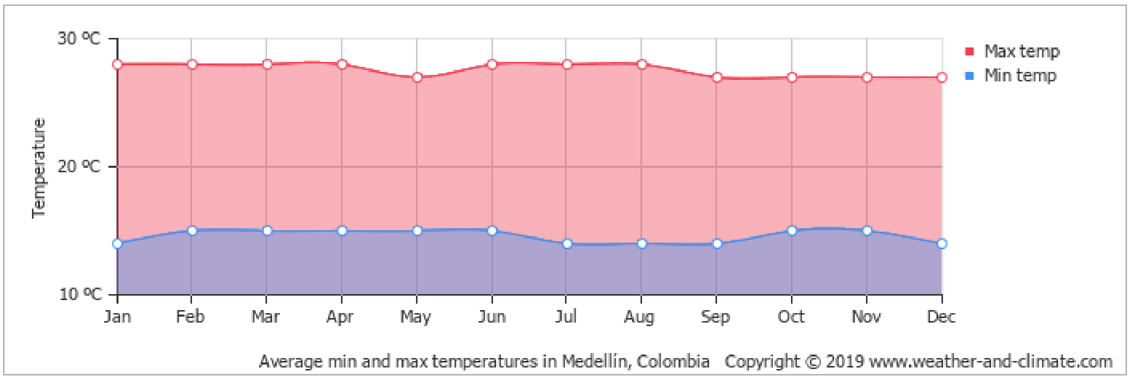

Figure 4.6: Average minimum and maximum temperature over the year in Medellin, Colombia.

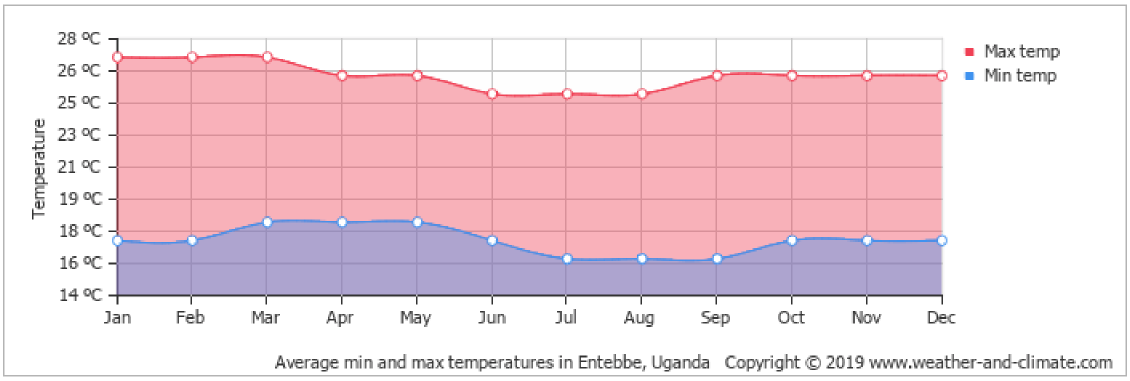

Figure 4.7: Average minimum and maximum temperature over the year in Kampala, Uganda.

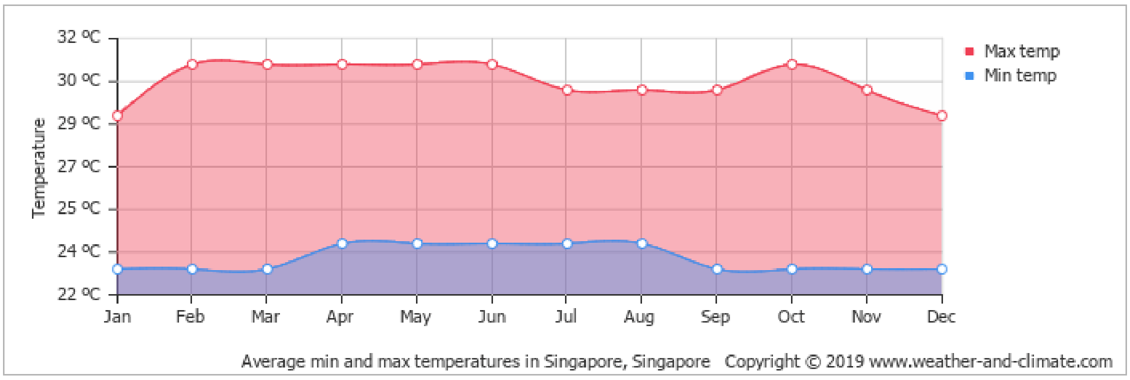

Figure 4.8: Average minimum and maximum temperature over the year in Singapore.

Then, the comparison of the range of relative humidity is made. The city of Medellin has the lowest value of relative humidity, followed by Kampala and Singapore, with a maximum relative humidity of 70%, 80% and 83% respectively.

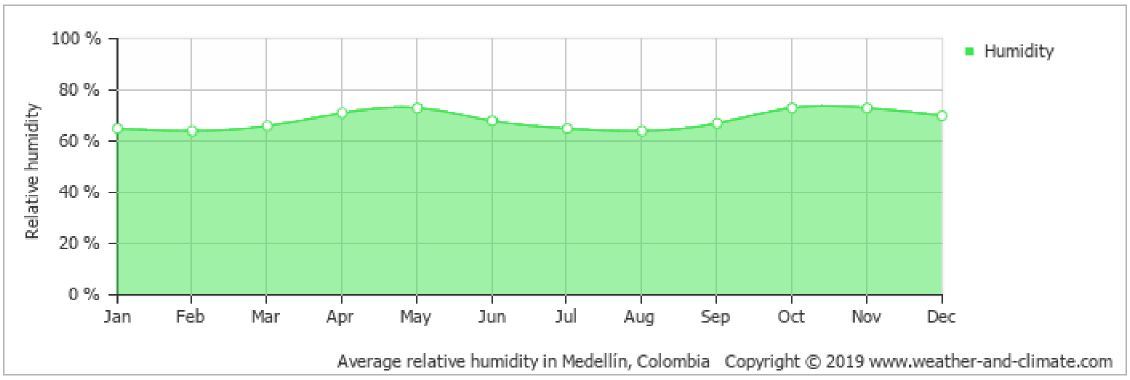

Figure 4.9: Average relative humidity over the year in Medellin, Colombia.

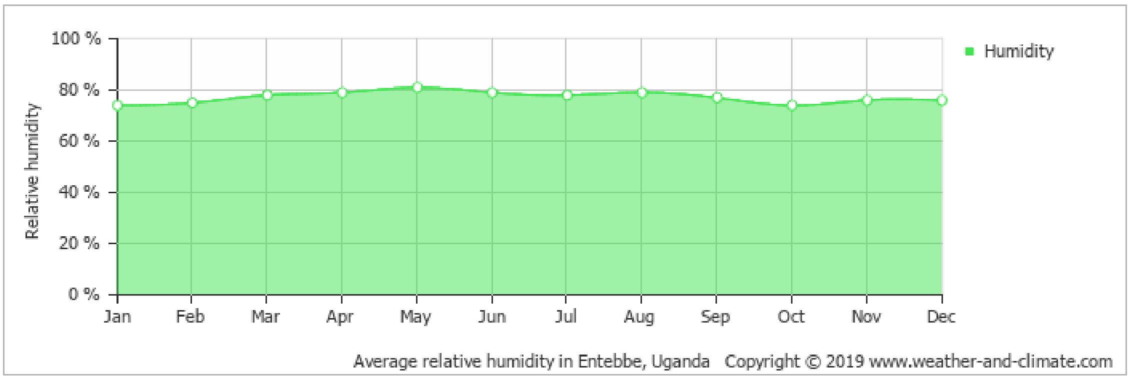

Figure 4.10: Average relative humidity over the year in Kampala, Uganda

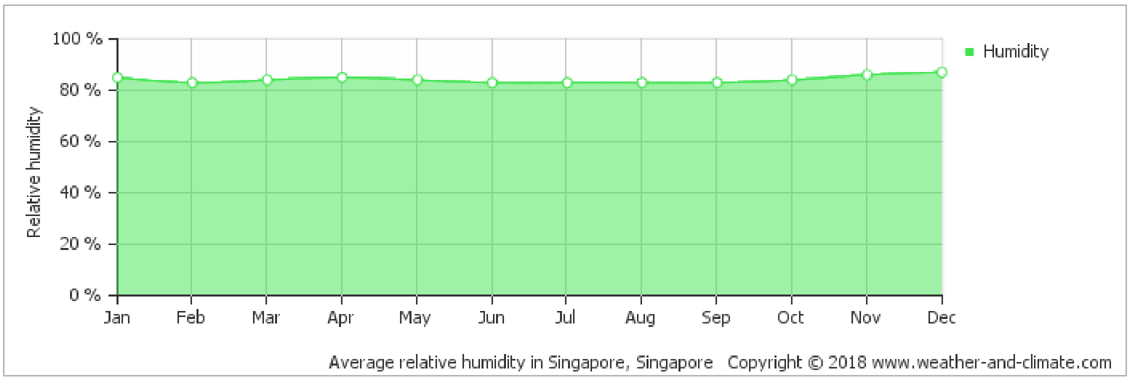

Figure 4.11: Average relative humidity over the year in Singapore.

Regarding the average sunshine hours over the year, it is clear that all the analysed cities has a minimal average of sunshine hours of 125 hours per year. If the city of Kampala is subjected to a constant number of sunshine hours over the year, the city of Medellin registers a peak between June and August, while Singapore is exposed to high amount of sunshine hours from January till August.

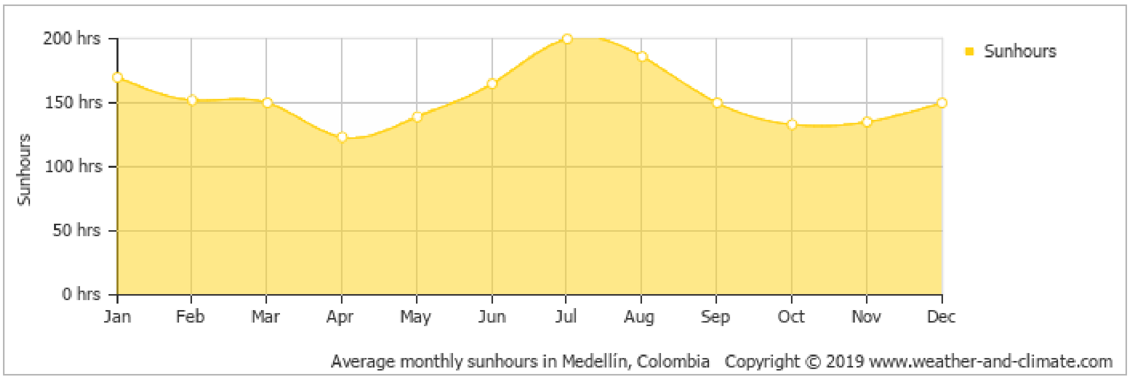

Figure 4.12: Average sunshine hours over the year in Medellin, Colombia.

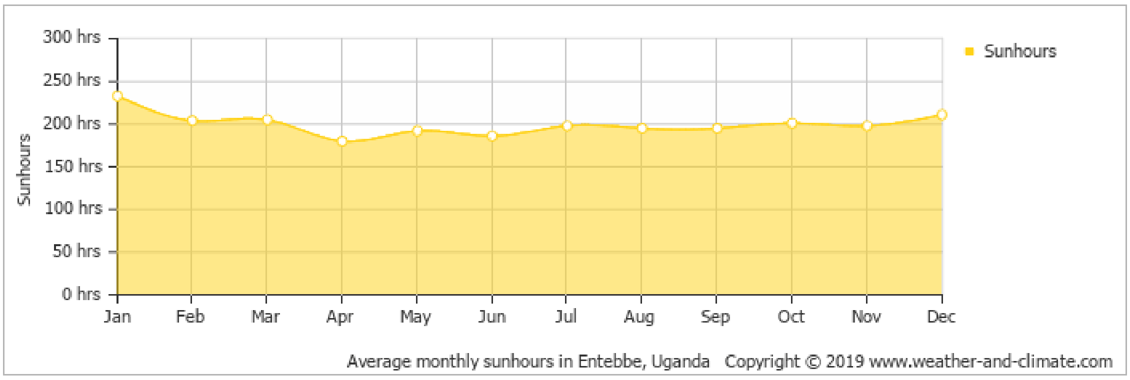

Figure 4.13: Average sunshine hours over the year in Kampala, Uganda.

Figure 4.14: Average sunshine hours over the year in Singapore.

In general, due to the fact that all the three cities have a tropical rainforest climate, the climate conditions are fairly in the similar range of values.

4.4. Indoor thermal comfort

The thermal comfort is defined as ”the condition of mind which expresses satisfaction with the thermal environment”. An essential design objective is to guarantee a space with thermal environmental conditions acceptable to a majority of the occupants within the space. (ASHRAE 2004) An even higher design goal is to achieve acceptable thermal conditions while using the minimum amount of energy with respect to a current standard.

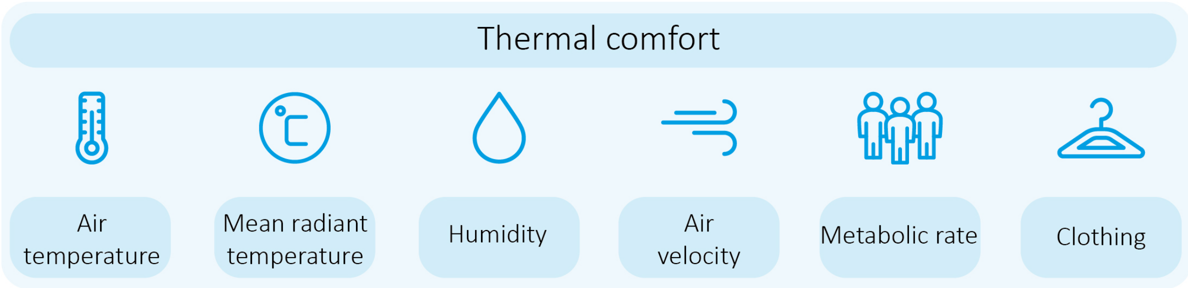

Figure 4.15: Diagram of the six factors to evaluate the thermal comfort of the users.

The American Society of Heating, Refrigerating and Air-conditioning engineers (ASHRAE) defines a standard outline to describe the thermal comfort based on the Predicted Mean Vote (PMV) model by Fanger. This model considers six factors shown in figure 4.15 in order to indetify the thermal comfort and the satisfaction experienced by individuals under varying thermal conditions. A comfort zone can be considered as not comfortable by only 10% of the individuals in the specific space by not respecting a certain range of operative temperature and relative humidity. This zone is also influenced by the level of clothing and metabolic rate of the individuals.

However, to facilitate the implementation of mixed mode cooling, the ASHRAE has modified its thermal comfort model in 2004 from the one based on the laboratory-based PMV model to one based on adaptive thermal comfort model. The adaptive thermal comfort model is based on field studies conducted in many buildings located at various climatic zones, taking into account the concept of outdoor temperatures. The outcome of this studies was that the range of comfortable indoor temperatures in a natural ventilated building resulted to be much wider than the range predicted by the previous model based on laboratory-based findings. Also, it was found out that indoor thermal comfort range was not related to the outdoor temperature since the buildings were naturally ventilated [18]. The adaptive comfort model defines internal comfort temperatures by observing how people adapt themselves, psychologically and physiologically, to reach a thermally neutral state [39].

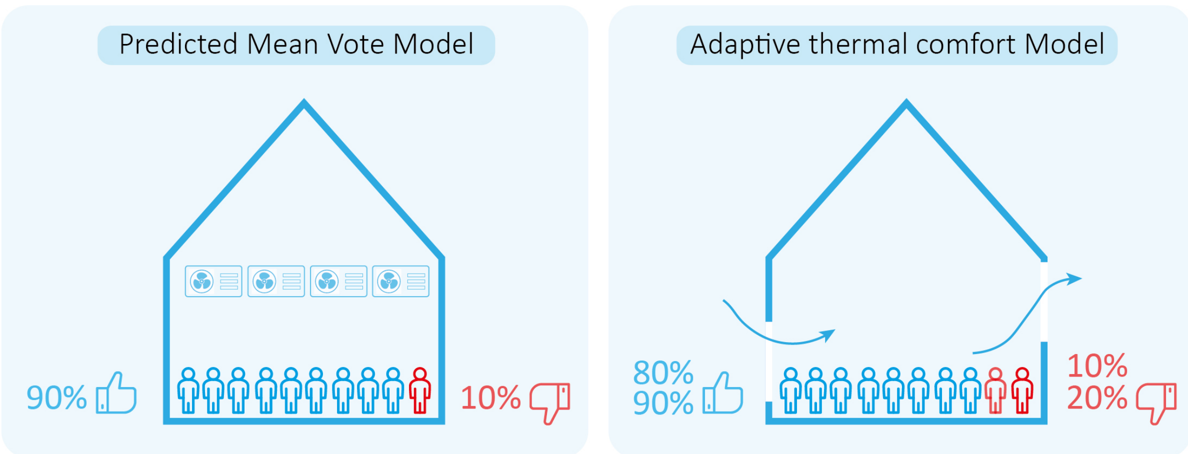

Figure 4.16: Comparison between Predicted mean vote model and Adaptive thermal comfort model.

Specifically, in the recent review of adaptive thermal comfort models carried out by Carlucci S. and de Dear R. in 2018, adaptive comfort theory is defined as dependent on the optimal operative temperature for residents who can get acclimate to the indoor conditions and on the outdoor environmental conditions. Also, a linear equation was defined to calculate the expected indoor comfort operative temperature (Tc) thorough the outdoor reference temperature (T0), the degree of compliance to the local climatic conditions (a) and the y-interecpt (b). The values of a and b are different for each adaptive thermal comfort model and this is affected by the cultural backgrounds, climatic conditions and other contextual factors. In the ANSI/ASHRAE 55:2017, the percentage of acceptability of operative temperature ranges are classified into two categories: namely 80% and 90%. This standard requires that the adaptive comfort model can be applied solely to resident-controlled naturally conditioned spaces, regardless of the function of the building, where either a mechanical cooling or heating systems are installed or operating, respectively. Moreover, residents are free to pick their clothing according to the indoor and/or outdoor thermal condistions as long as the clothing resistance ranges, at least, between 0.5 clo and 1.0 clo. In conclusion, the expected mean outdoor temperature should fall between 10 ºC and 33.5 ºC. This temperature is computed as the average value of the mean daily outdoor temperatures calculated over a period that ranges between 7 to 30 sequential days [14].

The application of adaptive thermal comfort refers to the fact that no mechanical installations are used, the metabolic rates of the occupants ranges between 1.0 met and 1.3 met, the occupants are free to adapt their clothing to the indoor conditions, and that the prevailing mean outdoor temperature falls between 10 ºC and 33.5 ºC [14].

The adaptive thermal comfort model is a possible solution to decrease the energy consumption in low energy building design maintaining acceptable indoor temperature ranges. The project launched in 2015 by the International Energy Agency ''Strategy and Practice of Adaptive Thermal Comfort in low energy buildings'' (EBC Annex 69) has the aim to create a worldwide guideline, by quantifying the thermal adaption of the occupants and , in order to outline a new indoor thermal comfort guideline based on the adaptive comfort model. The duration of the project is set until 2019, with the participation of 11 countries [7].

4.5. Thermal comfort in hot and humid climate

In hot and humid countries, especially in rapidly developing cities, the energy consumption for cooling purposes keeps in increasing. the application of adaptive comfort models seems to be a fruitful strategy to solve this issue. Also, it was found out in several studies that the PMV model is more suitable for moderate climate conditions, turning out to be hardly applicable in warm environments (Humphreys and Nicol, 2002). Since the adaptive comfort model take into account the climatic conditions, it represent a suitable model to assess the comfort in tropical countries, which lacks of comprehensive standards (Nicol, 2004; Toe and Kubota, 2011) [52].

In certain climates, a certain level of thermal comfort is guaranteed solely by the application of passive measures, but in a hot and humid climate it is more challenging to achieve thermal comfort just with passive design due to the high ranges of relative humidity. (Givoni, 1998) In the literature, it has been found that several studies have been conducted with the objective to define the boundaries of the thermal comfort in the tropical climate: Mallick (1996); Cheong et al (2006); Liping (2007); Karyono (2002); Wong et al (2002). Particularly, Nicol (2004) suggests how the adaptive comfort model can be used to specify comfort criteria in hot-humid climates. The results of his study showed that the relative humidity, however, has a marginal effect on comfort temperatures in naturally ventilated buildings for outdoor temperatures between 20°C and 30°C [39]. Another study conducted by de Dear in 1990 in Singapore involved 583 occupants of naturally ventilated dwellings and 235 occupants of air-conditioned office buildings. It was found out that the optimal thermal comfort in a naturally ventilated dwelling was 28.5°C and in air-conditioned offices was 24.2°C. Also, another comfort study carried out in Jakarta has as result that neutral (comfortable) temperature for office workers was 26.7°C [58].

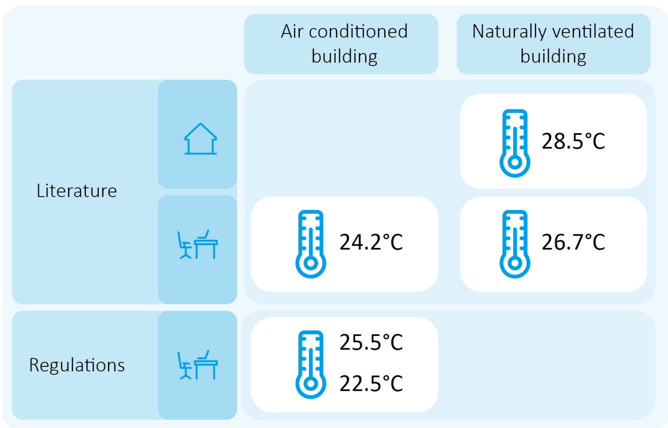

Figure 4.17: Comparison between air conditioned building and naturally ventilated building.

Furthermore, in literature was found that ”Givoni mentioned that the comfort zone in a warm humid country happens when indoor air speed is between 1.5 – 2.0 m/s, relative humidity within 50%, indoor temperature between 20°C and 30°C, while Szokolay suggested an air speed of 1.0 m/s to 1.5 m/s for air cooling through natural ventilation to achieve comfort in hot climates. In CIBSE Guide A1 the comfort zone in the tropics during summer will occurs when the relative humidity is between 45% and 70%, indoor temperature between 23.0°C and 26.0°C. Same ranges of temperatures are recommended In ASHRAE Standard 55 and in Iso 7730. However, the former suggest 50% relative humidity and 0.15m/s mean air speed, while the latter recommend relative humidity between 30% and 70% and 0.4m/s mean air velocity. On the other hand, in the late 90s some studies were conducted in Malaysia, finding that the comfort temperature in office building ranges from 23.0°C to 27.0°C and, relative humidity between 60% and 70% (Kannan K.S. 1995)”. Another research using a laboratory method conducted by Abdul Shukor A. in 1995, had as result that the comfort range is between 25.0°C to 31.4°C with 50% relative humidity. Finally, Ismail M.R in 2000 did a study in the same field observing that the comfort temperature in office building ranges from 20.8°C to 28.6°C and, relative humidity between 40% and 80%. In all the three cases the result of the comfortable temperature for office buildings in Malaysia differs, the first finding 25.0°C through energy audit technique, the second 28.2°C through laboratory method and the last 24.7°C through field study approach [24].

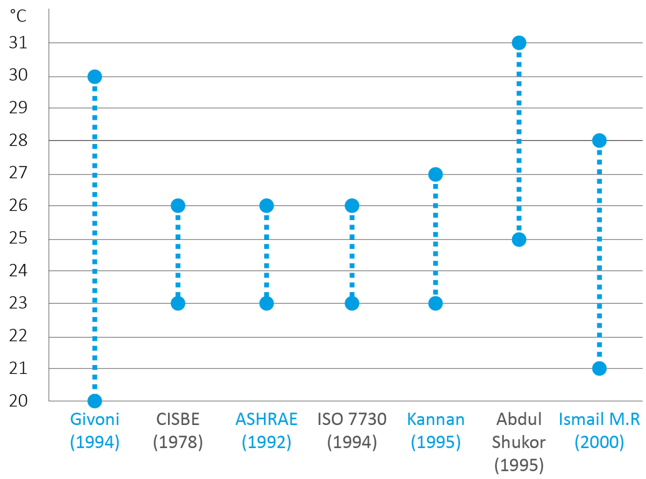

Figure 4.18: Comparison between different comfortable indoor temperature ranges found in the literature.

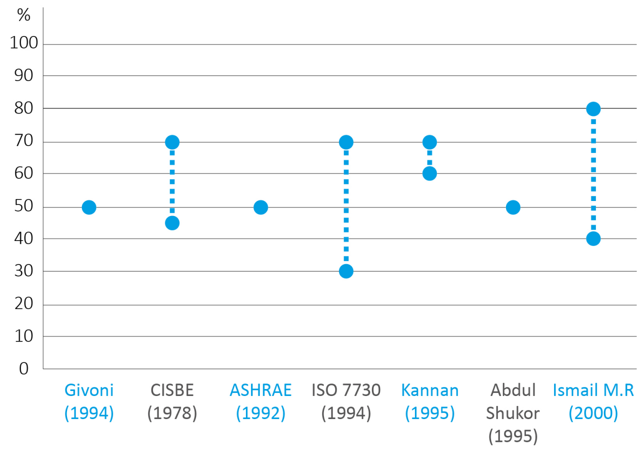

Figure 4.19: Comparison between different comfortable indoor relative humidity ranges found in the literature.

5

Background: Passive cooling strategies

5.1. Passive cooling strategies state-of-the-art

Before the implementation of refrigeration technologies in the building industry and the increase of thermal comfort levels, designers in tropical climates used to tackle the climate conditions using natural methods to prevent the building from unwanted heat and to control the heat gains from the surrounding environment. These methods, namely passive cooling strategies, were developed and integrated in the building design over thousands of years.

The passive cooling strategies can be categorized in three main steps: Prevention of heat gains,modulation of heat gains and heat dissipation [47].

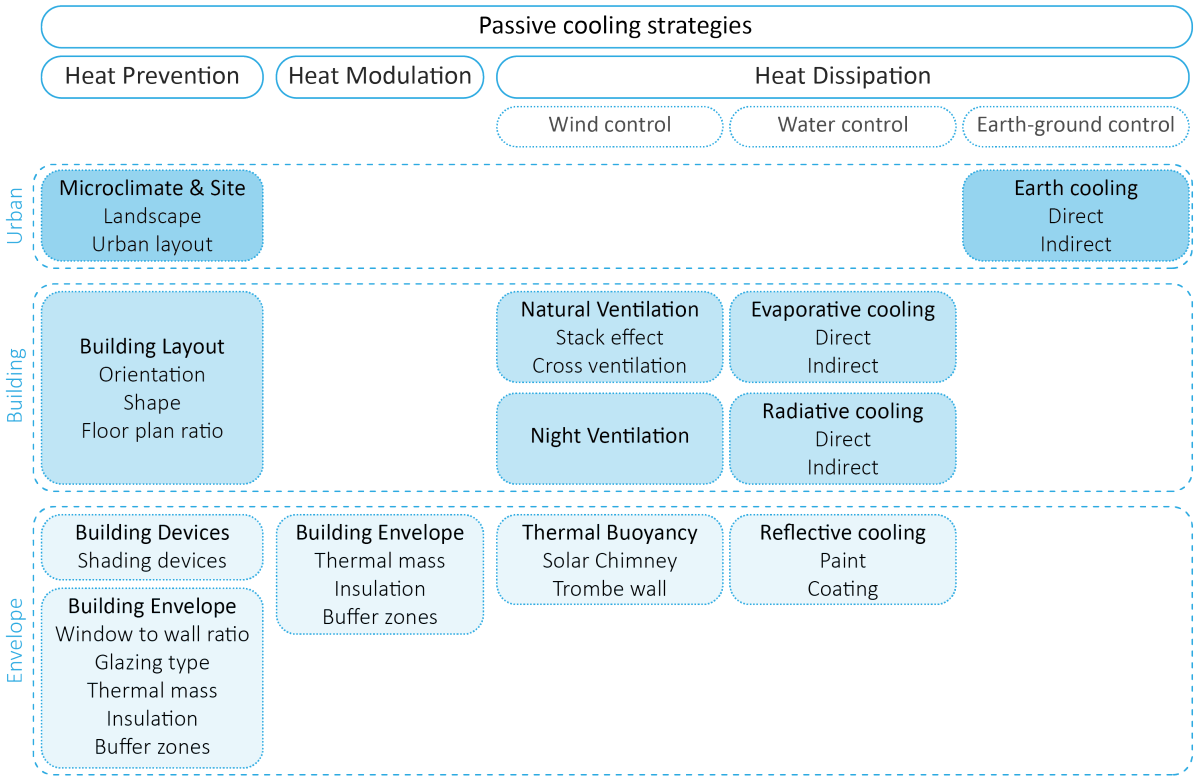

Figure 5.1: Description of the different passive cooling strategies.

Since in Tropical regions the main issues are related to high air temperature and high ranges of relative humidity, this study will mainly focus on preventing heat from entering the interior from external heat sources and on removing heat from the building to a natural heat sink.

5.2. Heat prevention

Heat protection techniques are meant to protect the building from unwanted solar heat gains, avoiding the heat to get through the building envelope. These techniques can be applied at the urban, building or envelope scale. The first one involves the integration of the building with the microclimate of the site, through green infrastructure or the design of the urban layout. The second one requires paying particular attention to the building layout, the orientation, the building form and the integration of building devices such as external or internal shading devices. Finally, the last typology of heat prevention techniques focuses on the building envelope design, meaning the window to wall ratio, the choice of suitable glazing type, the implementation of material with high thermal mass and the design of buffer zones [47]. This research is focused entirely on the application of passive strategies at the building and envelope scale.

5.2.1. Building Layout

Generally the layout of a building is influenced by urban regulations, constraints of the context of by the architectural concept of the architect. However, in tropical climates in particular, where cooling consumption accounts for the highest proportion of energy demand, the building layout must be designed in a way to reduce its exposure to solar radiation. In order to achieve this design objective, a more compact shape, with less surface-to-volume ratio and thus with less heat transfer through the envelope, is most suitable [44]. Figure 27 shows the total energy use with respect to the building shape from the most efficient to the less efficient building shape for tropical climates. As stated above, the most compact shape is the one requiring less amount of energy.

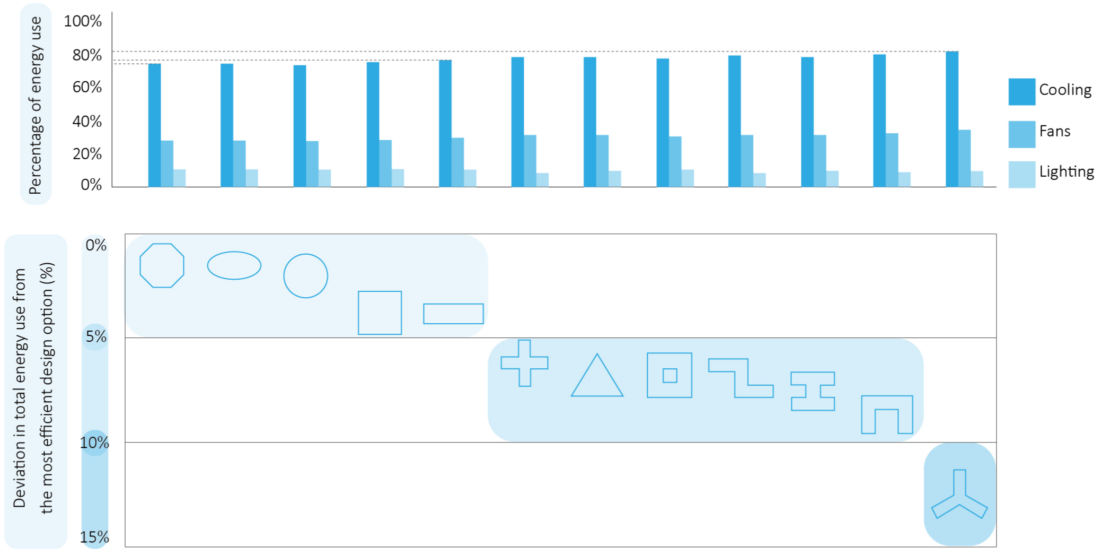

Figure 5.2: The maximum deviation of total energy use from the optimal solution for different plan shapes and their breakdown of total energy use in tropical climates. (Raji B. 2018)

On the other hand, as the building shape also the building orientation contribute to reduce the solar heat gains to decrease consequently the cooling load. These two design objectives are often contradictory, given that compact shapes as the octagon, the ellipse or the square, do not allow to have a specific orientation, while more elongated shapes allow to orientate the building towards a specific axis. In particular, in tropical climates east- and west-facing walls and windows are more subjected to high solar exposition, and thus causing overheating [44]. As stated by Kannan from a study in Malaysia, buildings lined longitudinally along north and south had 10% less energy consumption than building arranged longitudinally along east to west. (S. Mirrahimia, 2016) Also, as demonstrated by the study of Wong and Li, in Singapore buildings facing north and south have 8.57%-11.54% less cooling load compared to the buildings facing east and west [57]. A study of Raji B. claimed that in tropical climates buildings oriented along the east-west axis keeps out solar radiation in the early morning or afternoon and results in the lowest energy consumption, while the highest amount of energy consumption is reached by building oriented along the north-south axis [44].

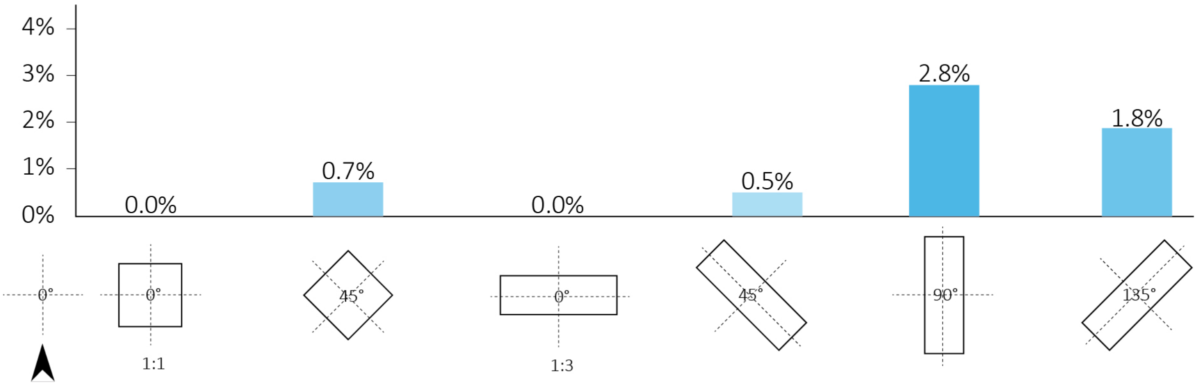

Figure 5.3: Percentile difference in the total energy use between different orientation and building configuration. (Raji, 2018))

Thus, a better sun protection can be achieved by designing a rectangular floor plan along the east-west axis, by reducing at maximum the surface area of the facade towards the east and west facade [44]. In the case of a more elongated building shape, another variable can influence the amount of solar gains through the building envelope: the floor plan ratio, defined as the ratio of the length and the width of the building. In particular, for each climatic zone specific floor plan ratio were established. As discussed by Tanuharja, M.K. the ratio for a building in cool climate zone should be 1:1, in temperate climate zone should be 1:1.6, in sub-tropical climate zone should be 1:2, and for a tropical climate zone 1:3 [51]. As discussed by Mirrahimi et al., the acceptable shape that suits the best the climate condition of hot and humid regions was found to fall in the range between 1:1.7 and 1:3, where 1:1.7 was considered the optimum shape that can be applied [32].

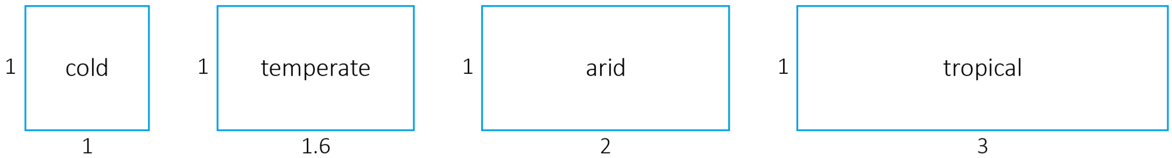

Figure 5.4: Floor plan ratio with respect to the climate. (Raji B. 2018))

5.2.2. Building envelope

A fundamental design variable that influence the level of overheating and thus the cooling demand is indeed the window to wall ratio (WWR). Therefore, it is suggested to choose a reasonable WWR for the most sensitive orientations that potentially increase the total energy consumption for cooling purposes. In the case of the tropics, the east and west facades must avoid high WWR values, if the shading devices were not included in the design of the envelope. The results of the study of Raji B. showed that the values of the WWR for a compact building (with a floor plan ratio of 1:1) for east and west facades must be kept in a range between 10 and 20%, and for north and south facades between 10 and 50% and 10 and 80% respectively. While for a more elongated plan layout, it was found out to avoid glazing on east and west façade, and to keep a range between 10-35% for the north-facing wall and a range between 10-55% for the south-facing wall [44].

5.2.3. Building shading

In recent years, many studies claimed the fundamental importance of the integration of shading systems at an early design stage for facades with large glazed portions [26]. The types of shading systems ranges from internal shading to venetian blinds, from external shading louvres to overhangs. Several researches were carried out to investigate the effect of different shading devices on the energy consumption and indoor thermal comfort in buildings. In particular, it was found out that external shading strategies provide the best energy performance, not allowing the solar radiation to reach the indoor environment, while internal shading elements were less efficient. On the other hand, external shading devices can influence the daylighting and the natural ventilation performance of the building.

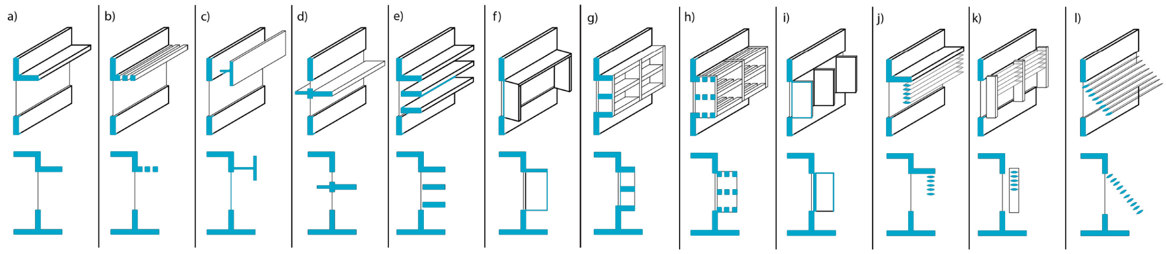

Figure 5.5: Different type of external shading devices. (Valladares-Rendon L.G., 2016)

Furthermore, in tropical regions, fixed horizontal shading devices must be applied on north and south facades to cover high sun angles, while for east and west facades, adjustable shades or higher coverage fixed louvres are most suitable to block a wide range of sun angles [44]. Regarding the effect of shading devices on energy consumption and thermal comfort, a recent study showed that shading elements have a great impact on energy savings and thermal performance of office buildings [40] The study of Wong and Li showed the efficiency of shading devices on cooling energy savings for east and west facades of a residential building in Singapore. It was found out that with a horizontal shading device of 30 cm depth a maximum of 3.24% of energy savings can be achieved. The energy savings can reach 10.13% if the depth of the shading devices increases to 90 cm [57]. Finally, with regards to the effect of the shading elements on the indoor thermal conditions, a study has been carried out by Wong Nyuk and by Yang and Hwang. The former found out a decrease on the indoor temperature of 0.61-0.88°C when horizontal shading devices were applied on a building in Singapore. (Wang L, 2007) The latter showed a decrease of 0.98°C due to the implementation of vertical shading device in a building located in Taiwan [32]. Also, the right combination of shading type and glazing type can lead to a great performance of the thermal effect of the windows [16]. Solar shading systems besides being one of the most important bioclimatic strategies in tropical regions to reduce the amount of heat through solar radiation, these systems also contribute to control and improve indoor spaces, in particular the visual and thermal conditions. Thus, during the design of building facade it is important to take into account thermal, daylighting and optical requirements. However, there are also other types of requirements that designers face at the production/construction phase, such as maintenance, safety, reliability,low cost, users' demands and other utilisations. In the table below all the requirements for the design of a shading device are showed [9].

5.3. Heat dissipation

Heat dissipation techniques are based on "the disposal of excess heat of the building to an environmental sink of lower temperature, like the ground, water, ambient air or the sky" [47]. The effectiveness of these techniques highly depends on two main factors: the availability of a proper environmental heat sink with sufficient temperature difference for the transfer of heat; and the efficient thermal coupling between the building and the sink.

The heat dissipation techniques are divided in three sub-categories depending on the natural sink used:

- Wind control: based on the use of air as a sink;
- Water control: using the water as a sink.
- Ground control: based on the coupling between the building and the ground as a sink;

However, the main techniques of heat dissipation that have been deeply studied and developed, are the following:

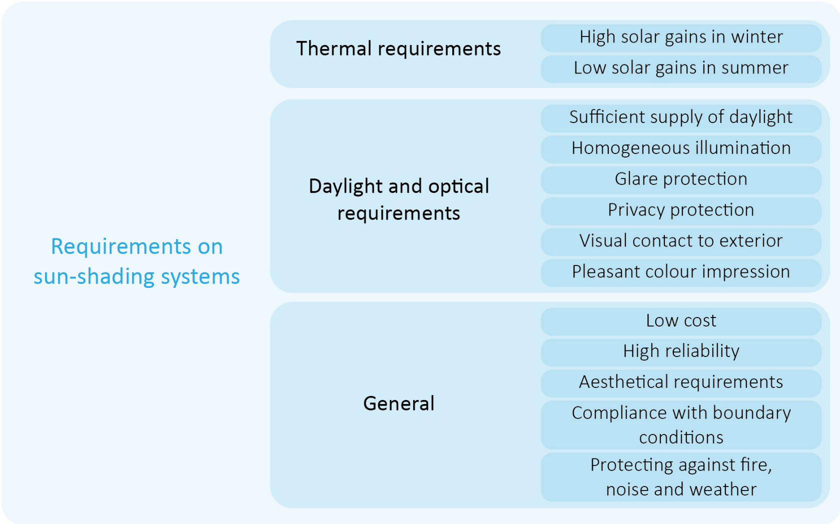

Figure 5.6: Requirements for the design of shading devices. (Salwa M.Al-Masrania)

- Ground control
- Natural ventilation
- Evaporative cooling
- Radiative cooling

[47].

5.3.1. Wind control

Natural ventilation is a simple and effective process which consists on the movement of air to contribute to the cooling of buildings, especially in the climates characterized by high ranges of humidity. According to Watson and Labs (1983), natural ventilation allows not only to cool down the building interior, but also to provide the fresh air needs to the occupants and to increase the rate of evaporative and sensible heat loos from the body [8]. This technique is generated by the following two forces:

- **Temperature difference between the outdoors and the indoors**: This technique is based on the thermal force of the air, which tends to expands, decrease in density and to rise, when heated up. Thus, the indoor pressure is higher at the higher part of the room, and lower at the bottom. With the positioning of two openings in the envelope, one at the bottom and one at the top, the pressure difference generated will induce an inward flow at the lower opening and an outward flow at the upper one. This phenomenon, for which cooled air enters from the bottom opening and the warm air exits from the upper opening, is termed as stack effect.

- **Wind flow against the building** (wind pressure force): This technique consists on the pressure generated by the wind against the building, creating pressure zones. The pressure at the leeward wall and above the roof is reduced, creating a suction zone. The points on the building's envelope, where a pressure difference occurs, determine the positioning of openings in order to have the phenomenon of cross ventilation. This process consists on the entrance of air from the openings with the higher pressure to the openings in the zone with lower pressure, passing through the building [8].

Figure 5.7: Different types of natural ventilation. Source: P. Sørensen, Wind and Ventilation, in: T. Dahl (Ed.), Climate and Architecture.

The implementation of natural ventilation strategies lead to the reduction of the building energy consumption and the enhancement of the indoor environment quality compared to a building with a mechanical controlled system. However, Givoni claims that in warm climates it is unlikely that natural ventilation provides acceptable comfort conditions. In this cases, it is necessary to combine natural ventilation techniques with additional techniques that can enhance the indoor thermal comfort, such as an accurate integration of the building with the planning site, the building mass and the building envelope. This approach is known as 'advanced passive cooling' [43].

The prevailing wind comes from the north to north-east and from the south to south-east direction, thus positioning opening windows facing the north and south directions implementing cross ventilation would enhance indoor thermal comfort. The figure 5.8 shows the effect on the comfort of the air velocity of the wind.

Air velocity (m/s)	Equivalent temperature reduction (°C)	Effect on comfort
0.05	0	Stagnant air, slightly uncomfortable
0.2	1.1	Barely noticeable but comfortable
0.25	1.3	Design velocity for air outlets near occupants
0.4	1.9	Noticeable and comfortable
0.8	2.8	Very noticeable but acceptable
1.0	3.3	Upper limit for air-conditioned spaces
2.0	3.9	Good air velocity in hot and humid climates
4.5	5.0	Considered a gentle breeze when felt outdoors

Figure 5.8: Air velocities and thermal comfort.

5.3.2. Water control

Evaporative cooling is a heat removal process based on the addition of water vapor in the air, contributing to lower its temperature and causing the increase od humidity. This phenomenon consists on the transfer of the heat from sensible heat in the air to latent heat in the moisture. Thus, the air is cooled down due to the absorption of the heat in the water during the process of evaporation of the water. This technique can be classified into direct and indirect evaporative cooling, the former is suitable for arid regions, while the latter can be applied also in humid regions [**?**].

- ”Direct evaporative cooling: a cooling process where the warm and dry air moves through a wetted medium to evaporate moisture in the air. The cool humid air is then used to cool a place”.
- ”Indirect evaporative cooling: a cooling process where the evaporative process is remote from the conditioned space. In this ptocess, the building surface is cooled down by the cooled air, such

as in a roof spray, or is passed through a heat exchanger to cool indoor air. The indirect process has the advantage of lowering temperatures without adding humidity to the air [**?**].".

5.4. Bioclimatic architecture: Ken Yeang

A bioclimatic approach during the design process is defined as a strategy that aim to ensure comfortable conditions for the users while using minimum energy sources. The main pioneer of this approach is the Malaysian architect Ken Yeang. Ken Yeang, described by The Guardian as " as one of the 50 people who could save the planet", he is considered a " theorist, practitioner, architect, and most importantly in his opinion an ecologist". His approach to the design process of a sustainable design consists of the right balance of three components: climate context, built environment and occupants [19].

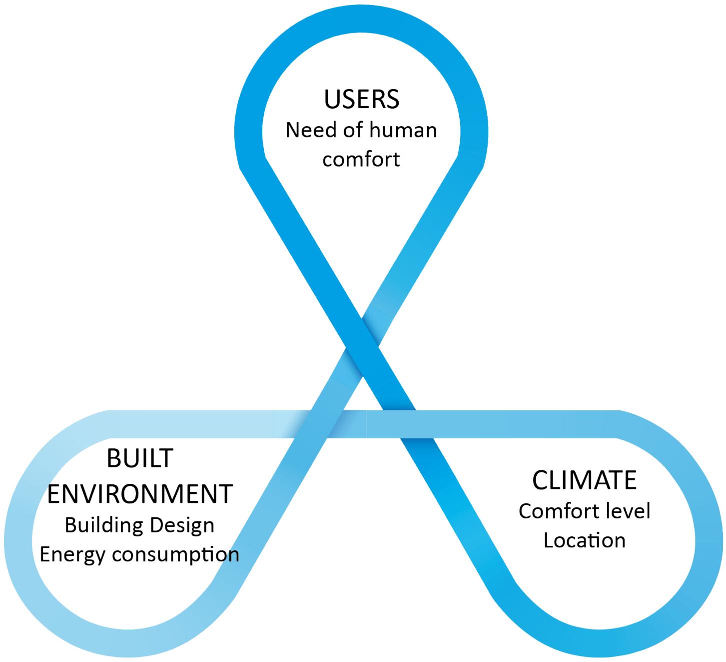

Figure 5.9: Bioclimatic Approach scheme.

According to Ken Yeang, main pioneer in the theory and practice of sustainable design and ecological architecture, there are two objectives of bioclimatic design concepts:

- "the achievement of maximum comfort level for the user in building operation";
- "the minimum energy consumption and cost in building operation"

[27].

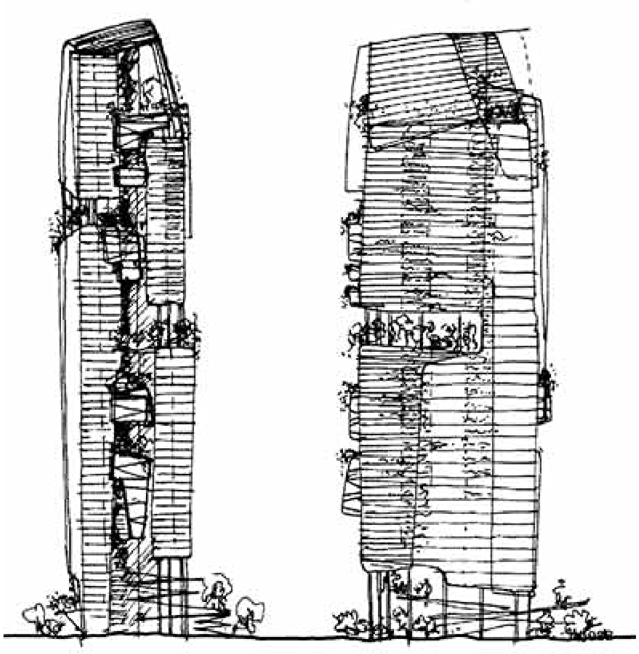

Figure 5.10: Skecth of a bioclimatic high rise by Ken Yeang. Source: http://www.comfortfutures.com/ken-yeang

Considered as a ”leader in skyscraper design”, during his entire career Yeang has researched and designed different bioclimatic high rises, proving the potential of passive design measures to achieve an energy efficient design.

The Malaysian architect Ken Yeang designed a bioclimatic design approach for high-rises designed exploiting the potentials of the natural environment. His method of working, so called Research, Design and Development, is a research-based process based on simulation and prototyping with subsequent verification. The following table shows the comparison made by Ken Yeang between his design approach, bioclimatic and environmental, and the less sustainable approach adopted buy others designers. The comparison is made for different aspects, such as building orientation, envelope design, comfort level or energy consumption [41].

The bioclimatic approach for the design of a multi-story building in the tropics area is composed by three steps: the analysis and design of the site plan, the design of the envelope and finally the interior design. Several analyses must be conducted, including:

- **Mass composition** (zoning and core placement arrangement) that will affect the performance of thermal and visual comfort
- **Building orientation**, which will affect performance in anticipation of high solar radiation
- **Cladding and exterior wall design**, which will affect the performance of thermal, solar buffer and cross ventilation.
- **Utilization of natural ventilation**, which will affect the performance of thermal comfort and building stiffness
- **Horizontal and vertical landscaping design**, which is used to obtain the ecological and aesthetic benefits, lowering the temperature of the micro climate, improving air quality through photosynthesis, and increase the biodiversity of ecosystems [27].

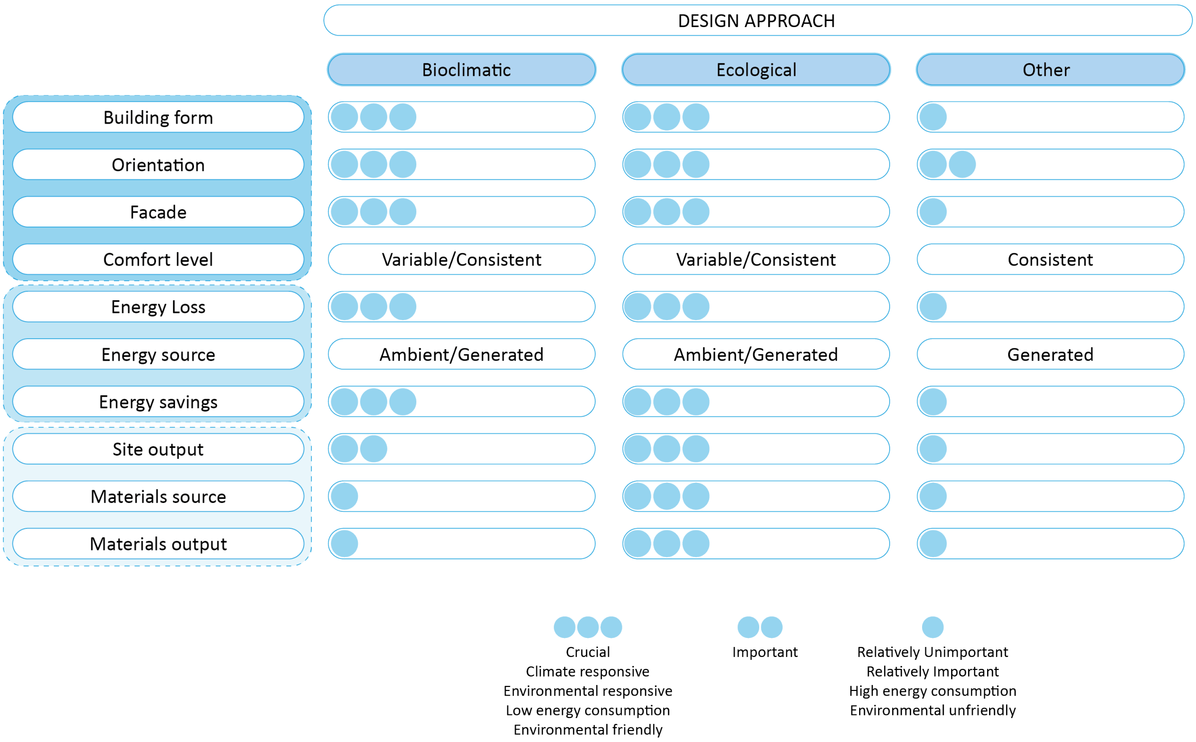

Figure 5.11: Comparison of different design approaches, namely bioclimatic, ecological and an ordinary approach.

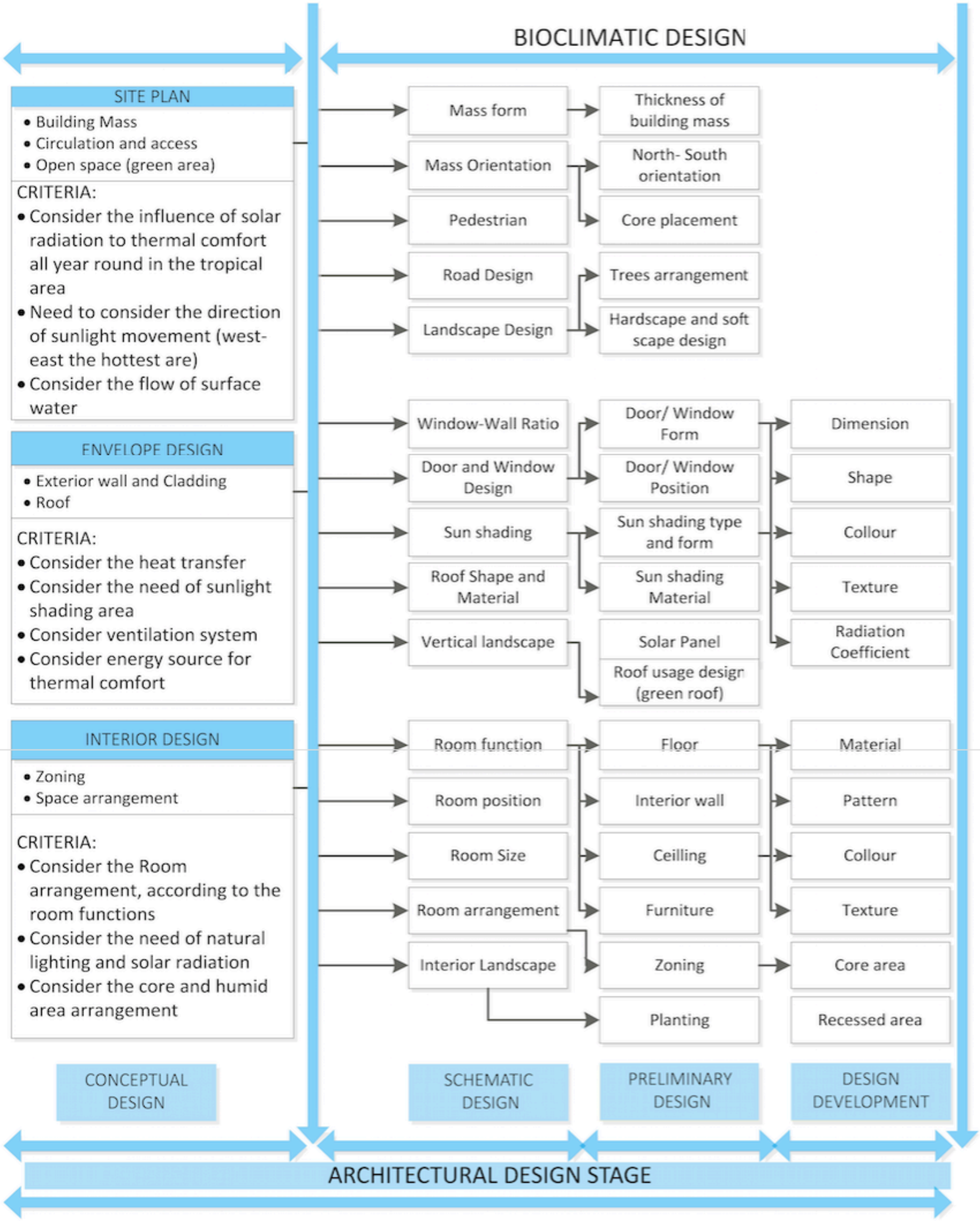

Figure 5.12: Detailed steps of a bioclimatic design process.

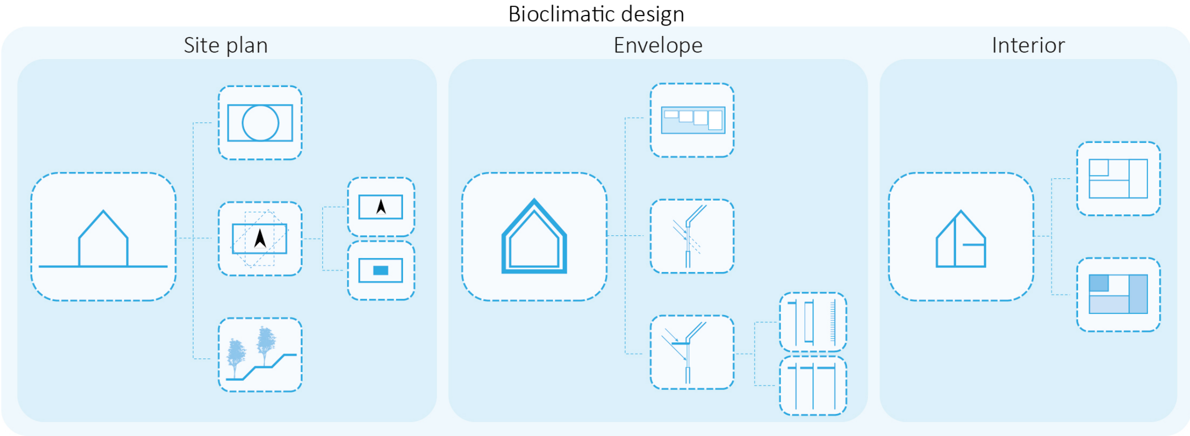

Figure 5.13: Detailed steps of a bioclimatic design process.

Since Ken Yeang focused his research and practice of bioclimatic design in tropical regions, where the main challenge is the cooling of buildings, an important component in bioclimatic design is indeed passive cooling. The latter can be achieved applying the following strategies:

- Correct building placement and orientation
- Good landscape planning
- Proper placement of windows and natural lighting design
- Selection of the proper material for the glass windows and the skylights
- Proper shading on the glass when the heat is not desirable
- The use of light-coloured material for the building envelope and roof

An important design feature adopted by the Malysian architect is the integration of natural ventilation in the building. The benefits of this technique are given by the climate conditions and by the characteristics of the building (shape, orientation and envelope). Ken Yeang suggest implement the following techniques in order to fully exploit the benefits of the natural ventilation:

- Use landscape elements to direct the wind
- Installation of operable windows
- Proper windows placement with window size for cross ventilation
- Reduction of internal barriers (e.g. walls) to ensure the flow of the wind
- The use of wing walls when natural cross ventilation is not possible to apply
- Use stack ventilation to get a chimney effect [27].

According to Yeang, the operational costs can be reduced up to 40% over the building's life cycle through the application of the features explained previously. Multiple examples of Yeang's designs in tropical Southeast Asia (eg. Mutiara Mesiniaga, UMNO Tower, etc) are indicative that the bioclimatic approach is a reliable method to reduce energy consumption and to lower the overall heat-island effect on the locality, integrating the design harmoniously into the ecological and geographical context of the site [19].

5.5. Ken Yeang's main projects

Figure 5.14: Presented projects of Ken Yeang: Menara Mesiniaga, Menara UMNO, The National Library and Solaris (from left to right).

Menara Mesiniaga (completed 1992)

Menara Mesiniaga is the headquarters of an IBM franchise, situated in Subang Jaya, near Kuala Lumpur. It is a fifteen stores high-rise building. The layout of the building is circular, which provides less surface exposure for solar penetration, with the integration of green terraces spiraling up outside of the tower. The elevator and stair core are positioned in the east side of the building in order to block the solar gain from the intense morning sun. Regarding the building envelope, a curtain wall system is implemented in the four facades with the exception of the east and west facades which are characterized by external aluminium fins and louvres as shading system. Also, the windows are openable in order to allow for cross-ventilation and in each floor terraces are designed in order to freely control the natural ventilation [22]. Finally, in order to guarantee a certain level of thermal comfort, air conditioning systems are installed. However, the use of this cooling system is still regulated in order to be combined with passive cooling strategies. It was found out that annually up to $13590 is saved on air conditioning costs (1993 statistic) [19].

Menara UMNO (completed 1998)

Another bioclimatic project is Menara Umno, the tewnty-one storeys tower in Penang. The building shape and layout is the result of two main factors: the urban context and the most suitable shape for the climate of the location. This project turned out to be one of the first innovative project of Yeang, which combined a naturally ventilated high-rise and an energy efficient building. In fact, thanks to the design of "wing-walls" on all the floors of the high-rise, the prevailing wind is easily channelled inside the building. Regarding other design choices, the bioclimatic architects implemented exterior and interior shadings on the north-west facade and double low-e glazing in all the facades.

The National Library, Singapore (completed 2005)

The National Library is one of the examples of Yeang's ecological architecture, proof that the application of passive cooling strategies can lead to the reduction of the energy demands for cooling in Singapore. The building consists of two blocks and it is characterized by a fully glazed façade, which represent a relevant challenge for a designers in a tropical climate, where solar exposure is a critical issue. In fact, to guarantee acceptable indoor temperatures, the building should be protected from the entrance of direct solar radiation between 10am and 4pm. This issue was prevented by implementing massive sun shadings to control the solar exposure and the glare probability by guaranteeing enough daylight. Whenever the external shading is not effective, then internal automated blinds are used. Furthermore, another relevant feature of the design of the National Library is the addition of biodiversity and green areas. In fact, up to 60% of the building's footprint is covered with landscape, sky terraces and roof gardens. These design features allow for cooling breezes and lead to the reduction of the ambient temperature around the building it self. Other design strategies that allow to decrease the cooling demands are the building orientation and the layout of the disposition of the two bodies of the building which create an internal plaza in order to enhance the natural ventilation. However, being the National Library a building for the public, the indoor comfort was highly considered during the design process. For this reason, three operational system were implemented: passive, active (air conditioners and artificial light) and mixed-mode (natural and artificial ventilation).The National Library was the first building to receive the platinum Green Mark Award due to its environmental responsive and sustainable design features [19].

Solaris, Singapore (completed 2010)

Solaris Building is the project designed by TR Hamzah & Yeang and completed in December 2010 in Singapore. This project is the combination of bioclimatic architecture with contemporary technology features. In fact, the designers applied vernacular cooling methods, such as the application of cross ventilation of the atrium, and analysis and computer simulations, such as sun-path analysis for the design of shading elements or Computational Fluid Dynamics simulations to control the air movement. Thus, shading devices were designed in order to limit the solar heat gains and the probability of glare, but at the same time in order to redirect the light into the building and guarantee natural daylight. (Widera, 2015) The combination of external shading system and low-e double glazing lead to the decrease of the energy consumption to 36% with respect to other similar buildings. Also this project was awarded with the highest sustainable certification BCA Green Mark Platinum rating in September 2009, thanks to the low energy consumption and the high comfort standards solaris.

5.6. Conclusions from Ken Yeang's projects

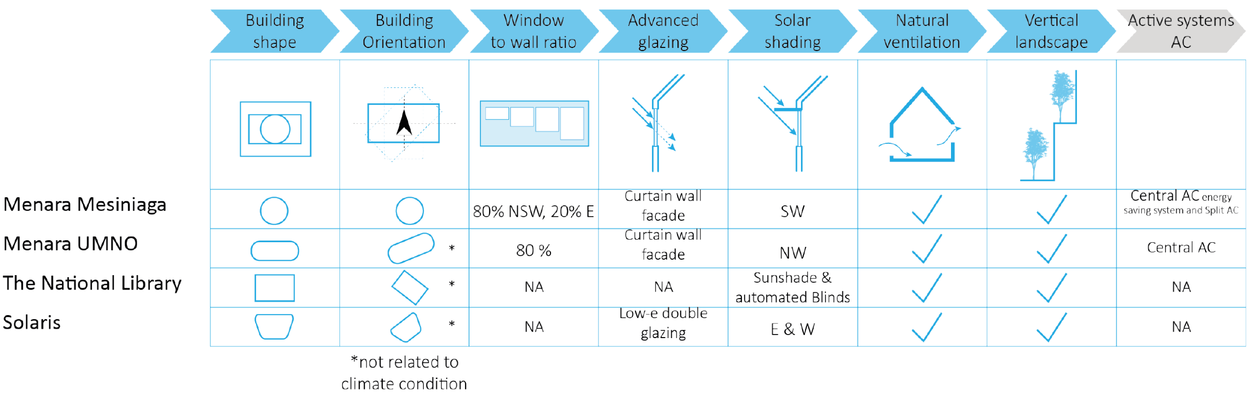

Figure 5.15: Summary of the analysed project designed by Ken Yeang.

5.7. Potential cooling technique for Singapore

The selection of the appropriate passive strategies fully depends on the local climatic conditions, in particular to the air temperature and relative humidity. In tropical regions in particular, the main objective is to reduce at maximum the direct solar radiation and to enhance the evaporation of the humidity through natural ventilation. The strategies that meets the environmental requirements and that attain the objectives abovementioned, are the following:

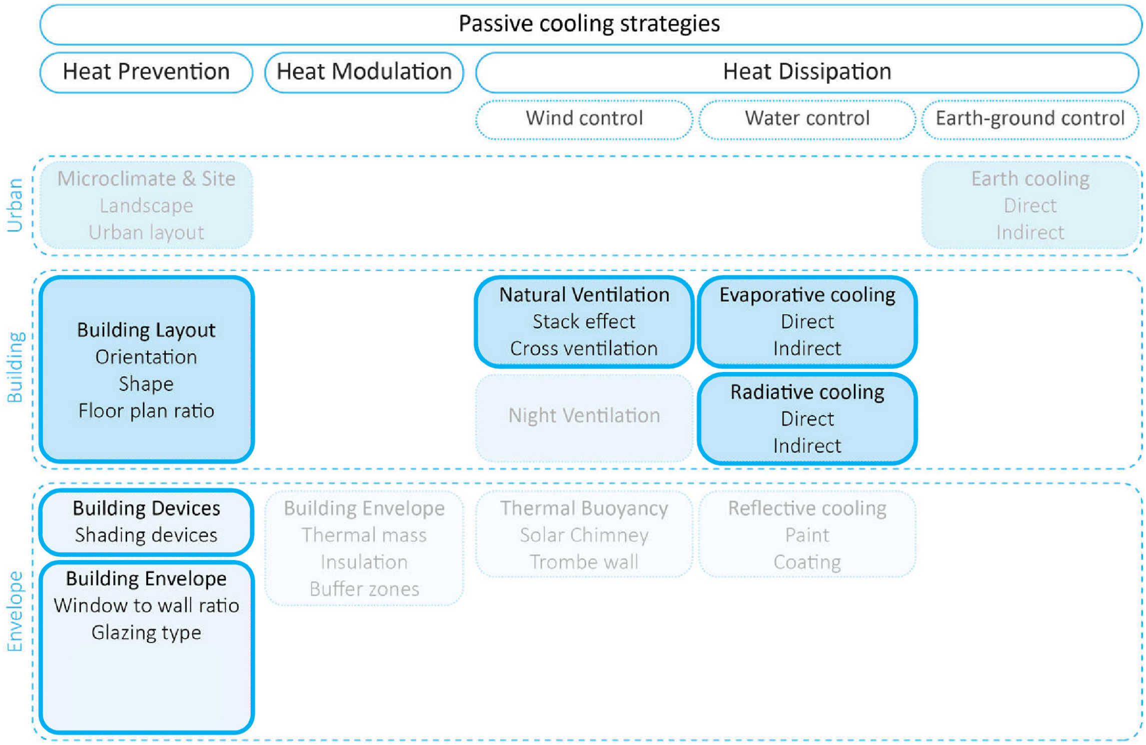

Figure 5.16: Applicable passive srategies in tropical regions.

6

Building Performance Simulation (BPS)

This chapter discusses the workflow and the tools implemented for the performance simulation of the design iterations of the building case study. Since buildings must fulfill the needs of the users, during the design process these needs are identified and translated into measurable performance requirements which are assessed through Building Performance Simulation's tools (BPS). The integration of BPS tools in the design process turned out to be fundamental in the design process of green buildings, assisting architects and engineers in achieving high building performance. During the design process the designer establish specific performance requirements, which are translated into performance indicators. The performance requirements can be related to the energy efficiency, indoor air quality, daylight-artificial lighting, acoustics, solar or to the photovoltaic analysis of the design proposed. Depending on the requirements and assessments established, the most suitable BPS tool is then used. The inputs of the design are the specifications of the design proposed, while the outputs of the assessment are the results of the indicators. Once the results are obtained from the building performance simulation, it is up to the designer or engineer to assess if the requirements are met. Thus, it is crucial to highlight that these tools are assessment-oriented rather than a decision-making tool, thus the designers have as result the performance of different iterations of the design initially proposed and not the final optimal design [53].

6.1. What is a BPS?

Building performance simulation (BPS) represents a tool that allows to evaluate the performance of a building taking into account different aspects such as energy, daylight, acoustics, heating, Ventilation and Air Conditioning (HVAC) systems, indoor air quality, costs, and so on. The use of BPS software is of utmost importance during the design process of a green building. In fact it plays a critical role especially in the early design phases: design parameters such as shape, orientation and envelove configuration can severly affect a building's performance by up to 40% [53].

6.2. Performance requirements

As introduced above, a building must satisfy specific requirements which are defined by the users needs. These needs are first identified and then encoded and translated in terms of performance requirements that has to be verified and fulfilled during the design process. The designer must then find the best design solution that satisfies and optimizes the performance requirements. Before finding the final design solution, several options must be assessed through computer models that evaluate different performance aspects. At this purpose, several simulations must be conducted in order to evaluate the overal performance requirements satisfaction [35].

6.2.1. Energy performance

Different systems are integrated in order to guarantee a comfortable indoor environment and aim at maintaining adequate temperature level, air quality, lighting and other technical specifications with regards to the indoor environment. When the design of the building fails in satisfying specific comfort requirements, one of the main consequences is a higher energy consumption. In particular, the use of external systems, such as heating or cooling systems, depends on the building design, the climate and the function of the building. In order to evaluate the energy performance of a specific design there are benchmark which can be consulted. In the benchmark analysis the energy-efficiency indicators are obtained by normalizing the energy use with floor area. The Energy Use Intensity (EUI) is often used to judge the energy-use performance of commercial buildings [35].

6.2.2. Indoor thermal comfort performance

The quality of the indoor environment influences the well-being and the health of the occupants, affecting also the productivity of the users in the case of commercial buildings. Different recommendations are already available to identify the factors of the building design that influence the indoor environment [35].

6.3. Performance assessment

An essential phase of the design process is the performance assessment in order to check that all the performance requirements are met, if not changes to the design to improve the performance must be investigated. The assessment is often conducted through different tools, which will be described in the following paragraph. In general, computer simulation is the tool most used, which differs depending on the performance aspect to be tested [35]. For each performance requirements there are different performance indicators, for instance the requirement of having a certain level of daylight can be translated into daylight indicators such as the amount of lux on the floor or the daylight autonomy. Or a requirement linked to the thermal comfort can be translated into air temperature, mean radiant temperature, humidity, air-speed etc. Defining the appropriate performance indicators is fundamental in order to achieve the requirements of the project with the most suitable design [13].

Since the main objective of this research is to reduce at maximum the cooling consumption of an office building, then the performance indicator used is the normalized cooling demand (kWh/m2/year). Regarding the indoor thermal comfort, the performance indicators taken into account are: percentage of comfortable time (%) and the operative temperature (°C). Finally, concerning the daylight comfort, the indicator used are the electric lighting energy (kWh/m2/year) and the spatial daylight autonomy (%).

6.4. Design tools

Nowadays, several tools were developed specifically for the assessment of the building performance and which can be used at each of the phases of the design process. These tools are able to compute, model, assess and quantify complex physical phenomena avoiding thus "by hand" calculation and reducing possible human error and time costs. The identified design tools can be classified according to the level of knowledge and information they are able to take into account. In particular, we can distinguish between simplified and detailed calculation procedures, specialized tools that consider only specific performances and integrated tools that assess several performances at the same time. A simulation tool often used in multiple BPS software is EnergyPlus [4]. The latter is a whole building energy simulation program that designers and engineers use during the design process. This software models heating, cooling, lighting, ventilation and other energy flows, importing idf.digital models with epw.weather models for site to accurately analyse specified zones of a building. EnergyPlus can be used to support the decision-making process through the combination of Grasshopper and the plugin Ladybug and Honeybee [35].

6.5. Parametric design for building performance simulation

Building performance simulation tools can be combined with parametric design tools in order to facilitate and speed up the design process. With the integration of building performance simulation and parametric design methods, the effect of environmental factors on building performance and the impact of various design decisions is easier to understand. Also, combining the potentials of parametric design and building performance simulations lead to the testing of multiple design variables. Parametric design methods, in fact, allow designers to explore geometries of building by changing certain parameters, keeping attention on the effect of the building performance. There are several software platforms that focus individually on environmental analysis or parametric design, but few integrate both such as the integration of Rhinoceros and the plug-ins Grasshopper, Ladybug and Honeybee [13]. These last cited plug ins are open source tools designed by the researchers Mostapha Sadeghipour Roudsari [33] and are constantly under development.

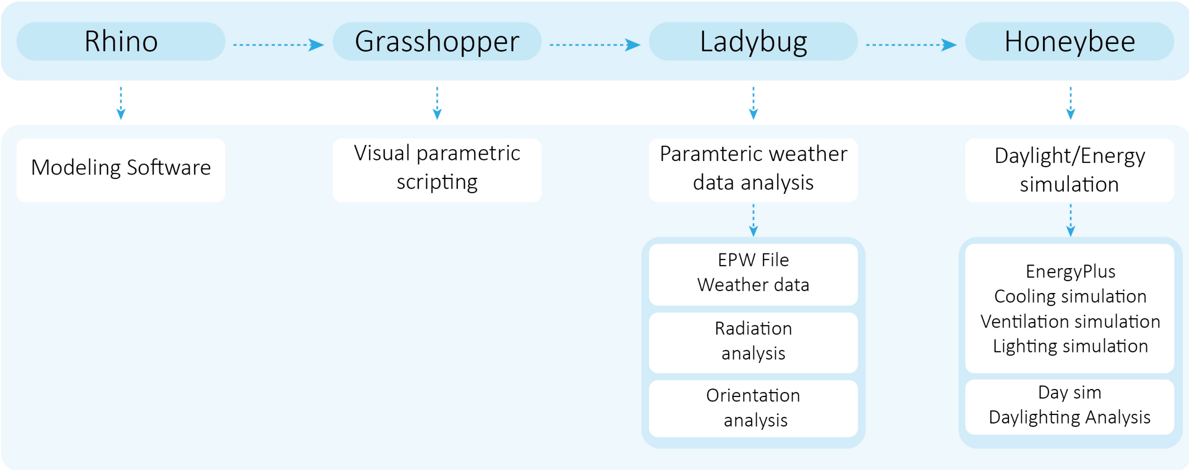

Figure 6.1: Definition of the integration of Rhinoceros and other plug in for building performance simulation.

Rhino is a 3D computer-aided design program, which can be turned into a parametric tool through the plug-in Grasshopper. Ladybug and Honeybee are two plugins for Grasshopper and Rhino for the exploration and evaluation of the environmental performance of the design. The former imports standard EnergyPlus weather files (.epw) into Grasshopper. The latter connects the parametric design of Grasshopper to validated simulation engines (EnergyPlus, Radiance and Daysim), which run different simulations, such as energy, comfort or daylight analysis. The analysis that can be performed with Ladybug are the following:sun path, shadow range analysis, solar radiation analysis, outdoor comfort, create psychrometric charts, wind roses.

While Honeybee can perform: energy simulation, daylight analysis, natural ventilation analysis and heat transfer analysis.

6.6. Simulation workflow

The framework is basically divided in two steps: the first is related to the parametric modelling of the building and of the analysis, defining the geometry, envelope properties, the weather data and the analysis type. The second step is related to the phase of simulation and of visualization of the results, defining the simulations to be run and visualizing the output of the analysis.

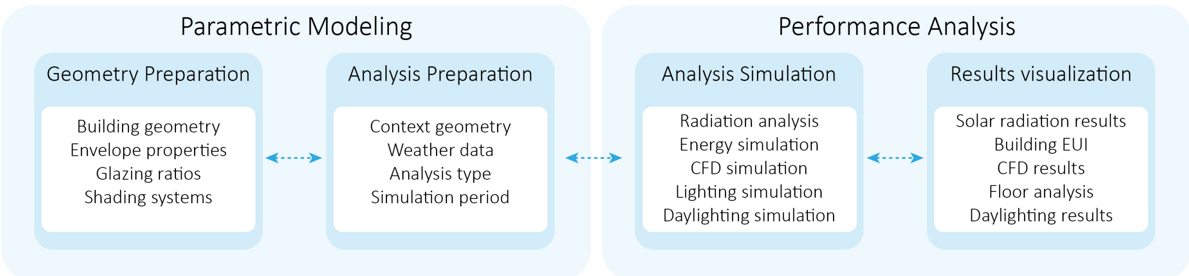

Figure 6.2: Simulation workflow

- In the **geometry preparation stage**, the building geometry is brought into Honeybee as zones, depending on the building form and program. Loads and schedules are subsequently assigned to each zone. The thermal and visual properties of building elements, such as walls, floors and windows can be altered for the purposes of energy or daylight simulations. Additionally, glazing and shading properties are assigned, while mechanical system selection and parameters are set.

- In the **analysis preparation stage**, the type of analysis is selected, and parameters that control the simulation are assigned. All simulations can use the analysis period and weather file as inputs, while other inputs are simulation specific.

- In the **analysis simulation stage**, the prepared geometry is run through their respective simulation engines. Energy simulations use EnergyPlus, while daylight simulations use Radiance and Daysim.

- Finally, in the **visualize results stage**, the data from the simulations is displayed according to the analysis type. Data from energy simulations is typically displayed as Energy Usage Intensity (EUI). Data for daylight and radiation simulations is typically shown as a colored grid with values on each grid point.

The workflow implemented is simplified in the following diagram and it is showed in the image below.

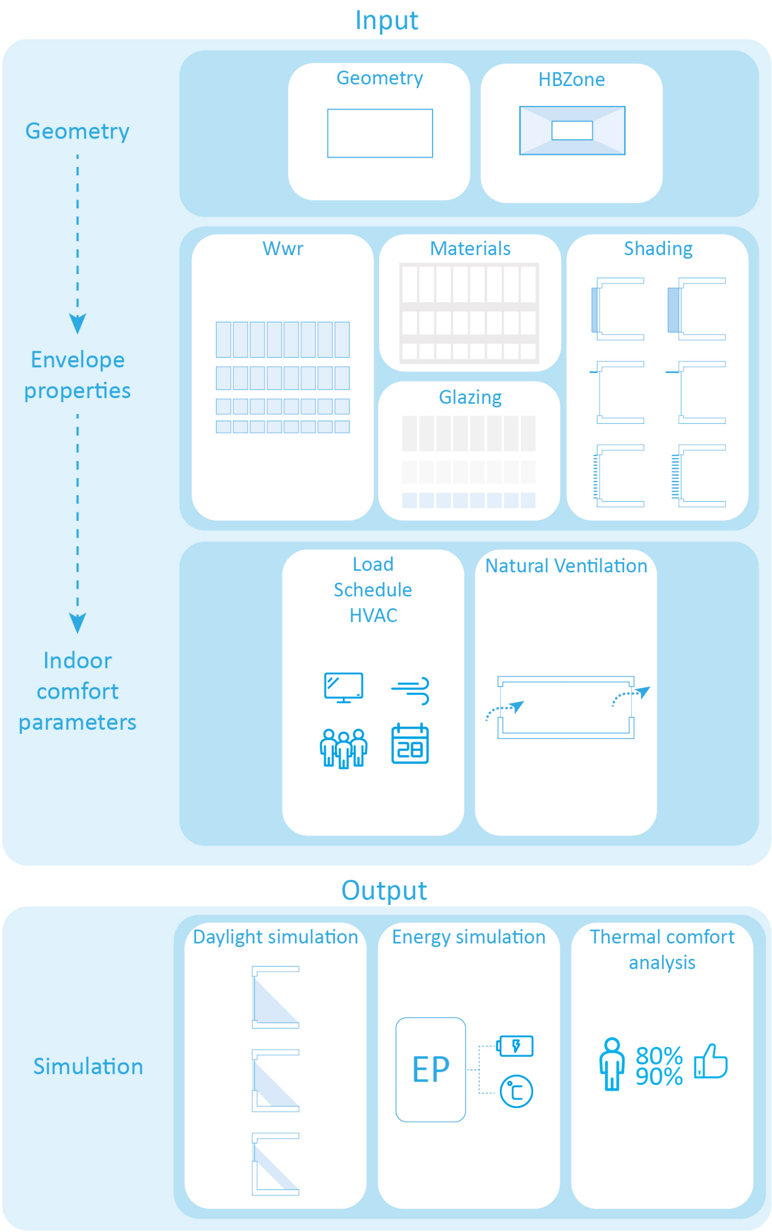

Figure 6.3: Workflow implemented

6.6.1. Geometry

Figure 6.4: Case study: One raffles quay. Source:http://www.data.com.sg

One Raffles Quay North Tower is an office building designed by Kohn Pedersen Fox Associates, located in the middle of the prestigious Raffles Place business district in Singapore. The design and construction of One Raffles Quay tower were challenged not only by the presence of existing twin subway tunnels below the site, but also by the highly soft ground conditions. In fact, the massing of the tower was rotated relative to the urban grid in order to solve the structural problems abovementioned. Also, in order to transfer the 50-storey tower loads safely a central box core for the internal vertical traffic was designed also as structural component.

The building is 50 x 34m and the core is 30 x 14m a typical floor are is of approximately 1700 m^2. The orientation of the building is tilted of approximately 45 degrees with respect to the north-south orientation [42]. Since the purpose of this study is to decrease at maximum the energy consumption for cooling, and since in the literature it was found out that in a tropical climate the most suitable orientation to reduce solar heat gains is the orientation with the north-south axis, in the simulation set-up the latter was implemented.

Regarding the definition of the geometry in Grasshopper, firstly the dimensions of the perimeter

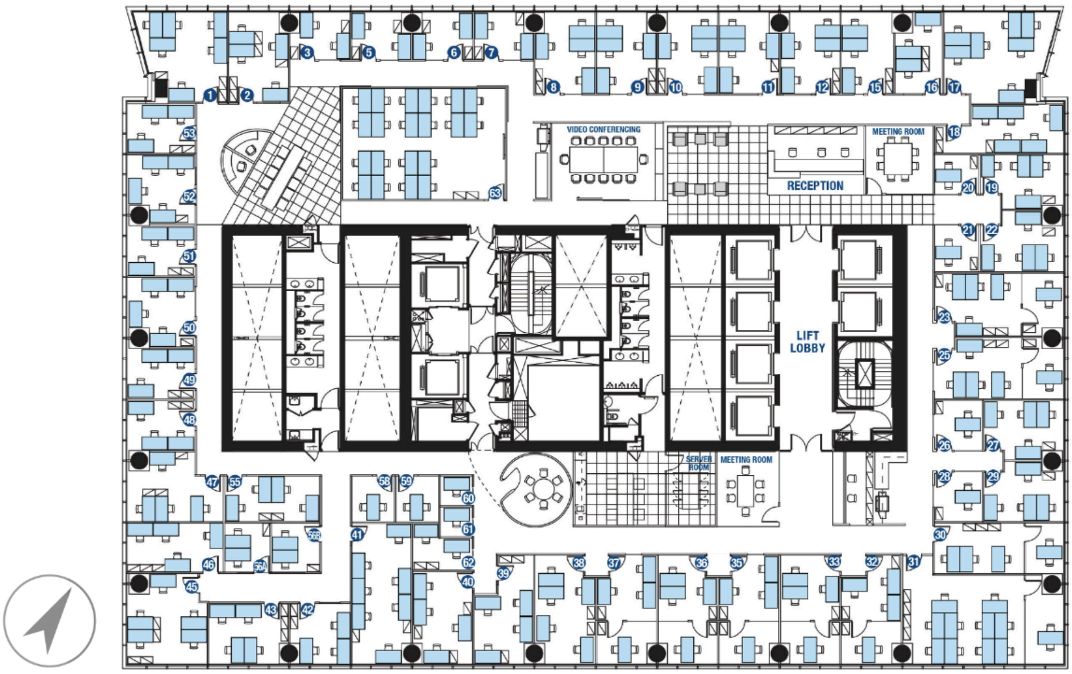

Figure 6.5: Case study: Plan of the 25th floor of One raffles quay. Source:https://www.mondestay.com

dimensions of the building are defined and then the core is defined as subtraction of the initial floor area, in order to create one floor of the geometry of the case study. Once the perimeter area and the core are created, the external and internal walls are built by extruding the "walls" in the the Z-axis (building height). Finally, four Honeybee-zones are created by creating a closed volume for each zone, composed of floor, ceiling, external facade wall, internal wall of the core and two adiabatic walls (that divide one Honeybee zone from the adjacent zones). Each Honeybee zone is characterized by the orientation (North, South, East and West zone). In order to test the geometry as if it was a random floor in the tower, the floor, ceiling and internal walls were defined as adiabatic surfaces. Only the external walls are defined as 'Outdoor' surfaces.

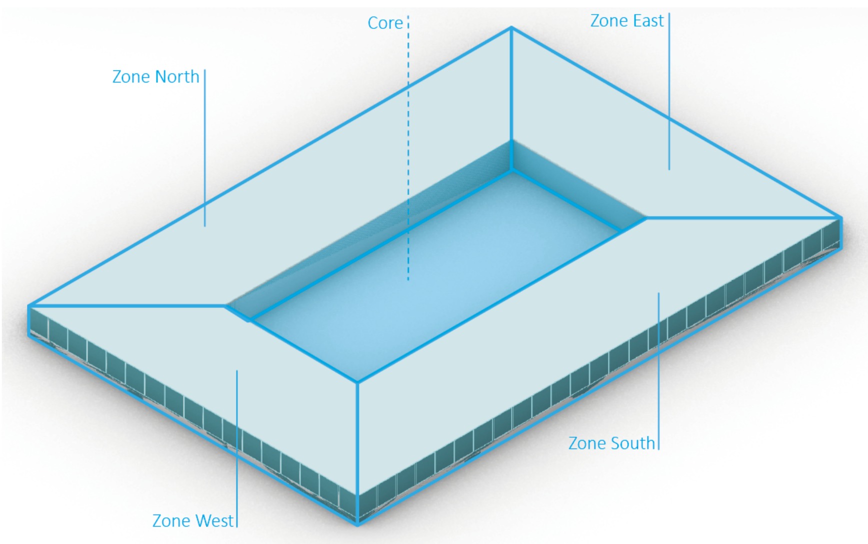

Figure 6.6: Visualization of HBzones.

6.6.2. Envelope properties

The facade consists of a unitized aluminium system with double glazed low E-solar tinted glazing with a finished floor-to-ceiling height of approximately 2705 mm [42]. The facade of the tower is fully glazed in order to offer the highest amount of natural daylight, therefore it can be presumed that the window to wall ratio adopted for the design of the facade of the tower varies between 80 and 90%.

Window to wall ratio

Windows will be assigned to the exterior wall surfaces based on the window to wall ratio and the glazing properties, by connecting the surfaces of the exterior walls into the Honeybee-glazing creator component. In the latter it must be specified the window to wall ratio (slider named: wwr_n, wwr_s, wwr_e. wwr_w) which one of variables of the optimization phase.

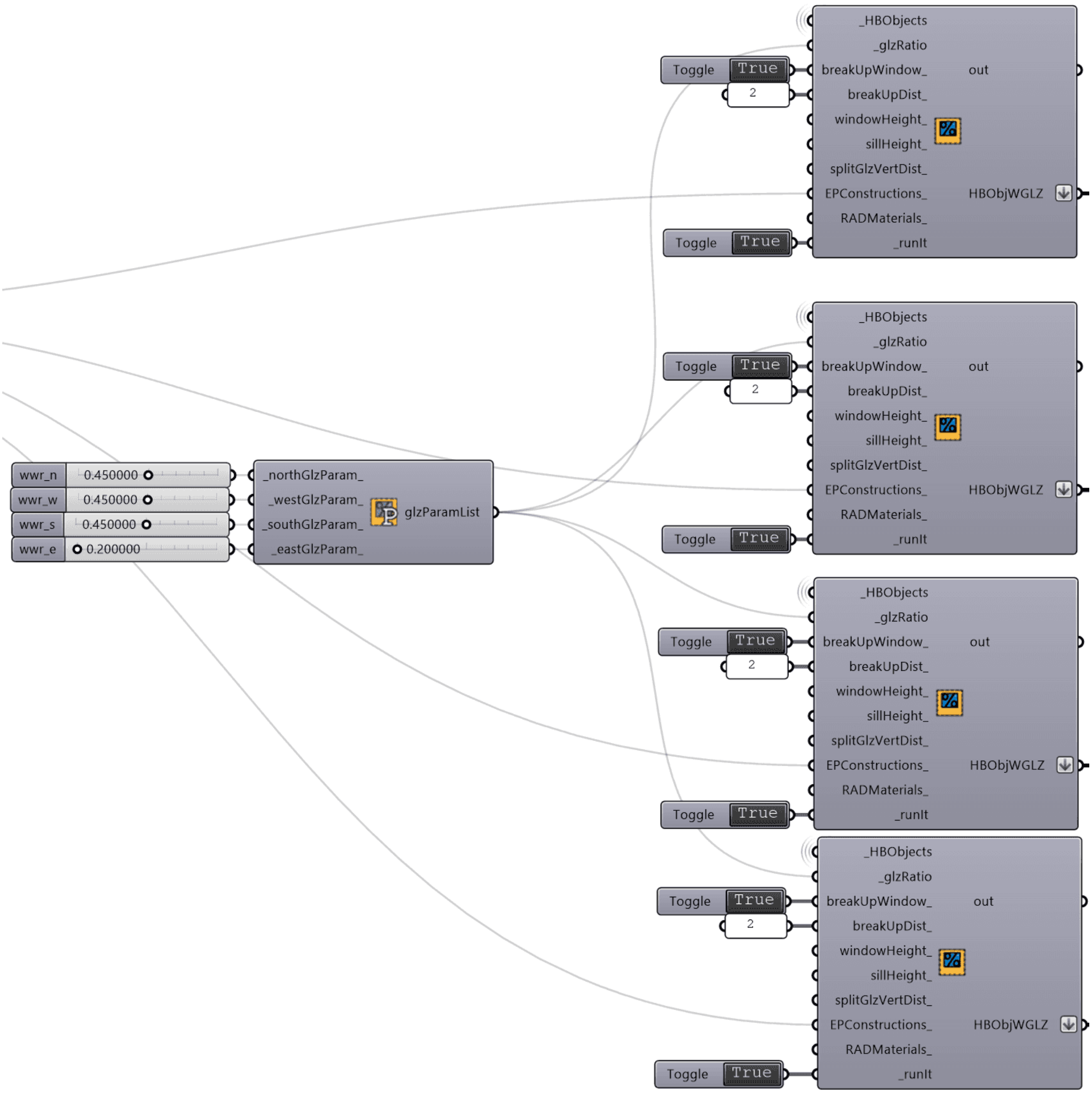

Figure 6.7: Grasshopper Script for window to wall ratio

Material

Customized materials are created and assigned to each surface: internal floors, interior walls, exterior walls and glazing. However, the floor and ceiling were set up as adiabatic surfaces.

Glazing

Since the purpose of this study is to find the optimal glazing that reduce at maximum the cooling loads, five glazing types were built to be tested. In the definition of each glazing type in Grasshopper, for each glazing the specific U-value, g-value and LT value were assigned, showed in 7.5. The glazing types chosen are frequently used in the building industry, because of their low U-value, balanced g-value and high LT value. During the optimization phase the slider 'combination' will vary in order to assign a different glazing type to the geometry tested.

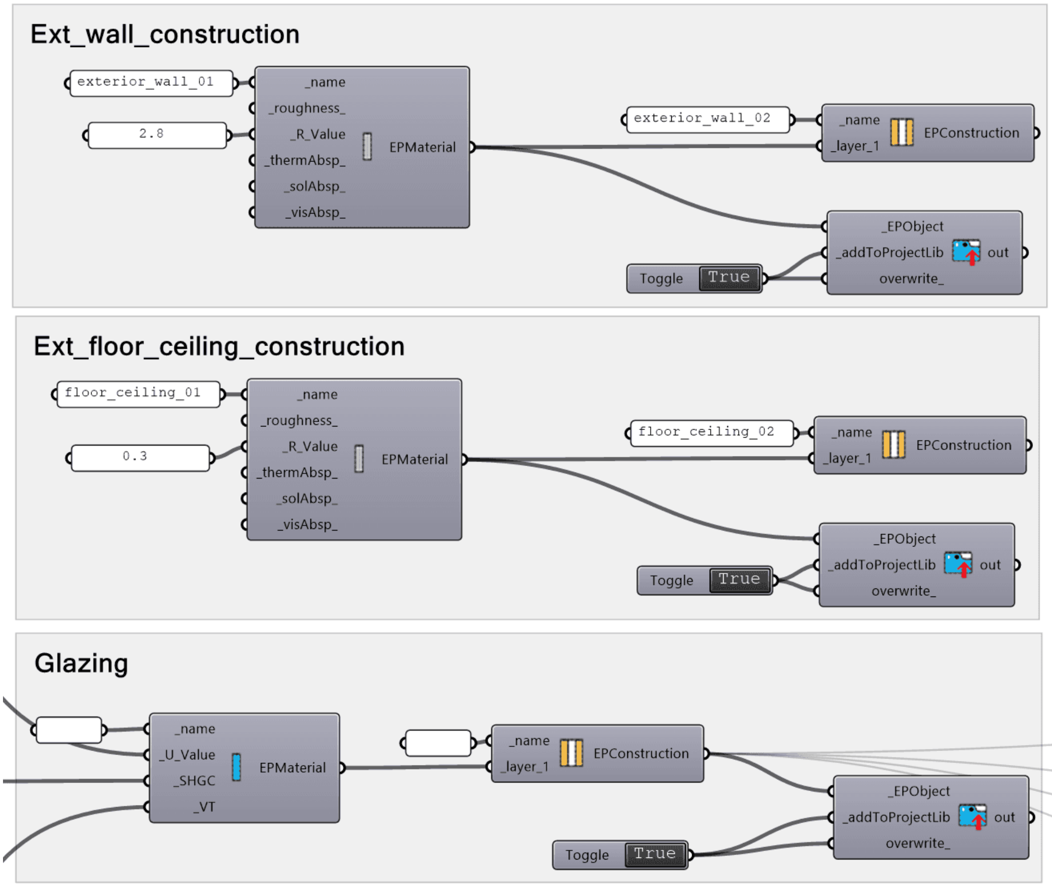

Figure 6.8: Grasshopper Script for material properties.

Name	Glazing type	U-value	g-value	LT value
0	Single clear glazing	5.8	0.8	0.9
1	Single coated glazing (ST120)	5.2	0.3	0.2
2	Double clear glazing	2.8	0.72	0.79
3	Double coated glazing (ST-108)	1.9	0.11	0.07
4	Double coated glazing (SKN154)	1.4	0.27	0.50

Figure 6.9: Glazing types

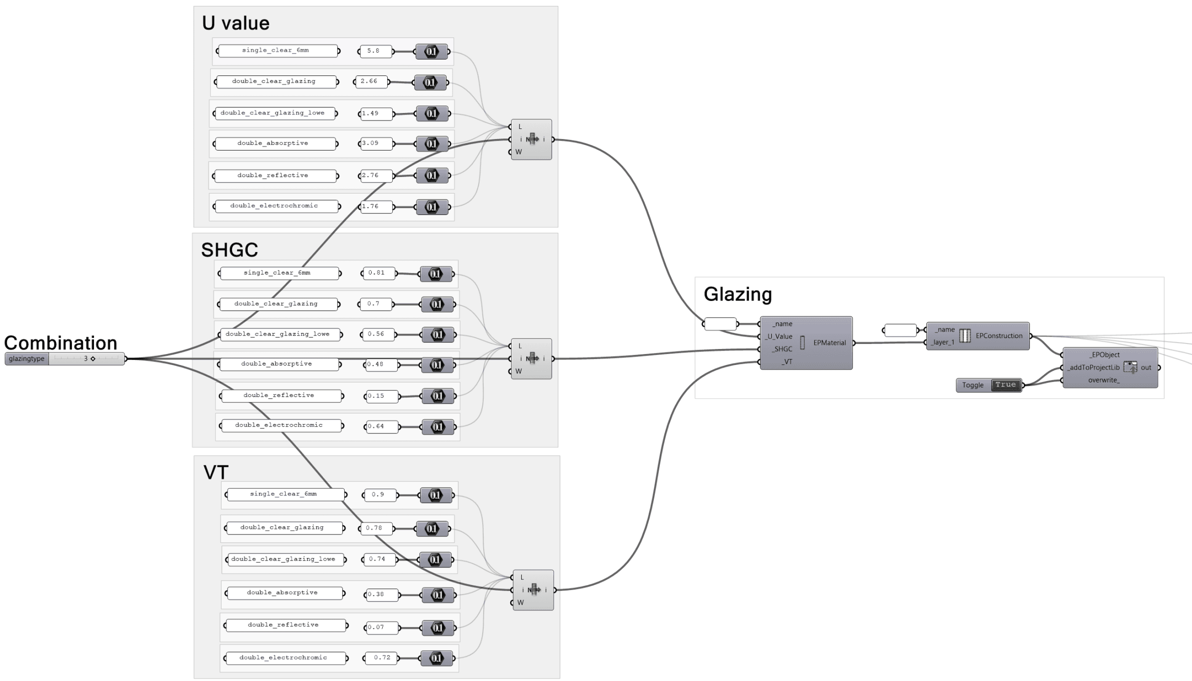

Figure 6.10: Grasshopper Script for glazing properties

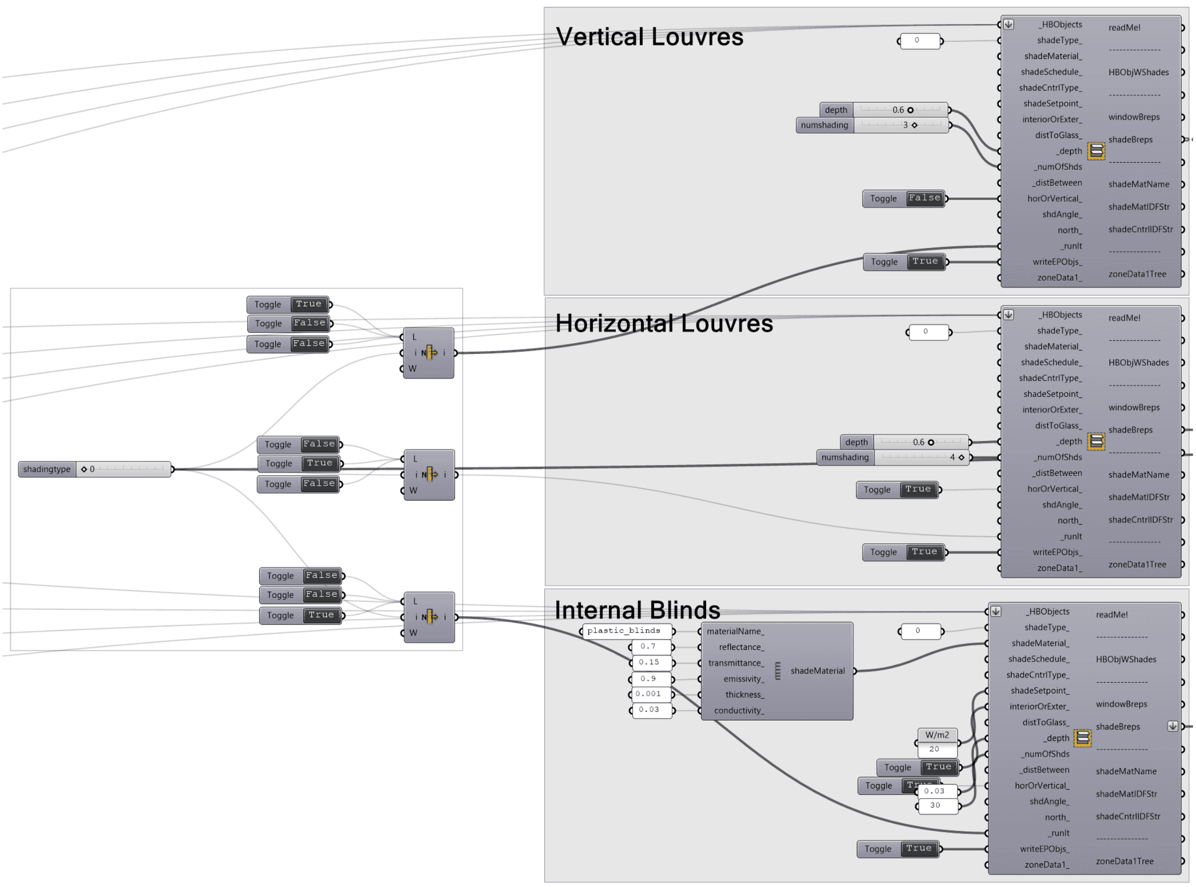

Figure 6.11: Grasshopper Script for shading devices.

Shading

A fundamental part of this research is the performance of shading devices with respect to the energy consumption for cooling in tropical climates. In fact, in the Grasshopper script were introduced three types of shading devices: vertical louvres, horizontal louvres and internal blinds. The latter are most commonly implemented in high rises even if external shading have shown to be more effective. The reason behind this is due to the complexity of maintenance at such high altitudes, high costs, but also due to the wind effect in the case of movable external shading. However, it is out of the scope of this study to solve these issues. Thus, these three types of shadings are applied and tested in the geometry of the case study.

The vertical and horizontal louvres can vary depending on the depth of the overhang (from 0.1m to 0.9m) and the amount of louvres (from 1 to 4 louvres). While the internal blinds are set up to be activated only when the total horizontal solar irradiance exceeds a shading set point of 20W/m2≈ 2500 lux.

Finally, the selection of one of these three shading types it is set up as a variable in the optimization phase, in order to test different combination of shadings with different window-to-wall ratios and glazing types.

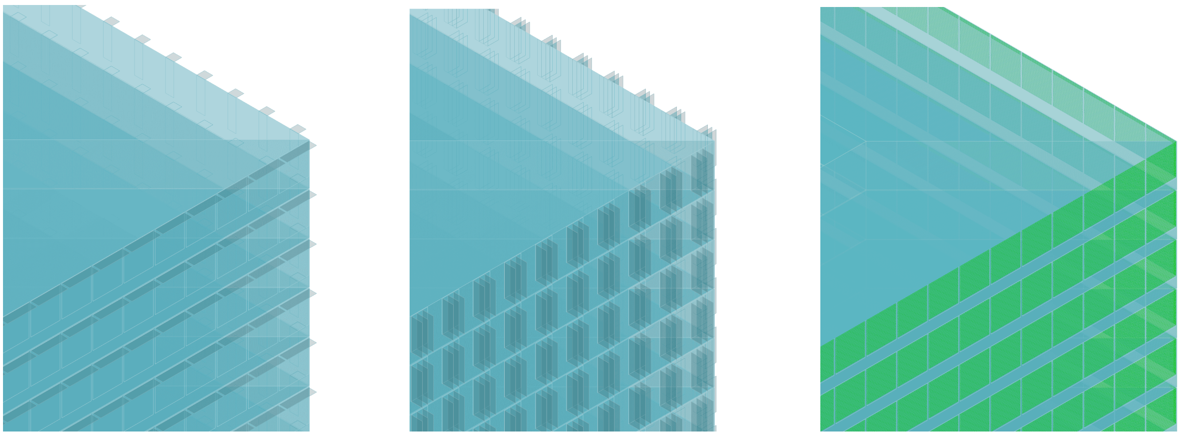

Figure 6.12: :Shading types: horizontal louvres, vertical louvres and internal blinds (from left to right).

6.6.3. Indoor comfort parameters

Load

The information for the internal loads in the current design of the tower were not found, thus assumption were made. Regarding the equipment load and infiltration rate were assumed to be 15 W/m2 and 0.0001 m3/s respectively. Regarding the lighting density, occupancy density and cooling set point these values were assumed to be fixed values for a first optimization: respectively 15 W/m2, 0.15 person/m2 and 24°C. While in a second optimization these parameters were taken as variables, in order to observe the impact of a low lighting density, low occupancy density and high cooling set point in the energy consumption.

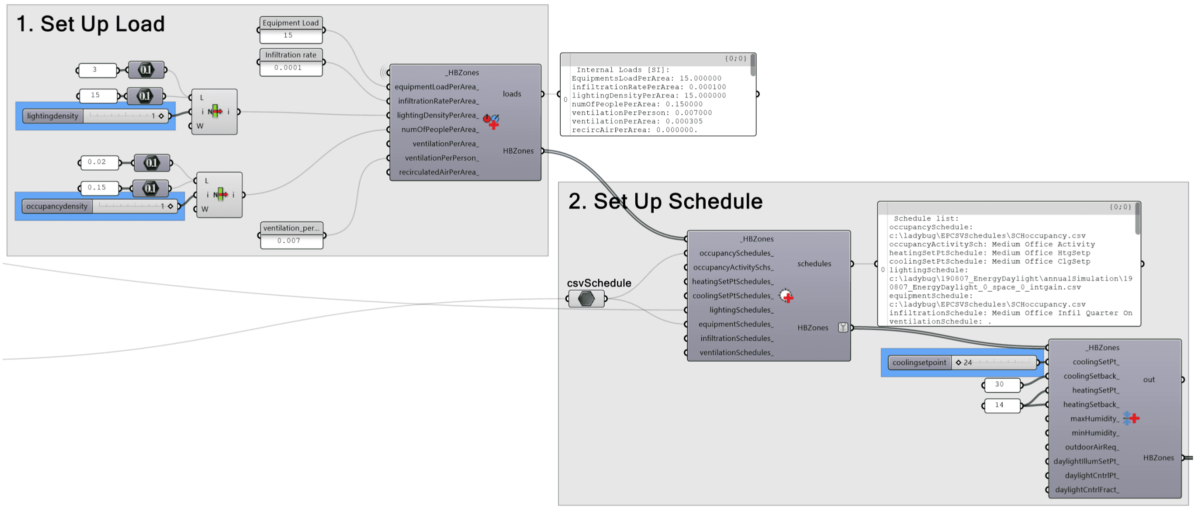

Figure 6.13: Grasshopper Script for load and schedule definition.

Schedule

The occupancy schedule that is used, it is a customized schedule where the office is partially in use between 7 and 8 a.m, between 5 and 6 p.m, totally in use between 8 a.m and 1 p.m and again between 2 and 5 p.m, and fully empty during the break between 1 and 2 p.m. The equipment schedule follows the occupancy schedule while the lighting schedule depends on the daylight simulation, which create a lighting schedule turning on the lighting system whenever the illuminance threshold (400 lux) is not reached.

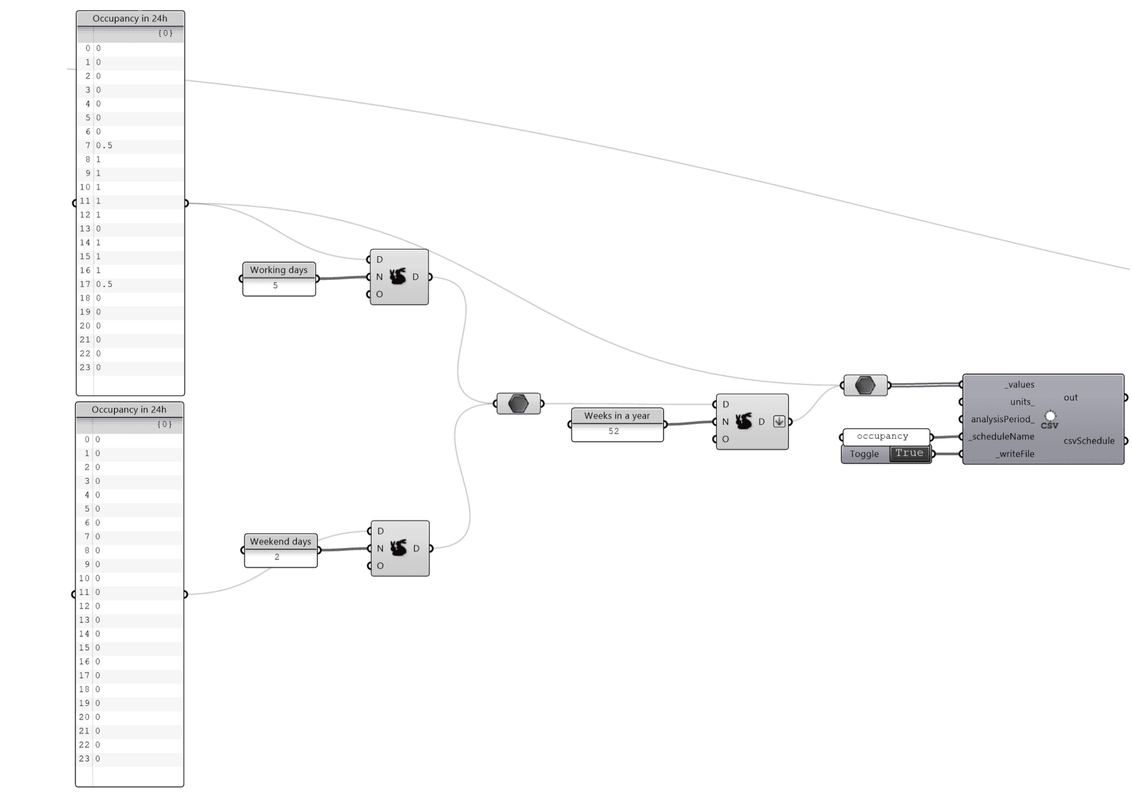

Figure 6.14: Grasshopper Script for definition of a personalized schedule

Natural ventilation

Since Natural ventilation is one of the cooling technique most used in bioclimatic projects to reduce internal heat gains, and since it was found out that air speed can decrease the air temperature in 6.15 it is shown the definition of the natural ventilation component in Grasshopper. Wind driven cross ventilation is implemented since there are operable windows in opposite facades. The minimum and maximum indoor temperature to activate natural ventilation are set up to 22 and 30°C respectively. While the maximum outdoor temperature allowed varies with the cooling set point variable. The latter is fixed to 24°C in the first optimization, while it varies from 24 to 30°C in the second optimization in order to test which temperatures are accepted using the adaptive thermal comfort, while decreasing the use of air conditioning. Finally the fraction of operable glazing area is set to 50% simulating sliding windows.

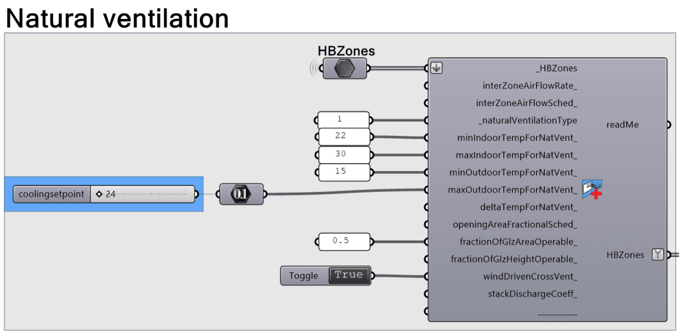

Figure 6.15: Grasshopper Script for definition of natural ventilation

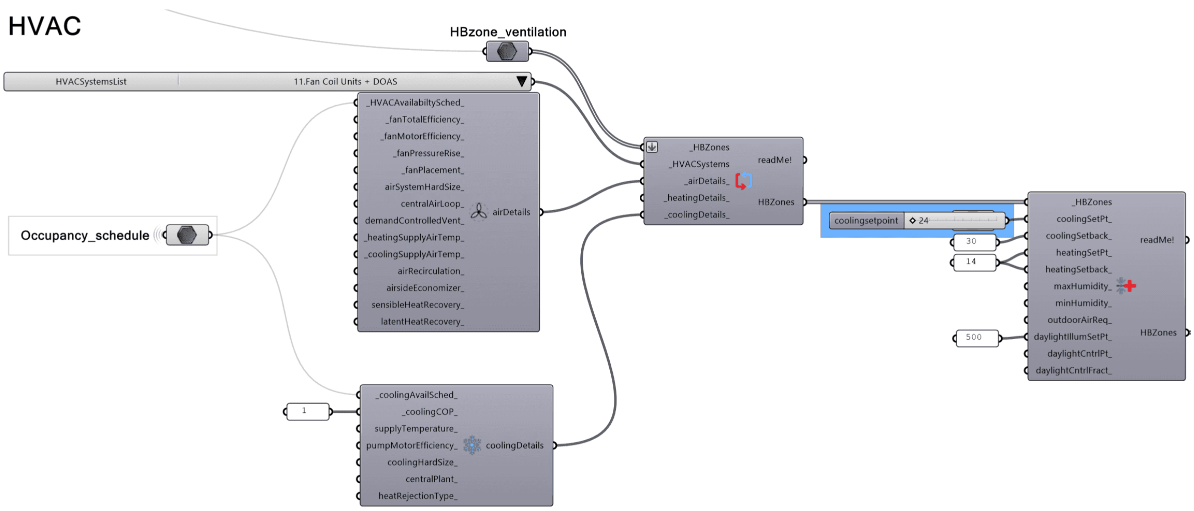

Figure 6.16: Grasshopper Script for definition of the HVAC system.

HVAC

As found in literature, in multinational offices the indoor comfort is controlled in a way to simulate the conditions of western offices, by implementing low cooling set point. In the case of One Raffles Quay office the cooling set point presumed is fixed to 24°C. The air conditioning system in use in the current design is a 24-hour chilled water supply from District Cooling System with 2 AHUs per floor, with an estimated cooling load for a typical office floor of approximately 210 kWh per floor. (source: http://www.orq.com.sg/northtower-specs.html) Since it was not found the exact HVAC System in use in the current building, it was assumed to use the fan coil unit with a dedicated outdoor air system (DOAS), which it is a common system for offices. Also, during the definition of the Grasshopper script other HVAC system were tested, and this system, with a cooling COP of 1, was the one that was giving a value of energy consumption near to current energy consumption of the building. The schedule applied to the HVAC system is the occupancy schedule defined earlier, and also in this case the cooling set point is fixed to 24°C for the first optimization and varies from 24 to 30°C for the second optimization. Finally the daylight setpoint is 400 Lux.

6.6.4. Simulations and Analysis

Daylight simulation

The daylight simulation is implemented in order to keep track of the visual comfort since the envelope parameters are optimized to reduce internal solar heat gains. The daylight analysis is applied only in the perimetrical office area with points subdivided in the four zones, based on orientation, 14 points in the north and south zones and 8 points in the east and west zones.

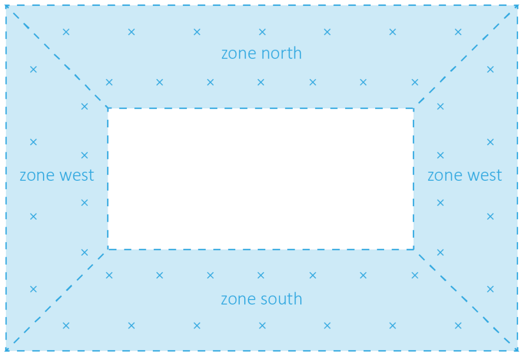

Figure 6.17: Position of points for the daylight simulation.

These points are located at 0.80m from the floor, and they simulate the position of the sensors that measure the illuminance level, in order to calculate the SDA (spatial daylight autonomy) and the Useful daylight illuminance percentage and to control the lighting system, creating for each simulation a different lighting schedule based on the illuminance levels of each point. If the illumimance level achieve the illuminance threshold of 400 Lux, then the lighting is turned off in that point.

The definition of the daylight simulation consists of three steps: the recipe, the run of the daylight analysis and the read of the annual results to generate the lighting schedule.

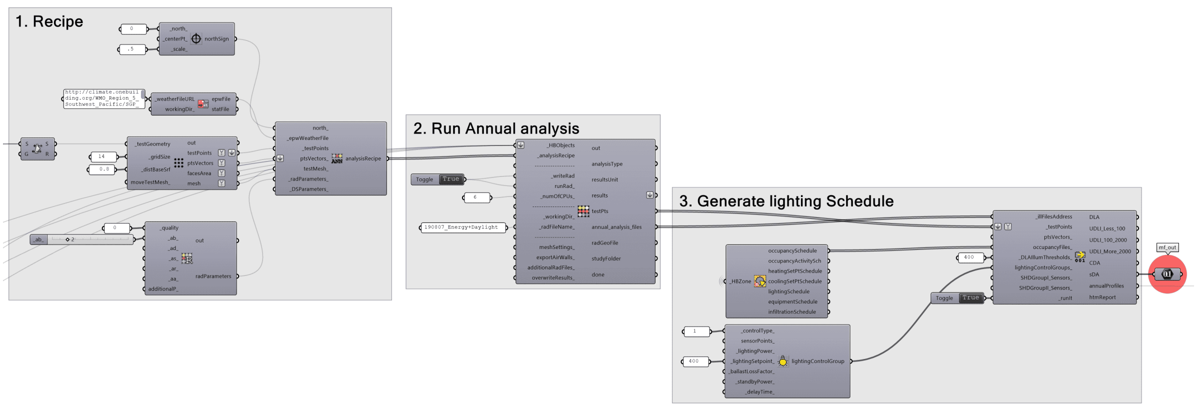

Figure 6.18: Grasshopper Script for the daylight simulation.

The recipe of the daylight analysis consists of defining the north, the epw Weather file (location in Singapore), the grid of the points, the distance from the floor and other radiance parameters as showed in figure 6.19. Then, in figure 6.20, the Run of the annual analysis collect the Honeybee zones (HBOjects) including the shading devices and the recipe defined above. The final part of the daylight simulation script is related to the setting of the lighting schedule. By defining the Illuminance threshold of 400 lux, connecting the occupancy schedule and defining the lighting control type (automate switch off occupancy sensor in this case) the lighting schedule is created for each simulation. This last components are shown in figure 6.21

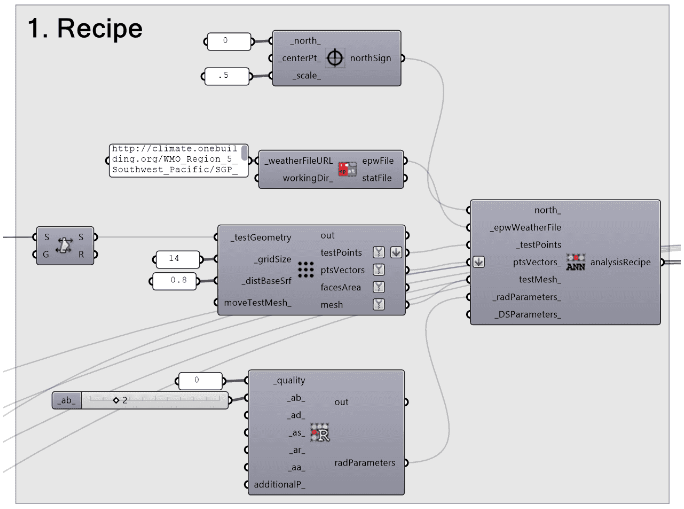

Figure 6.19: Grasshopper Script for the daylight simulation.

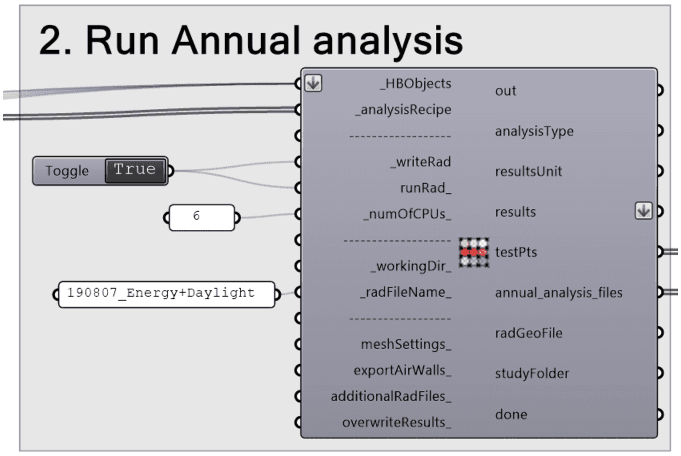

Figure 6.20: Grasshopper Script for the daylight simulation.

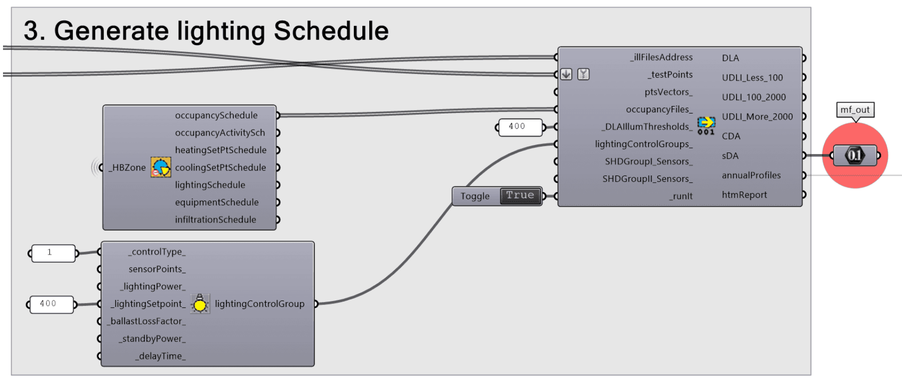

Figure 6.21: Grasshopper Script for the daylight simulation.

Energy consumption analysis

For the energy simulation the Open Studio component is used. This component has the same features as the Energy Plus component with additional features like the definition of the HVAC system. Before running the energy simulation it is fundamental to set up the analysis period (annual in this case), the epw file (weather file for Singapore), the simulation parameters, the shading system implemented, the simulation output and finally connect the Honeybee zones from the previous component (in this case from the HVAC system definition).

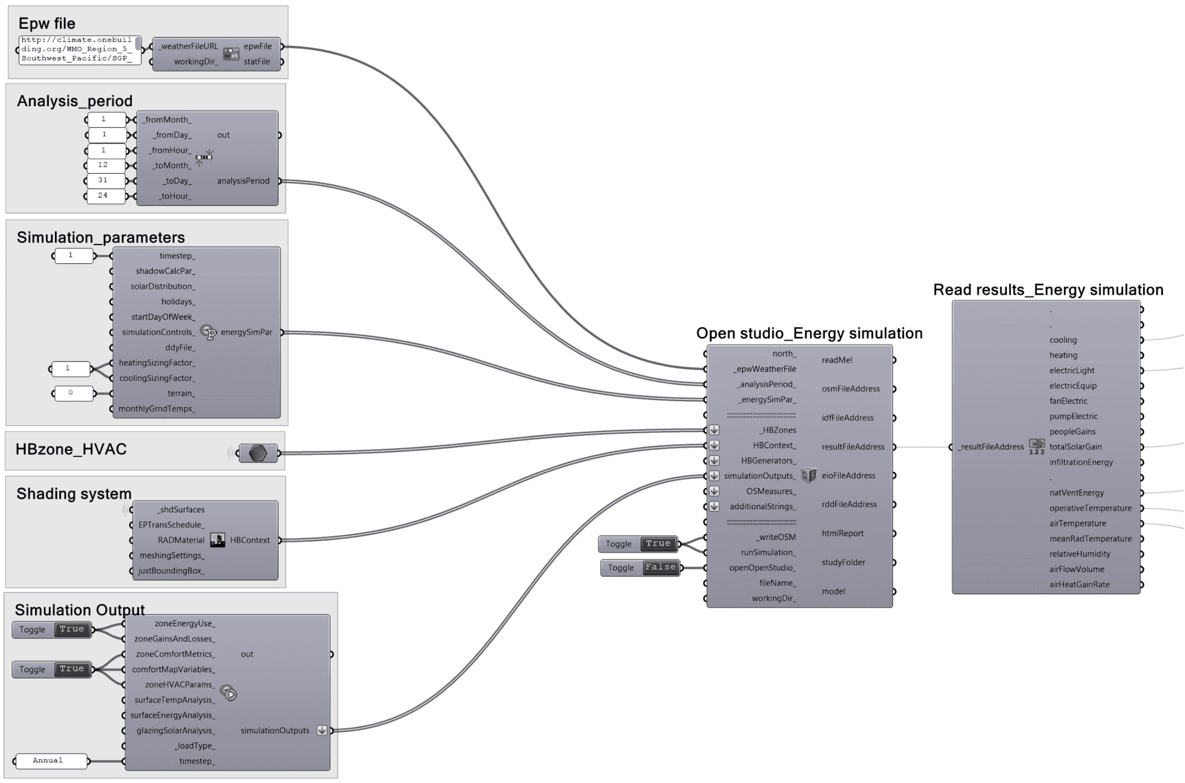

Figure 6.22: Grasshopper Script for the energy simulation.

In order to read the results of the energy simulation it is necessary to use the Honeybee_read EP results component. The outputs of the latter are different, the one used in this research are the following:

- cooling energy (Kwh)
- electric light energy (Kwh)
- total solar gains (Kwh)
- natural ventilation energy (Kwh)
- operative temperature (°C)
- air temperature(°C)

All the outputs related to the energy consumption are then divided by the floor area (m2) in order to have the energy consumption normalized (Kwh/m2). These outputs are finally grouped in the 'mf_out' in order to be recognized by the optimization software ModeFrontier.

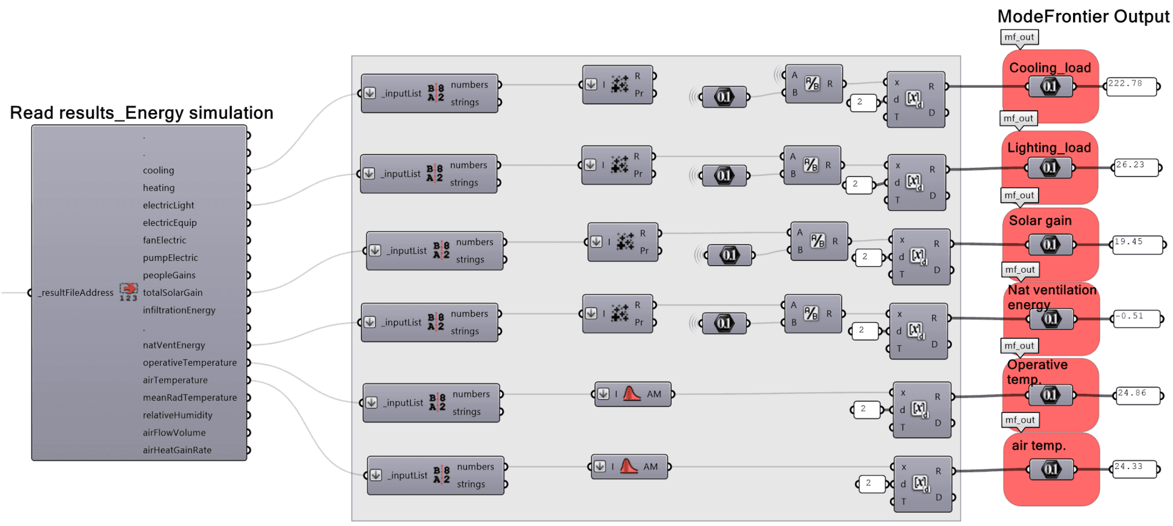

Figure 6.23: Grasshopper Script for the energy simulation.

Thermal comfort analysis

The thermal comfort is analysed through the component Ladybug_adaptive comfort calculator since the adaptive comfort model and natural ventilation technique are implemented in this study. The output used as result of this analysis is the percentage of comfortable time through the year, during the time that the space is occupied. In order to analyse the thermal comfort of each design simulated it is necessary to connect the operative temperature and air temperature outputs of the energy simulation to the adaptive comfort component. Also, it is needed to connect the outdoor temperature and wind speed of the location from the weather file (epw file). Then, the adaptive comfort parameters must be defined. Firstly, the choice between the US standards ASHRAE 55 2013 and the European standards EN-15251. Since there are no standards for tropical regions, the ASHRAE 55 2013 standard is used. Finally, the comfort limit must be defined. For the first optimization the limit was set to 90%, but for the second optimization both the limits 80 and 90% were tested, in order to see the influence of this parameter on the energy consumption.

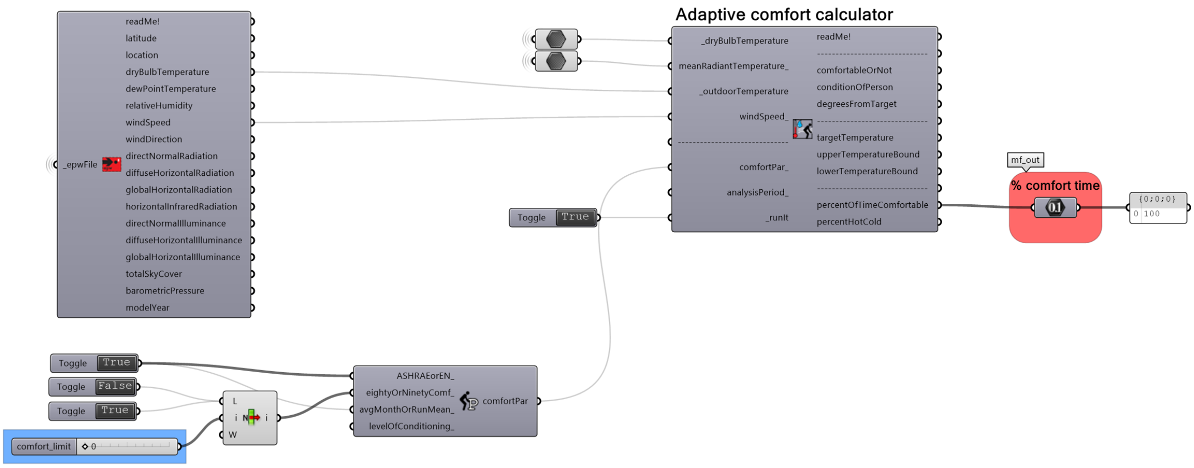

Figure 6.24: Grasshopper Script for the adaptive comfort calculation.

Calibration of the simulation

The results of the energy simulation done in Grasshopper were compared with the ones extracted from Design Builder, another energy modelling software. The energy simulation program used in both the softwares is the same (EnergyPlus). The information inserted regarding the building properties, the internal loads, etc are the same in both the simulations, but the end result of the simulation is slightly different. In fact, the cooling demands calculated for one floor of the current building in Design Builder is equal to 294 kWh/m2/year, while in Grasshopper the cooling demand is equal to 218 kWh/m2/year. More information regardin the settings of the calibration simulation can be found in the appendix.

7

Building Performance Optimization

As explained in the previous chapter, building performance simulation (BPS) softwares became a necessary tool for architects and engineers in order to be able to assess the energy performance or indoor comfort of the design proposed. However, the result of the use of BPS is the assessment of the performance of the proposed design, without giving any support for the decision-making procedure. Thus, it is up to the designer to explore the design space manually and compare the results of the BPS in order to choose the design that meets the requirements set in the beginning of the design process. However, when the solution space is large, it is not possible to analyse one by one each possible design alternative. This trial-error based approach end up being time-consuming and inefficient since the designer is required to modify manually and gradually the variables in order to find the solution that get closer the most to the optimal result. The disadvantages of this approach were solved with the combination of the BPS and a design optimization tool, developing the Building performance optimization (BPO) approach [53].

7.1. What it is BPO?

A building performance optimization (BPO) is a process used with the objective to identify the optimal solution to achieve one or more design objectives, among several possible alternatives. The optimal solution is chosen with respect to specific performance criteria defined at the beginning of the design process. Also the design objectives are defined at the beginning of the optimization process as a mathematical functions, called objective functions, which must be maximized or minimized. In order to find the optimal solution of the objective function, optimization algorithms must be defined. As abovementioned, optimization is coupled to BPS tools. In 2002 on the DOE website were found out around 406 BPS tools, of which less than 19 tools are allowing BPO [11].

7.2. Optimization tools

Nowaday, because of the development of computer science, there is a wide choice of the software tools which can be used to carry an optimization study. This is the case also for optimization tools for architectural designs. Some of these are integrated in the modeling software. For instance, Grasshopper allows the integration of optimization tools such as: Galapagos, Octopus, Opossum, Goat, Silvereye, FRoG , Nelder-Mead Optimization and Design Space Exploration. Other architectural modelling software with integrated optimization tools are Dynamo Studio or Design Builder [59]. However there are other external optimization software that can be connected to the modeling and simulation package used. Examples are ModeFrontier, Matlab, GenOpt, ParaGen, MultiOpt, Gene_Arch, MOBO, etc [23].

7.3. Optimization workflow

The workflow to set up a building design optimization consists of four steps:

- **Identification of the design variables** : During the early design stage it is necessary to identify the possible design variables that can be combined and tested. In the architecture field, the design variables range vary from the geometry of the building to the properties of the materials implemented, or to the indoor comfort parameters.

- **Selection** of a **BPS and BPO tool**.

- **Identification** of the **objective function** to be implemented. The formulation of the objective function depends on the optimization objective to be achieved. An objective function can be related to the minimization of energy consumption, or the maximization of daylight or even the minimization of costs.

- **Selection** of an appropriate **optimization algorithm** [28].

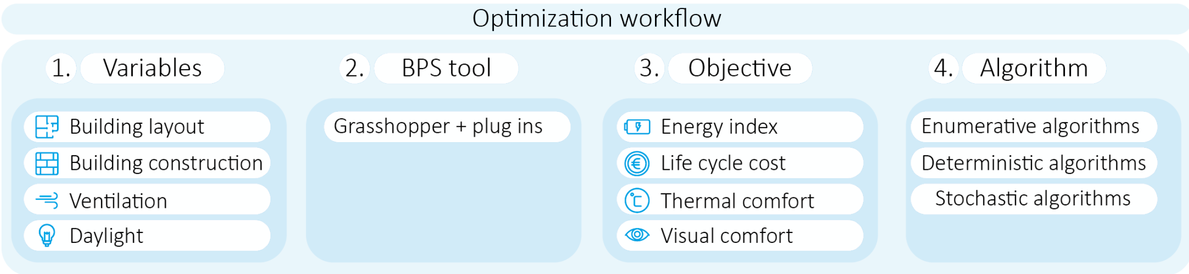

Figure 7.1: Optimization workflow

7.4. Design variables

The first step of the definition of the optimization workflow is related to the identification of the design variables that will be explored during the optimization phase. Possible design variables are related to the building geometry, such as floor plan layout, building form, or to the envelope properties, such as density of fenestration and material properties of the envelope, or to the integration of shading devices, such as the shape and dimensions of the shading system, or to the sizing of the HVAC system, in particular HVAC system control parameters and/or strategy, integration of natural ventilation strategies and thermal comfort [11].

7.5. Optimization objectives: Objective functions

The second step is to define the objectives of the optimization. The optimization can either single-objective, with only one objective function, or multi-objective, with two or more objectives. In the building design optimization, the objectives are mainly related to the energy performance, the indoor comfort or the costs of the building. These macro objectives include specific indices:

- **Energy performance index:** meaning cooling and heating demands, HVAC system energy consumption and the total building energy consumption.

- **Life cycle cost index:** meaning life cycle CO2 emission, life cycle primary energy consumption and life cycle financial investment.

- **Thermal comfort index:** meaning mean PMV level, mean PPD level, thermally comfortable hours and operative temperature.

- **Visual comfort index:** meaning illumination level, daylight factor, daylight autonomy and useful daylight illuminance and DGP.

The first two objectives are the ones that drew the most attention in the last decades. Huang and Niu [23] found out that the 80% of the total optimization cases found in literature has as objective function the reduction of the energy demands and the life cycle costs. Right after, another recurring objective is the optimization of the factors that influence the indoor thermal comfort of the users. However, most of these studies have been focused on the optimal design of HVAC systems, while few researches have analysed the effects of building envelopes on indoor thermal comfort [23]. As mentioned before, an optimization analysis can have one or more objective functions. In the case of a multi-objective optimization, it become harder to find the optimal solution that meet the requirements of all the objectives, especially when these are depending on each other. Thus, contradictory solutions could occur, by solving one objective and not another one. In this case, it is necessary to find a trade-off to satisfy individually all the objective functions through the optimization algorithm. The latter has the role to find the trade-off solutions, which usually are defined as Pareto optimal solutions [11]. The set of Pareto optimal solutions is called Pareto Front, which is a two or three-dimensional visualization of the relationship between two or three objective functions [59].

7.6. Optimization algorithms

The last step to set up the optimization workflow is the choice of the optimization algorithms. In order to solve multi-objective optimization, the algorithms available are classified in three categories:

Enumerative algorithms The enumerative methods search in a discrete space, evaluating all the solution space and choosing the solution that meet all the requirements of the objective functions. In particular, during a direct search, the optimization starts with the definition of a landscape of possible solution around one point recording and comparing the results obtained. Whenever the latest result get closer to the optimization target, this point is recorded and the next points are generated around it. This process goes on until an optimal solution is found. Direct search methodologies can be either the gradient deterministic or the gradient-free methods [23], [29].

- Gradient-based methods are based on mathematical procedures and are effective mostly only in case of smooth and continuous functions,

- Gradient-free direct methods are based on stochastic techniques, which allow dealing also with non-linear behaviour of the values to be optimized.

Deterministic algorithms
Deterministic algorithms require an evaluation function that satisfies continuity and derivability conditions. Therefore, such approaches fail in presence of discontinuous building and HVAC problems with highly constrained characteristics and multi-objective functions.

Stochastic algorithms
Stochastic algorithms, also known as evolutionary algorithms, do not require many mathematical requirements for solving highly complex optimization problem. In general, evolutionary algorithms generate an initial population selecting random individuals, which are evaluated to assess their fitness. The closest individuals to the optimal solution are chosen as parents, in order to reproduce a second population, through crossover and mutation. A second round of selection is carried among the individuals of the new population. This process is repeated until the algorithm identifies a possible optimal solution. This method turned out to be faster, more accurate and with a stronger adaptability with respect to the direct search methodology. Stochastic algorithms can be divided into genetic algorithms, neuroevolution, particle swarm optimization and other types of algorithms [23].

In the recent years genetic algorithms (GAs) have been increasingly used for optimization of building and HVAC systems. In particular, the elitist non-dominated sorting genetic algorithm (NSGA-II) has been reported as the most efficient GA. In particular, the NSGA-II is implemented to find a trade-off relation between energy consumption and investment cost or thermal comfort level of buildings [11].

7.7. Optimization workflow with ModeFrontier

After collecting a general knowledge on the BPO, in specific on the optimization tools, workflow, objectives and algorithms, in this paragraph the tools chosen and the workflow implemented are presented. The selection of the optimization software is based on the ability to link the process to the BPS used (Grasshopper), on the simplicity and fluidity of data exchange and on the rapidity and flexibility of the connection between the simulation and optimization workflow/process. The optimization workflow consists of the connection of Grasshopper and ModeFrontier [5]. The latter is a platform with a ”process automation and optimization in the engineering design process” [5], characterized by a wide range of design of experiments and optimization algorithms for the search of the optimal solutions and by the opportunity to integrate external tools such as Grasshopper. Also, ModeFrontier offers an extensive set of advanced tools for the analysis and visualization of the output data, and thus facilitating the final decision making phase [5].

The connection of Grassjopper to ModeFrontier it is done by installing the Grasshopper node Mynode in Modefrontier and by naming the outputs in the Grasshopper file with the code 'mf_out'. The optimization loop between Grasshopper and ModeFrontier consists simply in running one simulation at a time from Grasshopper and recording the results in ModeFrontier till the objective function that has been set up is met as shown in 7.2.

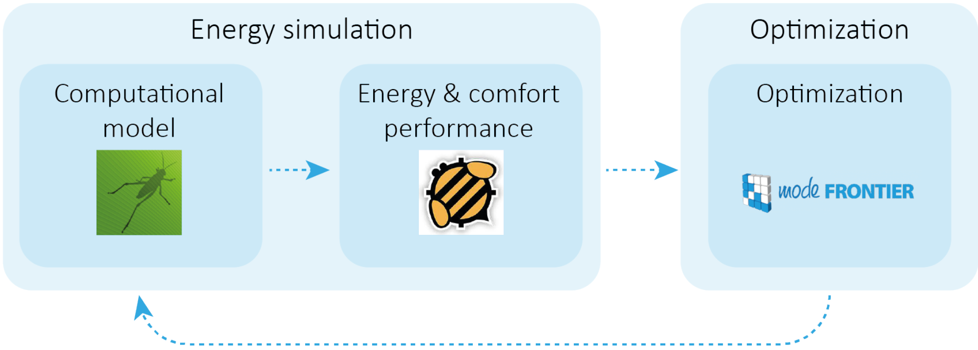

Figure 7.2: Workflow between Grasshopper and ModeFrontier

To implement this simulation-optimization workflow it is necessary to follow the following steps:

- in Grasshopper: group all the output of the simulation in one group named 'mf_out'
- in ModeFrontier: connect the Gh file through the Gh node.
- define the properties of the inputs, the outputs: ranges of the values, value of the steps, etc;
- define the objectives to minimize or maximize, and the constraints to respect;
- define the algorithm for the Design of Exploration (DOE) to implement for the combination of the values of the variables in order to reach the objective function;
- define the optimization algorithm.

The interface of ModeFrontier shows clearly the optimization workflow by subdividing and connecting the input variables (on top), the output, the constraints and the objective (in the bottom) and the optimizer and the connection to GH (in the middle).

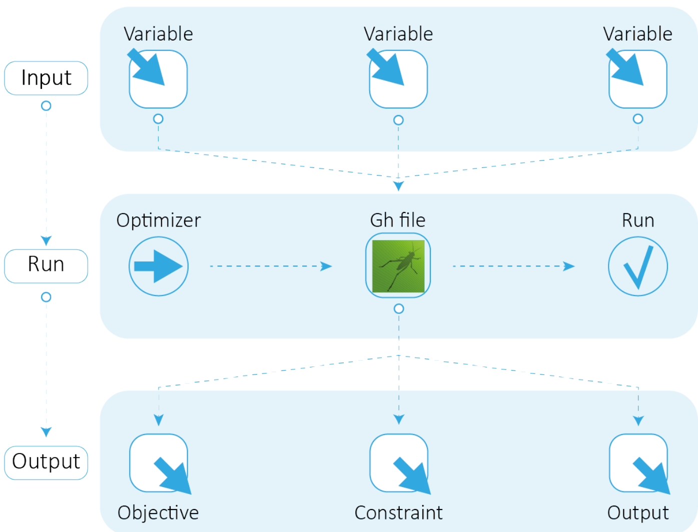

Figure 7.3: Schematic representation of the workflow and interface of Modefrontier.

In this study two optimization are run: the first has as variable envelope parameters, while the second implement as variables envelope and indoor comfort parameters. In 7.4 it is shown the variables and the constant parameters in the two optimizations. Regarding the set up of input variables, output, constraints and objectives slightly differ in the two optimizations, while the optimizer implemented is the same in both the optimizations. The optimizer used is Pilopt which allows a fast convergence to the optimal result, that meet the best the objective function [5]. This optimizer contain different strategies to investigate and explore in a smart way the design space, optimizing time and computational resources available thanks to the internal adaptive algorithm strategy (source: esteco.com) The self-initializing mode is used setting 250 evaluations, with 20 evaluations for the Design of Experiments (DOE) for the first optimization, while 1070 evaluations are done for the second optimization.

	1st Optimization		2nd Optimization	
	Variable	Constant	Variable	Constant
Building shape		✓		✓
Building orientation		✓		✓
Window to wall ratio	✓		✓	
Glazing properties	✓		✓	
Shading system	✓		✓	
Shading properties	✓		✓	
Occupancy density		✓	✓	
Lighting density		✓	✓	
Cooling set-point		✓	✓	
Adaptive comfort acceptance		✓	✓	

Figure 7.4: Workflow set-up of the two optimizations in ModeFrontier

7.7.1. Optimization workflow: envelope optimization

In the case of this research the design parameters can be subdivided in envelope parameters and indoor comfort parameters. The former are the variables of the first optimization while the second are fixed parameters. In the figure 7.6 the ranges of the variables and the values of the constant parameters are shown. For this first optimization the values of the window to wall ratio to be tested for each facade are only three (20, 45 and 70 %) in order to limit the calculation time of the simulation. Regarding the glazing type, five types of glazing were set in the grasshopper script. In the figure 7.5 the glazing properties of each glazing type are shown, namely U-value, g-value and LT value. Also, the glazing type are listed in the same order of the value (from zero to four) given to the slider in grasshopper to assign a specific glazing type to the simulation. Thus, single clear glazing is the glazing type zero, single coated glazing (ST120) is the glazing type one, etc.

Name	Glazing type	U-value	g-value	LT value
0	Single clear glazing	5.8	0.8	0.9
1	Single coated glazing (ST120)	5.2	0.3	0.2
2	Double clear glazing	2.8	0.72	0.79
3	Double coated glazing (ST-108)	1.9	0.11	0.07
4	Double coated glazing (SKN154)	1.4	0.27	0.50

Figure 7.5: Table of the properties of the glazing types implemented in the optimization phase. At the left the number next to each glazing type refers to the number used in the optimization phase.

Variables		
Envelope properties	Wwr	[20 / 45 / 70] %
	Glazing construction: Glazing type	[0 / 1 / 2 / 3 / 4] Refer to table of glazing type to see the glazing properties of each glazing type
	Shading system	[0] Vertical Louvres [1] Horizontal Louvres [2] Internal blinds [3] Electrochromic glazing
	Shading properties	Depth: [0.1 / 0.3 / 0.6 / 0.9] m N° of shadings: [1 / 2 / 3 / 4]
Constant		
Comfort	Cooling setpoint	[24] °C
	Lighting density	[15] W/m2
	Occupancy density	[0.15] people/m2

Figure 7.6: Table of the values of the variables and the constant inputs implemented in the first optimization.

Once the variables are set, this values must be set also in ModeFrontier. The interface of ModeFrontier is shown in 7.7. The variables described in the previous paragraph are in the top part of the MF interface, where wwr_e refers to the window to wall ratio of the east facade, wwr_n to the window to wall ratio of the north facade, and so on, while the glazing type refers to the type of glazing described in the figure 7.5. Regarding the shading system, three variables are set up:

- the *shadingtype* which refers to the choice of horizontal louvres, vertical louvres or internal blinds, respectively named 0,1 and 2 in MF;
- the *numshading* which refers to the number of shading overhangs in the case of the horizontal and vertical louvres, with a range from 1 to 4 louvres.
- the *depth* which refers to the depth of the overhang, from 0.1 to 0.9 meters. Again this variable is set only in the case of the horizontal and vertical louvres.

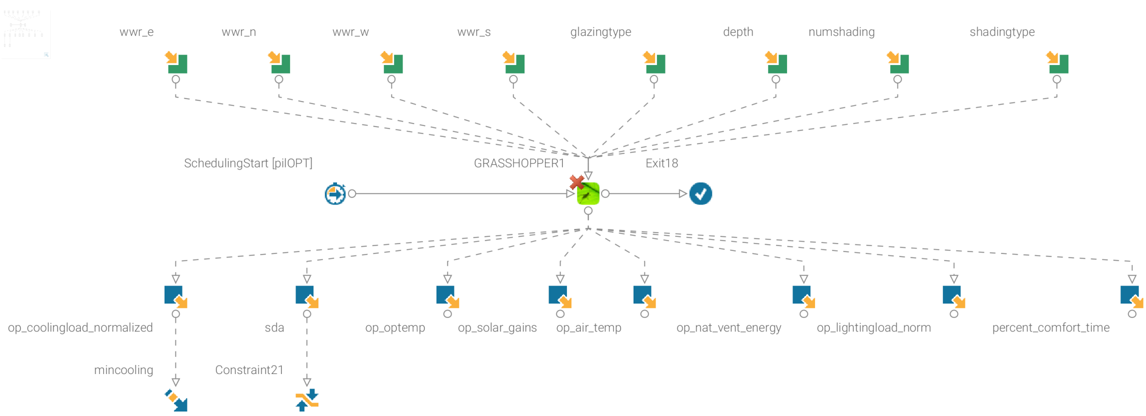

Figure 7.7: Workflow set-up of the first round of optimization in ModeFrontier

Concerning the results of the optimization, different output have been set up to understand the impact of the variables from different point of view:

- *op_coolingload_normalized:* refers to the energy consumption for cooling purposes, and it is the objective to be maximised. The unit of this output is in Kwh/m2 since the cooling load is divided by the floor area of the tested geometry.

- *sda* is the Spatial daylight autonomy, which is the percent of analysis points across the analysis area that meet or exceed the daylight illumination threshold value (set to 400 Lux) for at least 50% of the analysis period. The sda is set as a constraint, meaning that when the sda is less than 50% the design tested is defined as unfeasable.

- *op_optemp* refers to the internal operative temperature.

- *op_solar_gains* refers to the internal solar heat gains.

- *op_air_temp* is the internal air temperature. The unit is degree celsius (°C).

- *op_nat_vent_energy* is the value of the heat loss (negative value) or the heat gains (positive value) due to natural ventilation. The unit value is Kwh/m2.

- *op_lightingload_norm* is the electric lighting load needed. This output is used during the assessment of the optimization results, in order to choose a design that requires less lighting energy and thus that assures enough daylight. The unit is Kwh/m2.

- *percent_comfort_time* refers to the percentage of time for which at least 90% of the occupants are comfortable.

This first optimization is defined as single objective optimization, because the only objective to optimize is the cooling load. While the other output are used to help the designer during the decision making phase.

7.7.2. Optimization workflow: indoor comfort optimization

In this second optimization the variables set are both the envelope properties and the indoor comfort parameters, as shown in 7.8. Differently from the previous optimization setting, in this second phase the values of the window-to-wall ratio and of the shading properties are slightly different. The steps of the window-to-wall ratio are of 10%, while the steps of the depth of the shading louvres are every 0.2 meters. Concerning the indoor comfort parameters, these were set as variables in this optimization in order to observe the impact of these parameters on the energy consumption for cooling of the building. In particular, the cooling set point tested range from 24 to 30°C, every 2°C. By increasing the cooling set point temperature, thus allowing to have higher inner temperature, the use of airconditioning is decreased. Also, given the fact that in this study the adaptive comfort method is applied and that one of the output of the simulations is the percentage of comfortable time, it is important to highlight that the users comfort is taken into account. Secondly, two types of lighting density are implemented: efficient LED bulbs and incandescent heat lamps, with a value of 3 and 15 W/m2 respectively. Finally, two values of occupancy density are tested: namely 0.1 and 0.15 ppl/m2, meaning the density for a normal office and the current situation of the office respectively. These parameters are tested in order to observe the impact of factors that do not depend on the architectural concept of a building, but that indeed concern the comfort of the users.

	Variables	
Envelope properties	Wwr	[20 / 30 / 40 / 50 / 60 / 70] %
	Glazing construction	[0 / 1 / 2 / 3 / 4] Refer to table of glazing type to see the glazing properties of each glazing type
	Shading system	[0] Vertical Louvres [1] Horizontal Louvres [2] Internal blinds [3] Electrochromic glazing
	Shading properties	Depth: [0.1 / 0.3 / 0.5 / 0.7 / 0.9] m N° of shadings: [1 / 2 / 3 / 4]
Comfort	Cooling setpoint	[24 / 26 / 28 / 30] °C
	Lighting density	[3 / 15] W/m2
	Occupancy density	[0.10 / 0.15] people/m2

Figure 7.8: Table of the values of the variables implemented in the second optimization.

Once the ranges and steps of the input variables are set up, the output, objectives and constraints are established. The output are the same as the previous optimization set-up except for the introduction of the percentage of comfortable time (percent_comfort_time), to be maximized, and the percentage of time that the test points receives more than 2000 Lux (udli_2000) in order to minimize the glare probability.

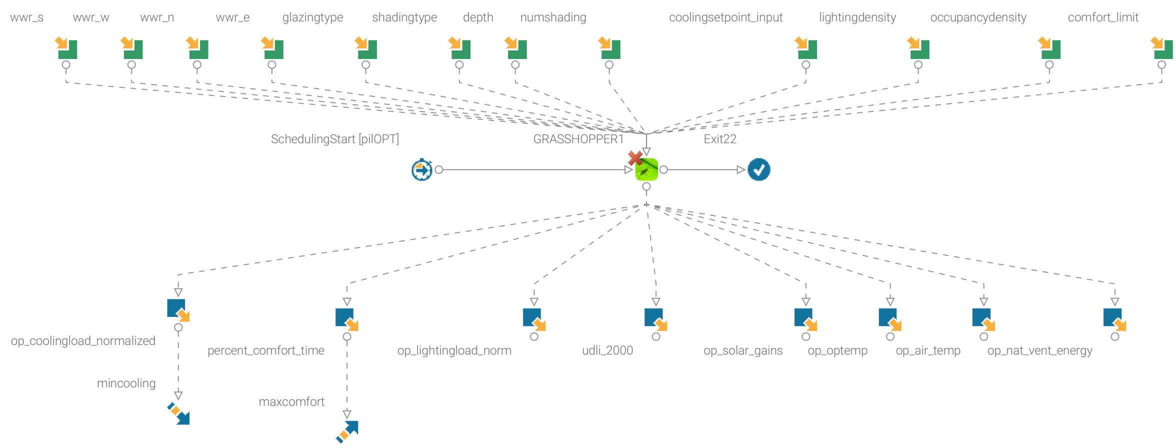

Figure 7.9: Workflow set-up of the second round of optimization in ModeFrontier

7.8. Optimization results

7.8.1. Optimization results: envelope optimization

In this paragraph the results of the first optimization are shown and discussed. As mentioned earlier, ModeFrontier [5] was chosen because of it presents an extensive variety of tools for the post processing of the results with a comprehensive environment for data analysis and visualization. Understanding the outcome of the optimization, and thus understanding the relations between the design variables and the impact of those on the performance indicators is essential for the design decision making step. ModeFrontier offers different types of visualization analysis: design charts, statistical charts, distribution analysis charts, sensitivity charts, RSM charts, MCDM charts, Clustering charts, PCA charts and

MDS charts. For this research only the design charts and the statistical charts are used. The former are basic post-processing tools for the visualization of trends, distribution and density of the design solutions in the design space [5]. This type of visualization includes bubble chart, scatter chart, parallel coordinates chart, etc. ModeFrontier offers several statistical charts, in order to assess distributions, find correlations, such as the correlation matrix chart, scatter matrix chart, DOE main effects and others. However, although ModeFrontier provides advanced charts with sophisticated statistical analysis, because of the basic knowledge on statistical analysis, these charts are used exclusively to to identify the most significant variables. In particular the process followed to read the results of the optimization is based on three steps:

- Screening the results through the **Correlation matrix chart**: this chart shows the direct and indirect impact of each variable on each variable or output. This chart is used to identify the variables that have the highest impact on the output of the study. It is not necessarily taken into account the numerical value of the strength of correlation of the parameters since it might be needed a further understanding of statistical knowledge, which is out of the scope of this research.
- Screening the results through the **bubble chart**: choosing two outputs for the X and Y axis, and then a third variable for the color code of the points in the chart help to see the behaviour of each design with respect to three aspects.
- Selecting the final design through the **parallel coordinates chart**, after limiting the ranges of the variables with less impact on the final outcome.

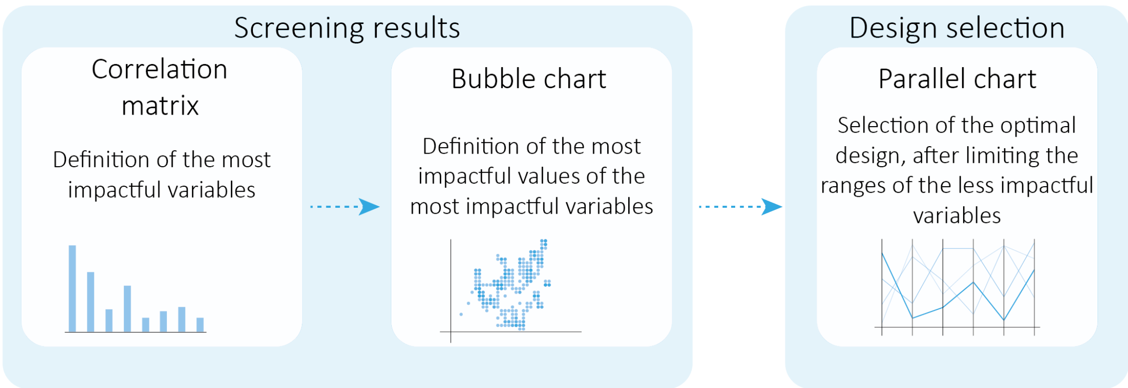

Figure 7.10: Process followed to analyse the results of the optimization through three graph types of Modefrontier, respectively Correlation matrix, bubble chart and parallel chart

In the following three graphs (7.12, 7.13 and 7.14) it is possible to observe the direct and indirect impact of each variables on the output selected, namely cooling load, electric lighting load and spatial daylight autonomy (sda). In order to be able to evaluate the significance of the impact of a specific variable on the outputs of the simulations in 7.11 it is shown the threshold of strength of association between two parameters. In particular, if the correlation is between (+/-)0.1 and (+/-)0.3 the strength of association is low, between (+/-)0.3 and (+/-)0.5 it is medium and finally between (+/-)0.6 and (+/-)1.0 the strength of correlation is high.

Strength of association	Direct correlation	Indirect correlation
Low	0.1 to 0.3	-0.1 to -0.3
Medium	0.3 to 0.5	-0.3 to -0.5
High	0.6 to 1.0	-0.6 to -1.0

Figure 7.11: Guideline in order to define the strength of a correlation between two variables with the Pearson Correlation. Source: ModeFrontier User guide

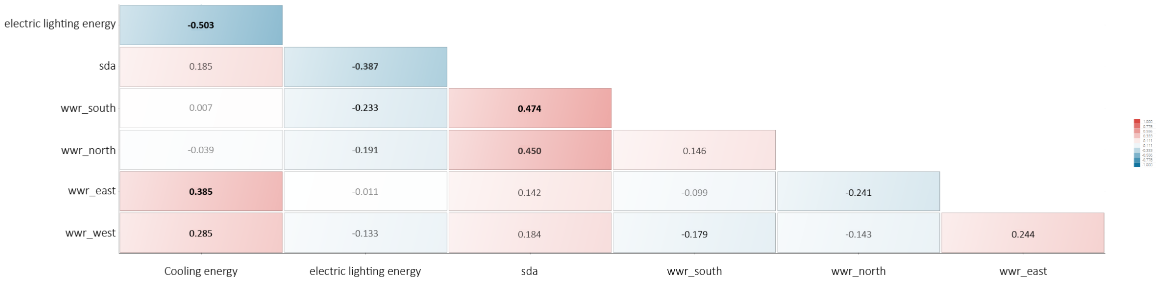

Figure 7.12: : The correlation matrix shows the Pearson relation between the variables (Window to wall ratio) and the outputs of the optimization (exported by ModeFRONTIER2019R2)

In 7.12 only the variable of the window to wall ratio for each facade is selected. This graph can be read throughout a color code, the most intense read means highest direct correlation, thus increasing of the two values, while intense blue means highest indirect correlation, thus increase of one value and decreasing of the other. The second way to read the graph is numerically, through the value of the correlation. It is visible that the variable that has the highest direct impact on the cooling consumption is the wwr_east and the wwr_west, with a value of 0.385 and 0.285 respectively on a maximum value of 1. The direct correlation means that the increase of the value of one parameter (for instance the wwr of the east facade) lead to the increase of the cooling consumption with a correlation value of 0.385. On the other hand, it was expected an indirect correlation between cooling consumption and electric lighting energy, at the increasing of one, the other would decrease. Another expected result, is the low impact of the window to wall ratio of the north and south facades for the cooling consumption, but a relative high impact oh the electric lighting energy and a high impact on the Sda.

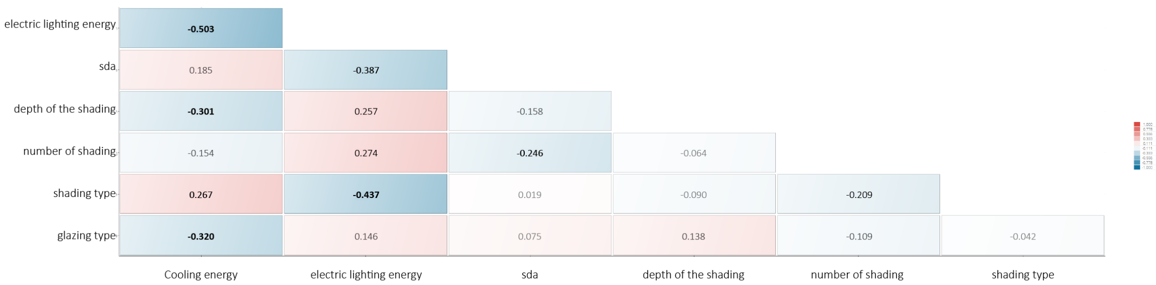

Figure 7.13: : The correlation matrix shows the Pearson relation between the variables (glazing and shading type and properties of the shading) and the outputs of the optimization (exported by ModeFRONTIER2019R2)

In 7.13 only the variables linked to the properties of the envelope are taken into account, namely the glazing type, the shading type and the properties of the shading device (number of overhangs and depth of the shading device). Concerning the cooling consumption, it is clear that the glazing type has the highest impact, meaning that the choice of the glazing can reduce or increase the cooling consumption. If it is a indirect or direct correlation in this case it is not visible, since the values of the variable of the glazing depends on the way they were listed and not on the properties of the glazing it self, as showed in 7.5. Regarding the shading system the depth of the overhang has a medium strength of correlation with the energy needed for cooling, in particular the deeper is the shading the lower is the energy consumption for cooling. Also, the choice of the shading type has an impact of 0.267 out of 1 for the cooling consumption, while it has the highest impact for the lighting energy, with a value of 0.437 out of 1. Regarding the electric lighting energy, the depth of the shading and the number of louvers have a medium impact of approximately 0.257 and 0.274. A final correlation matrix graph is shown to compare the overall impact of each variables on the Cooling load. As expected the wwr of the east facade is the highest impact on the cooling load, followed by the choice of the glazing type, the depth of the shading system, the shading type and finally by the wwr of the west facade. Thus, the wwr of the north and south facade can be neglected for the second optimization, with regards to the cooling consumption.

	Cooling energy	wwr_south	wwr_north	wwr_east	shading type	number of shading	glazing type	depth of the shading
wwr_south	0.007							
wwr_north	-0.039	0.146						
wwr_east	0.385	-0.099	-0.241					
shading type	0.267	0.028	0.028	-0.058				
number of shading	-0.154	-0.120	-0.004	0.114	-0.209			
glazing type	-0.320	0.169	0.079	-0.096	-0.042	-0.109		
depth of the shading	-0.301	0.114	0.057	-0.077	-0.090	-0.064	0.138	
wwr_west	0.285	-0.179	-0.143	0.244	0.098	0.011	-0.163	-0.017

Figure 7.14: : The correlation matrix shows the Pearson relation between the variables and the outputs of the optimization (exported by ModeFRONTIER2019R2)

As showed in the correlation matrix chart 7.14 the facade with the higher impact and the one with the lower impact are respectively the east and north facade. In order to understand their different impact, the charts 7.15 and 7.16 show the window to wall ratio for the north and east facade of each design solution. As expected, the north facade allows for a higher window to wall ratio as it can be noticed by the amount of red dots. Different is the case of the east facade, which present a more variegated range of values of window to wall ratio. However, in the chart 7.16 four design solution are highlighted because of the high window to wall ratio and low cooling energy. These designs are analysed in the table 7.18 from which it is possible to understand that although it is possible to implement a high window to wall ratio for all the facades, it is needed to implement as well a shading system of a depth between 0.5 and 0.9 meters.

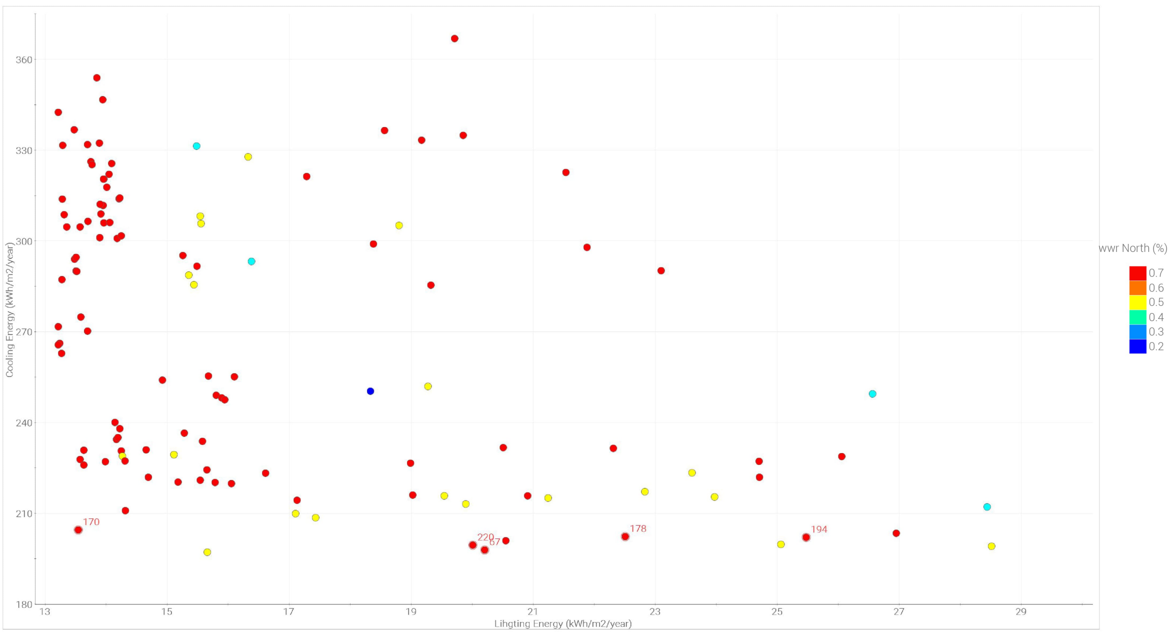

Figure 7.15: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the window to wall ratio of the North facade.(exported by ModeFRONTIER2019R2).

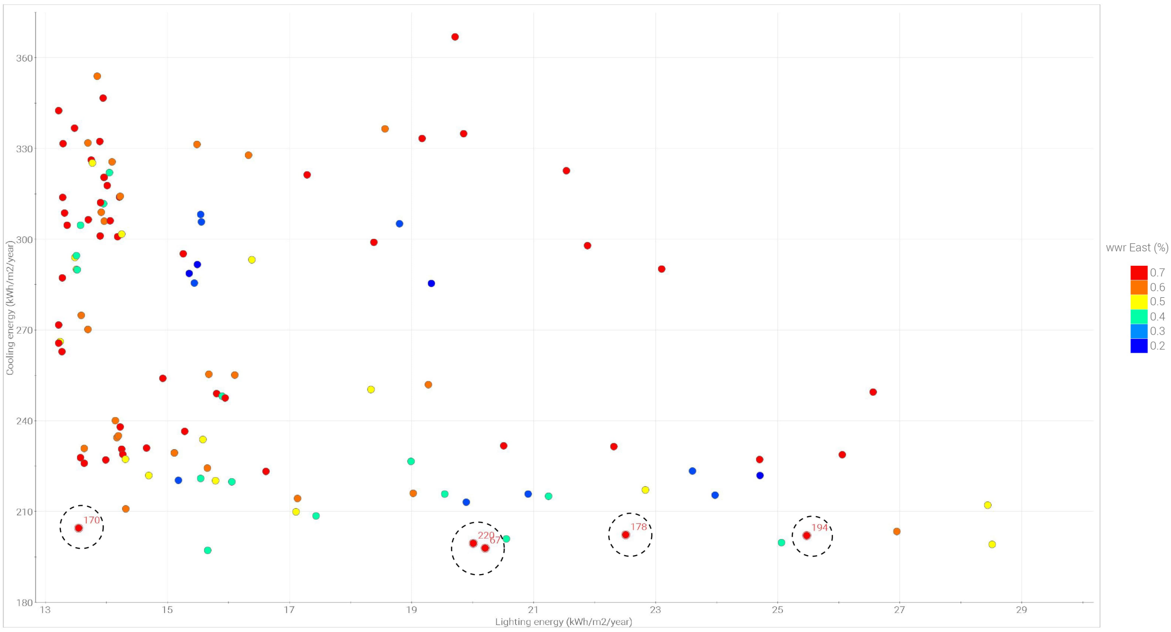

Figure 7.16: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the window to wall ratio of the East facade. In the chart the designs with the lowest cooling demand and with the highest value of wwr are highlighted and discussed. (exported by ModeFRONTIER2019R2).

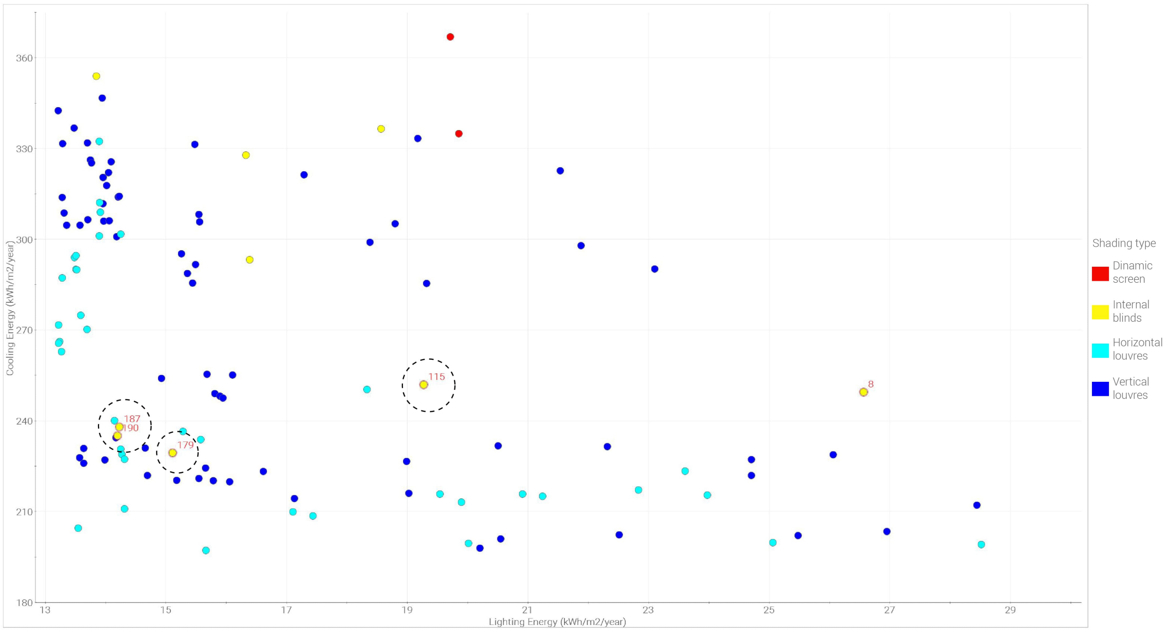

Figure 7.17: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the shading type. In the chart the designs with the lowest cooling demand and with no external shading louvres are highlighted and discussed. (exported by ModeFRONTIER2019R2).

Concerning the shading system, the charts 7.17, 7.20 and 7.21 show respectively the type of shading, the number of external louvres and the depth of the shading elements for each design solution. As it can be noticed from the chart about the shading type, the vertical and horizontal were the shading type the most tested by the optimization algorithm. However, there are some cases which use internal blinds and that lead to a relatively low cooling consumption with respect to the overall design solution range. These design solutions are analysed in the table 7.19. It can be noticed that these design solutions differs in the percentage of window to wall ratio and the glazing type. Also, if the results of this table are compared with the results in the table 7.18 it is possible to understand the impact on the cooling energy needed for designs with external shading and internal blinds. Finally, the last two charts are mainly about the characteristics of the external shading system implemented, number of louvers and depth of the overhangs. In it is interesting to read these two charts simultaneously since these two factors depends on each other. In fact, in the table 7.22 four design solutions that are highlighted in the two charts are further analysed, in order to understand the trade-off between the number of external louvres, the depth of the latter and other variables in order to achieve the lower values of cooling consumption. In particular, if compared the last two designs (n°1 and n°67), it can be noticed that a similar energy consumption for cooling can be achieved either by implementing a high number of external louvres with a low depth and reducing the window to wall ratio for all the facades (as the design n°1) or by implementing only one overhang with a high depth with a fully transparent facade (as the design n°67).

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
170	70%	70%	70%	70%	4	horizontal	2	0.9	0.15	15	24	204
178	70%	70%	70%	70%	3	vertical	2	0.5	0.15	15	24	202
220	70%	40%	70%	40%	4	horizontal	4	0.5	0.15	15	24	199
67	70%	70%	70%	70%	3	vertical	1	0.9	0.15	15	24	197

Figure 7.18: Table summarizing the four designs selected in the previous chart.

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
115	60%	50%	60%	60%	1	internal blinds			0.15	15	24	251
187	70%	70%	70%	70%	4	internal blinds			0.15	15	24	237
179	60%	60%	60%	60%	4	internal blinds			0.15	15	24	229

Figure 7.19: Table summarizing the three design selected in the previous chart.

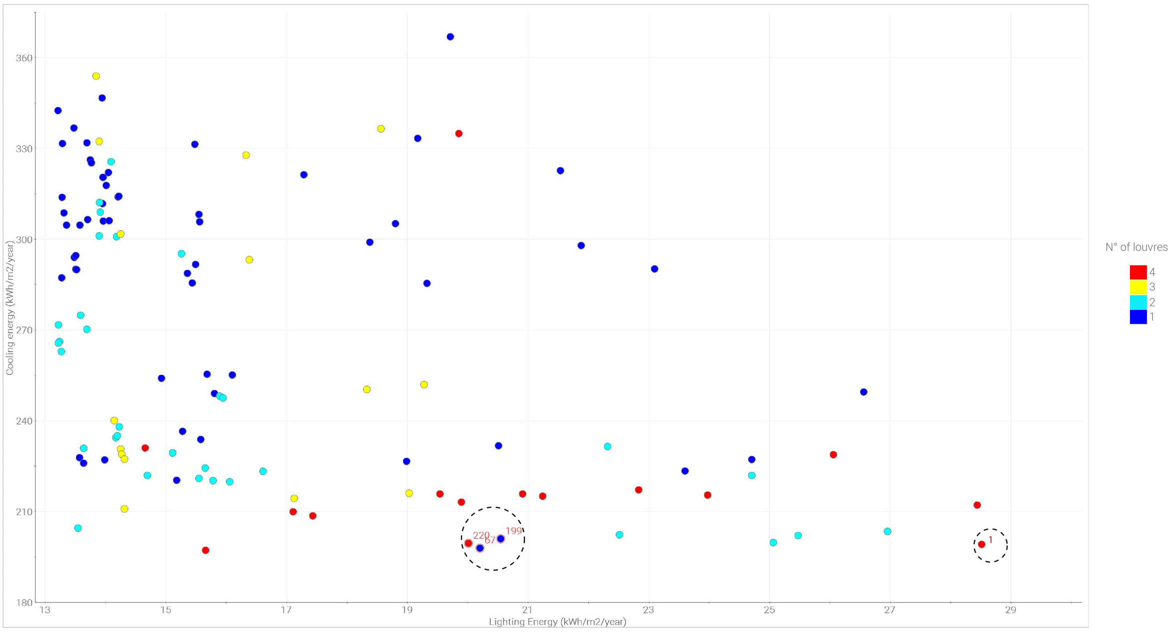

Figure 7.20: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the number of external louvres. In the chart the designs with the lowest cooling demand and with the highest and lowest value are highlighted and discussed. (exported by ModeFRONTIER2019R2).

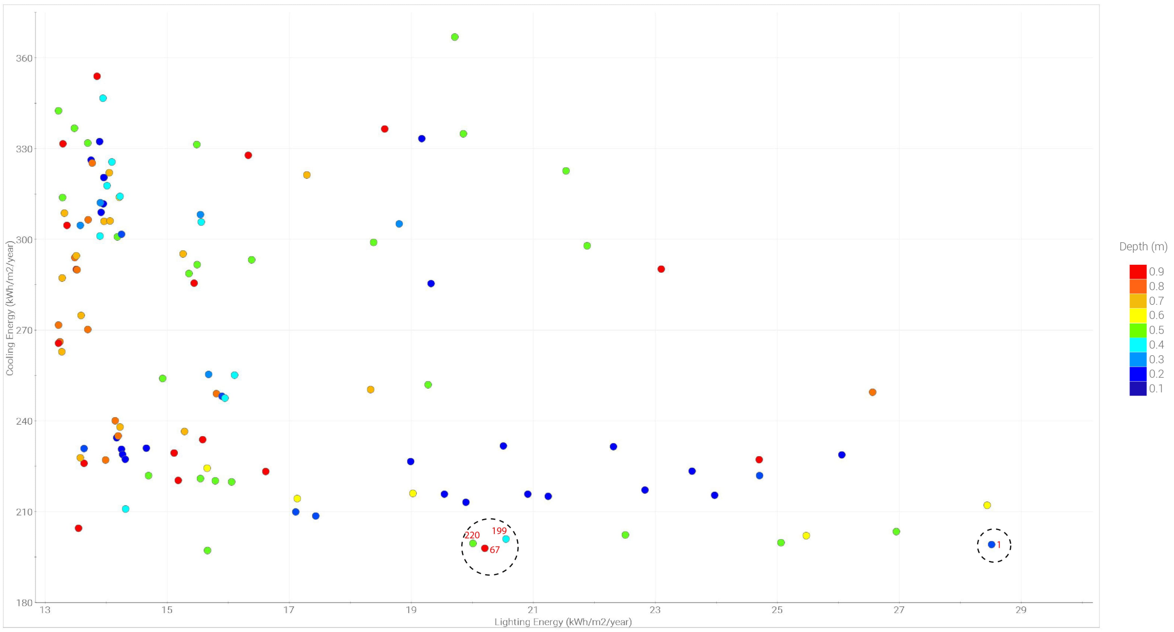

Figure 7.21: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the depth of the external louvres. In the chart the designs with the lowest cooling demand and with different value of the depth of the shading are highlighted and discussed. (exported by ModeFRONTIER2019R2).

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
199	70%	70%	40%	70%	3	vertical	1	0.4	0.15	15	24	200
200	70%	40%	70%	40%	4	horizontal	4	0.5	0.15	15	24	199
1	60%	70%	50%	40%	3	horizontal	4	0.2	0.15	15	24	199
67	70%	70%	70%	70%	3	vertical	1	0.9	0.15	15	24	197

Figure 7.22: Table summarizing the four design selected in the previous chart.

7.8.2. Optimization results: indoor comfort optimization

The results of the second optimization are observed and discussed using the same charts of the previous optimization results, namely correlation matrix chart, bubble chart and parallel coordinates chart. Out of 1070 simulations done, only 500 are taken into account and showed in the charts. This is due to the fact that only the design solutions with a spatial daylight autonomy (sda) greater than 50% were selected, in order to guarantee a minimum level of daylight in the indoor spaces. In a first phase the impact of each variable on the cooling consumption is observed throughout the correlation matrix chart, also in this case is used the ranges of strength of correlation shown in the figure 7.11. In figure 7.23 it is shown only the envelope properties and the main outputs of the simulation, namely cooling energy, electric lighting energy and percentage of comfortable time. In particular, regarding the cooling energy the variables that have a medium correlation (between +/-0.3 and +/-0.5) are the depth of the shading devices, the window to wall ratio of the west facade, the shading type, and the window to wall ration of the south facade. Surprisingly, the window to wall ratio for the east facade has a low correlation with the cooling energy (0.17 over 1.0) while the glazing type has a relatively high correlation (-0.67 over 1.0). Regarding the energy needed for electric lighting and the percentage of comfortable time, all the variables have a low impact on the first output and a totally negligible impact on the second one.

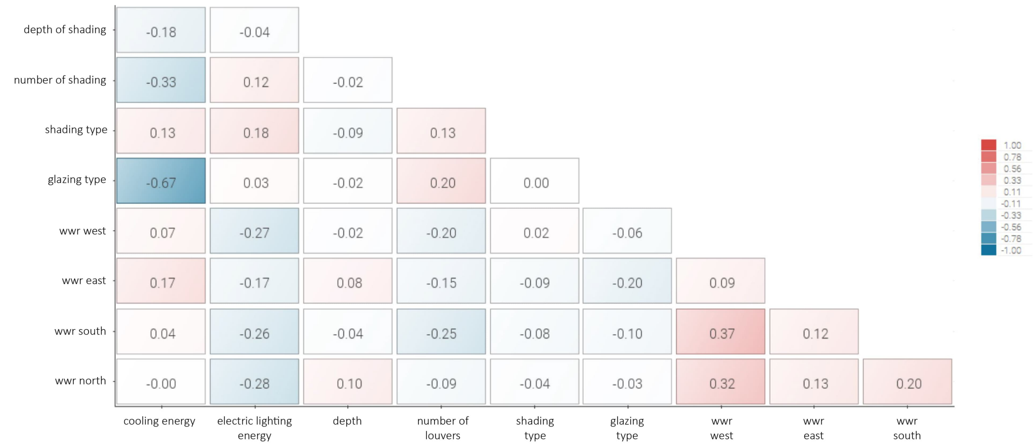

Figure 7.23: : The correlation matrix shows the Pearson relation between the variables related to envelope properties and the outputs of the optimization (exported by ModeFRONTIER2019R2)

On the other hand, in figure 7.24 it is shown the impact of the indoor comfort parameters on the outputs. In particular, it is evident that the factors with the highest impact are the cooling set point and the occupancy density respectively -0.65 and 0.45 regarding the cooling energy. While for the lighting energy, the lighting density has a strong correlation, of 0.88 out of 1.0 as expected, while the other factors can be neglected.

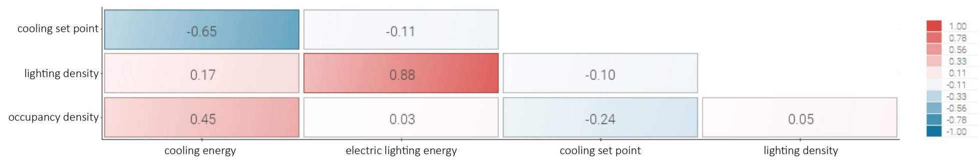

Figure 7.24: : The correlation matrix shows the Pearson relation between the variables related to indoor comfort parameters and the outputs of the optimization (exported by ModeFRONTIER2019R2)

In 7.25 it is shown a general chart showing the overall view of the impact of all the variables on the main outputs. In general, the cooling consumption turned out to be highly influenced by the indoor comfort parameters, such as cooling set point, lighting density and occupancy density, rather than by the envelope properties. However, also the latter have a certain influence, namely the depth of the shading, the window to wall ratio for the west facade, the shading type and the window to wall ratio of the south facade. Concerning the electric lighting energy only the lighting density has a high correlation. Also, in this second optimization it is taken into account also the minimization on glare probability, by minimizing the percentage of time that the daylight illuminance is higher than 2000 lux. As shown in the chart 7.25 the glare probability (named:udli>2000) is highly influenced by the window to wall ratio of the east and west facades.

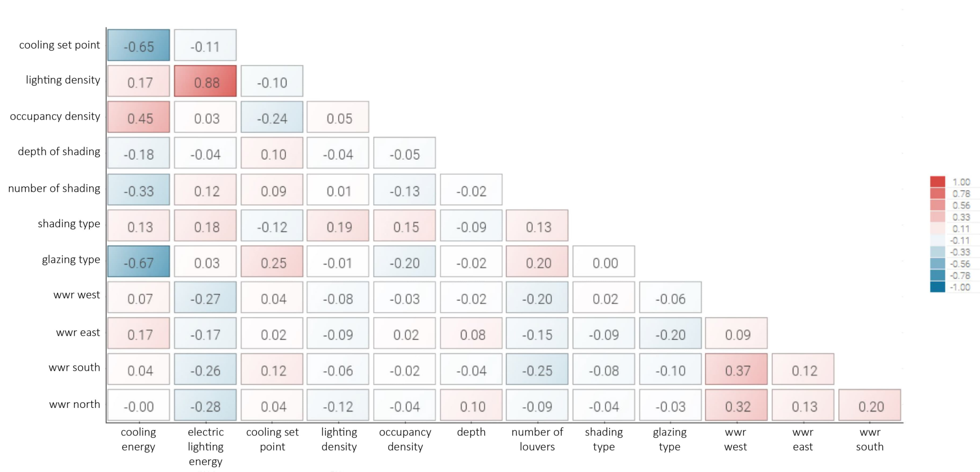

Figure 7.25: : The correlation matrix shows the Pearson relation between all the variables and the outputs of the optimization (exported by ModeFRONTIER2019R2)

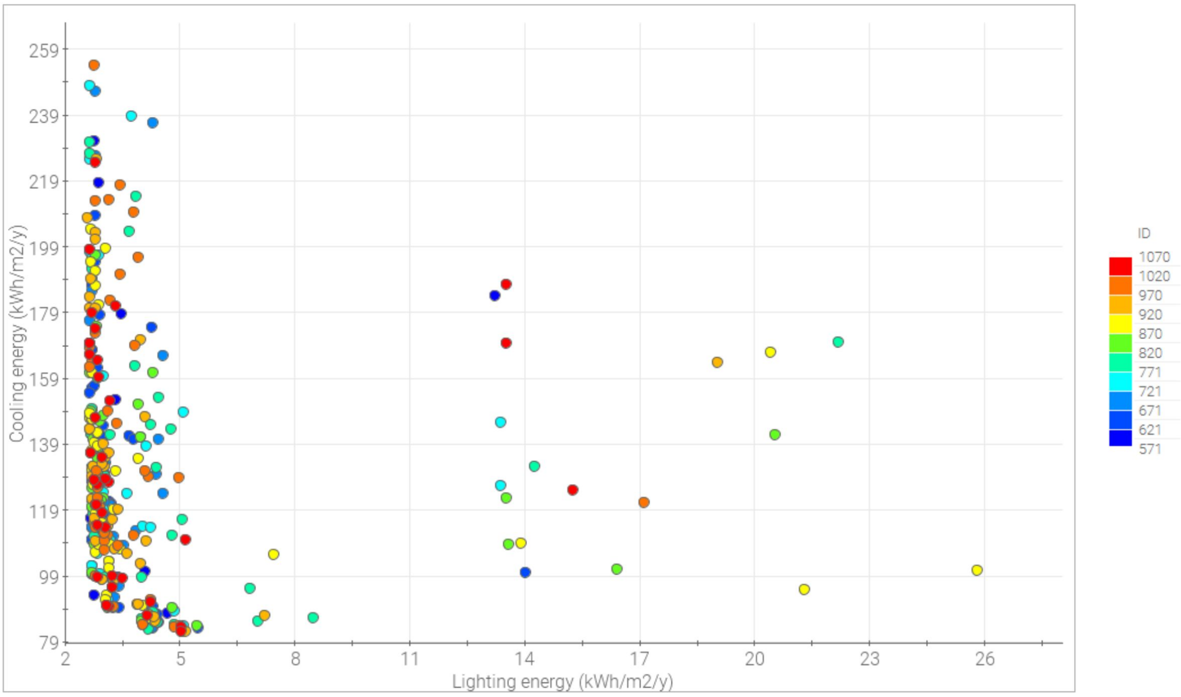

Figure 7.26: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for each design solution (exported by ModeFRONTIER2019R2).

The graph 7.26 shows the design solutions with respect to the cooling energy and the lighting energy. In the following paragraphs the different variables of the optimization will be analysed, discussing the most efficient ranges of the variables when it is possible. Also, specific cases with a special behaviour on the energy performance of the building will be discussed further. Since from the previous graphs was visible that the window to wall ratio of the East and West facade have the highest impact on the cooling consumption, it is necessary to observe more specifically the landscape of the values of this variable with respect to the cooling load and lighting load. In order to understand the impact of the East facade, the chart 7.27 shows the complete different behaviour of the North facade. In fact, if a window to wall ratio of 70% is prevailing for the north facade, both for low and high cooling energy consumption, the window to wall ratio of the east facade is definitely way more variegated as shown in the chart 7.28. In particular, the figure 7.29 shows a zoom of the previous chart, in order to observe the trend of the window to wall ratio values of the east facade for the lowest values of cooling energy. From this chart it is interesting to analyse the design solution that lead to low cooling demands still having high percentage of window to wall ratio, such as the three red dots in the bottom (designs n°992, 796 and 1029).

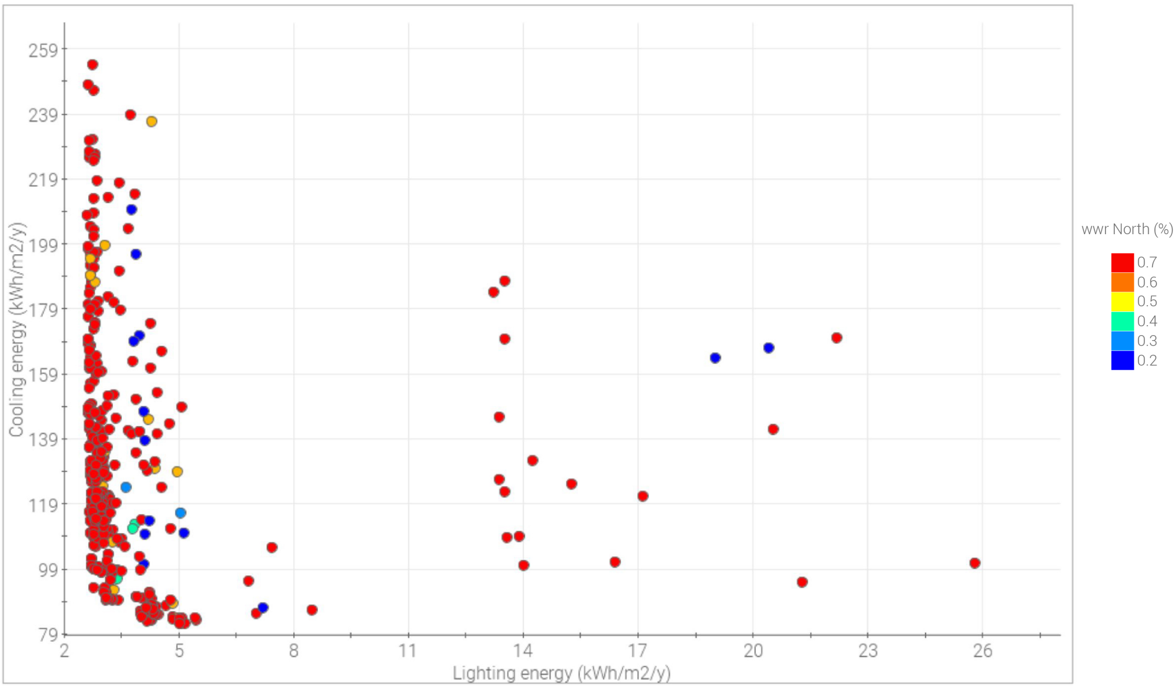

Figure 7.27: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for window to wall ratio of the North facade (exported by ModeFRONTIER2019R2).

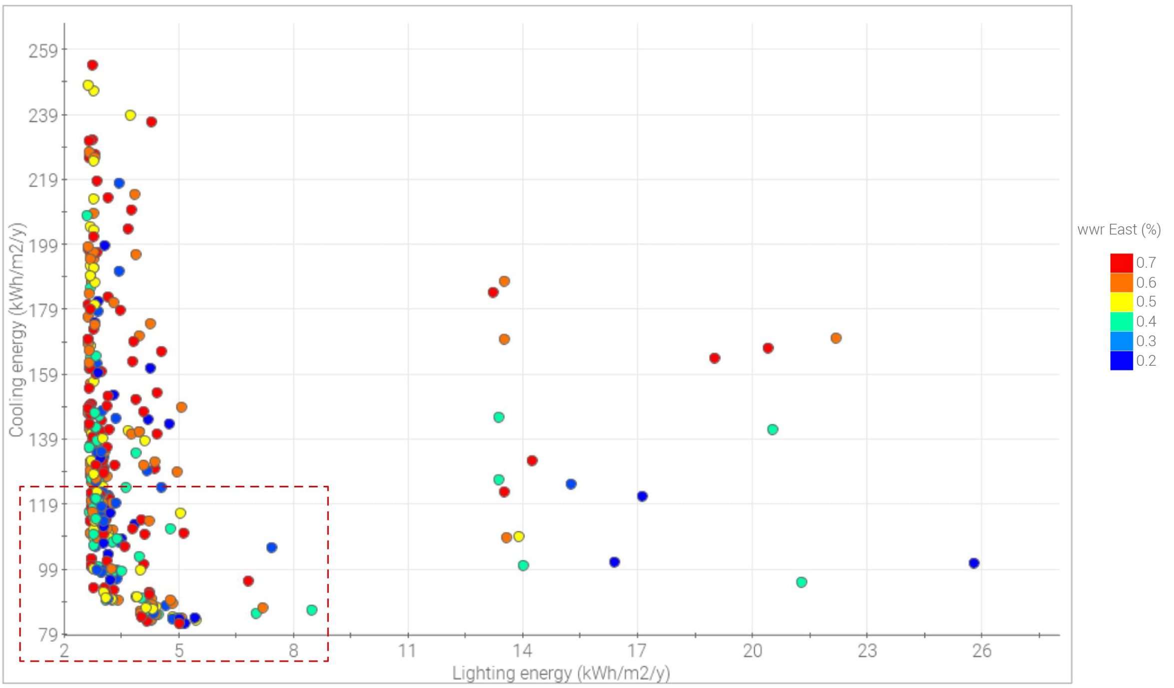

Figure 7.28: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for window to wall ratio of the East facade (exported by ModeFRONTIER2019R2).

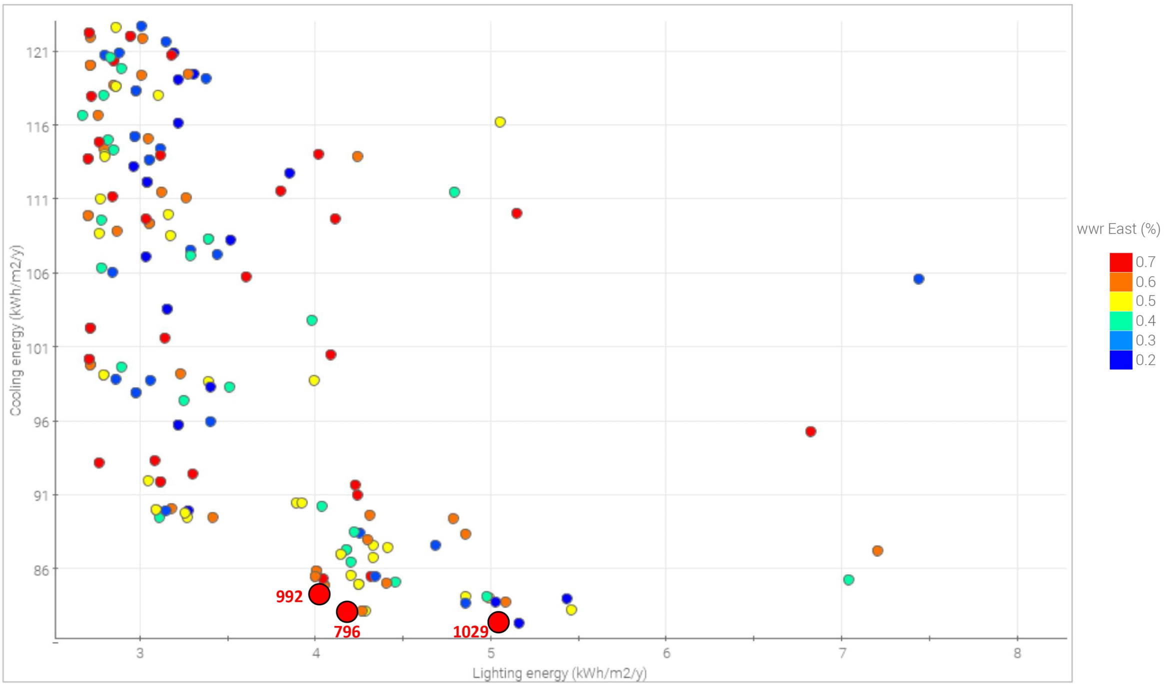

Figure 7.29: :The figure shows a zoom of the previous graph with the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for window to wall ratio of the East facade (exported by ModeFRONTIER2019R2).

The three design solutions highlighted in the chart 7.29 were selected because of the high percentage of window to wall ratio and the low energy consumption for cooling purposes. In the table 7.30 the values of the variables of each design are shown. In particular, it can be observed that all the three design solutions have the same window to wall ratio for the different facades, the same glazing type (double coated glazing ST108), same shading system and the same indoor comfort parameters. However, these designs differ for the number of external louvres and their depth.

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
1029	70%	70%	70%	70%	3	horizontal	3	0.9	0.1	3	30	82
796	70%	70%	70%	70%	3	horizontal	4	0.5	0.1	3	30	83
992	70%	70%	70%	70%	3	horizontal	2	0.9	0.1	3	30	84

Figure 7.30: : Table summarizing the selected designs (n°1029, 796 and 992) in the previous bubble chart.

The chart 7.31 shows the glazing types applied in each design solution with respect to the cooling and lighting energy. In particular in the chart 7.32 the most beneficial glazing types are respectively the double coated glazing (ST108), double coated glazing (SKN154) and the single coated glazing (ST120).

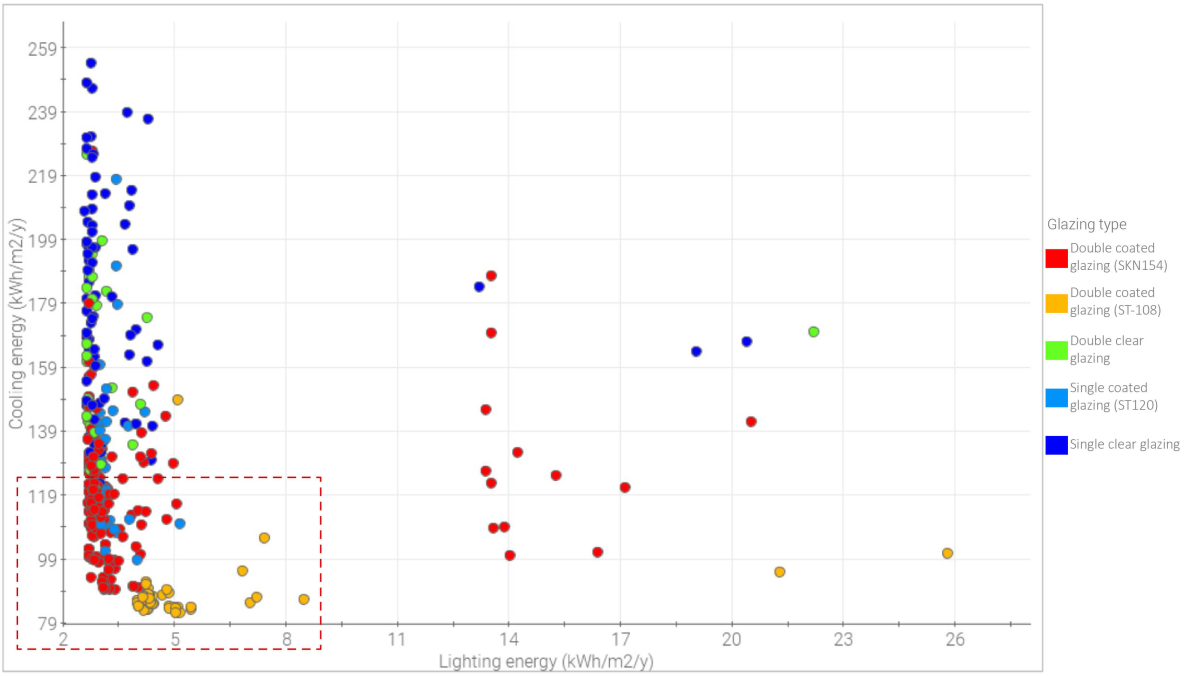

Figure 7.31: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the glazing type (exported by ModeFRONTIER2019R2).

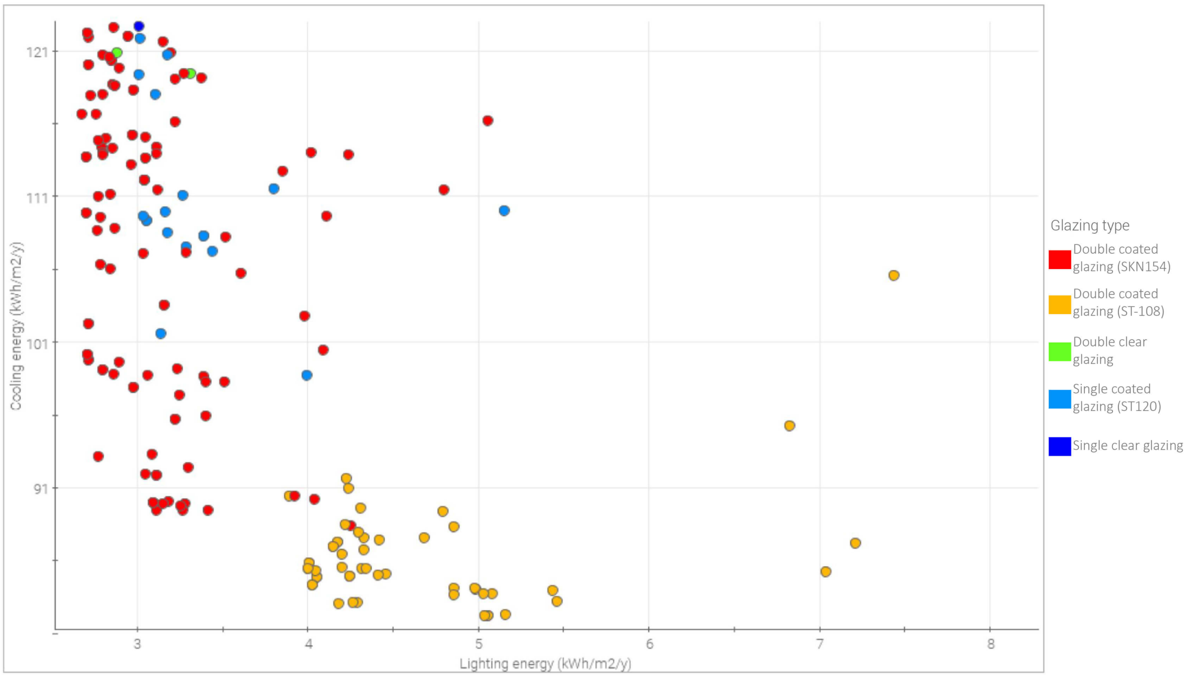

Figure 7.32: :The figure shows a zoom of the previous graph with the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the glazing type (exported by ModeFRONTIER2019R2).

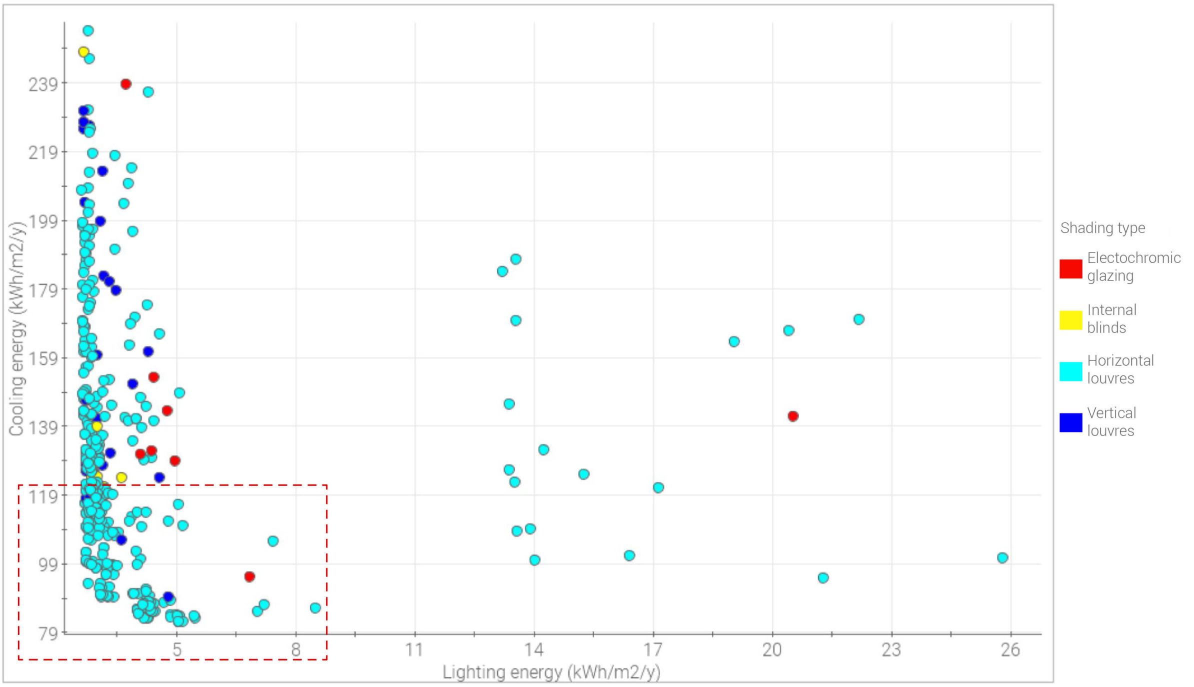

Figure 7.33: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the shading type (exported by ModeFRONTIER2019R2).

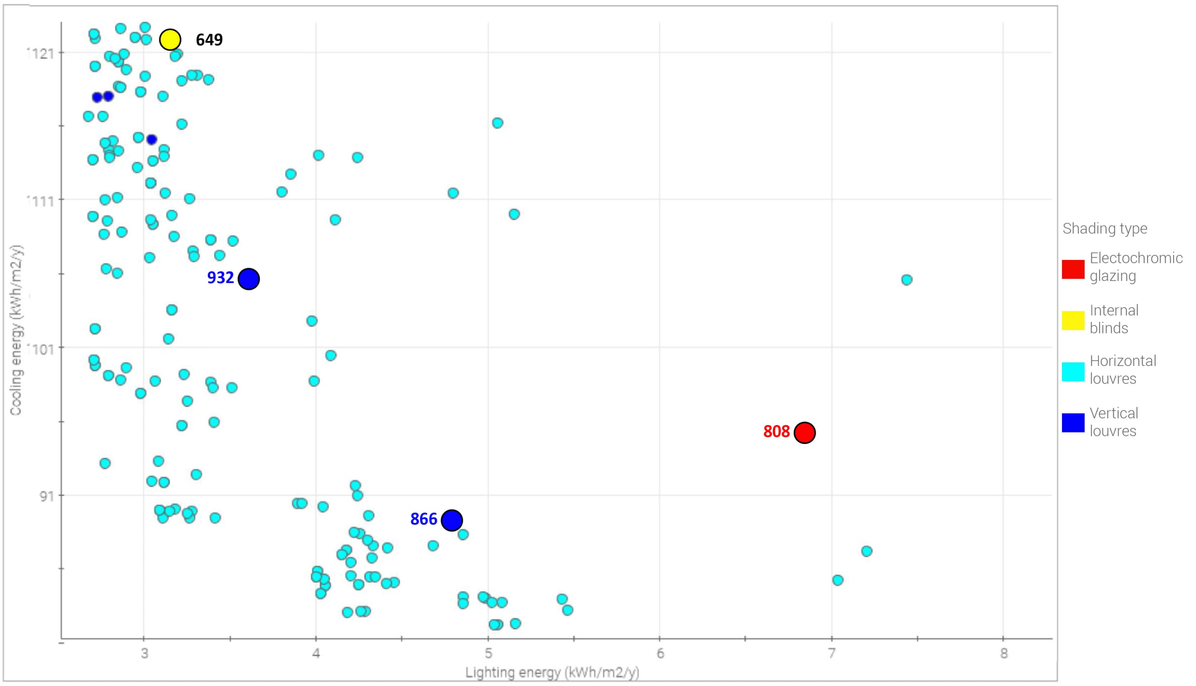

Figure 7.34: :The figure shows a zoom of the previous graph with the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the shading type. In the chart, the designs highlighted are the ones with a peculiar behaviour (exported by ModeFRONTIER2019R2).

Regarding the shading system, the horizontal louvre is the type the most performed during the optimization phase, being the most efficient shading system. However, as shown in figure 7.33 there are some cases in which a low cooling consumption is reached even with other types of shading. For instance, the lowest blue dot in the chart (design n°866, refer to the table in the appendix for more details) represent a design solution with a cooling demand of roughly 90 kWh/m2/year with vertical louvres, while the red dot (design n°808) on the bottom right of the chart represent a design with electrochromic glazing. Also, on the top left part of the chart, it is represented a design (design n°649) with internal blinds, which reach a cooling consumption of 121 kWh/m2/year. In the table 7.35 the design highlighted in the chart 7.34 are displayed with the specifications of all the variables. These designs have the same internal loads and schedules and similar values for the window to wall ratios of the four facades, but they are characterized by a different shading system and also different lighting energy consumption.

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
866	70%	70%	60%	70%	3	vertical	2	0.5	0.1	3	30	89
808	70%	70%	70%	60%	3	electrochromic glazing			0.1	3	30	95
932	70%	70%	70%	70%	4	vertical	4	0.5	0.1	3	30	106
649	70%	70%	40%	50%	4	internal blinds			0.1	3	30	122

Figure 7.35: :Table summarizing the four selected design solutions highlighted in the previous chart.

With respect to the depth of the external louvres, the chart 7.36 shows the variety of possible dimensions of the louvres in order to achieve low level of energy consumption. As represented from the blue dots in the bottom of the chart, there are specif designs which allows external shading overhangs of 10 cm, still reaching high energy performance targets. While the chart 7.37 shows the number of external louvres assigned to each design solution. In both the charts the designs with a low depth of the overhangs and with a low range of cooling consumption are highlighted and analysed in the table 7.38. It can be noticed that the cooling energy difference between the design n°1005 and the design n°600 is of 5 kWh/m2/year, and that these two designs differs also for the number of external louvres and the percentage of window to wall ratio for the east facade. This means that if the design aims to be an energy efficient building a trade-off must be done for the number of shading louvres and the window-to-wall ratio for the east facade.

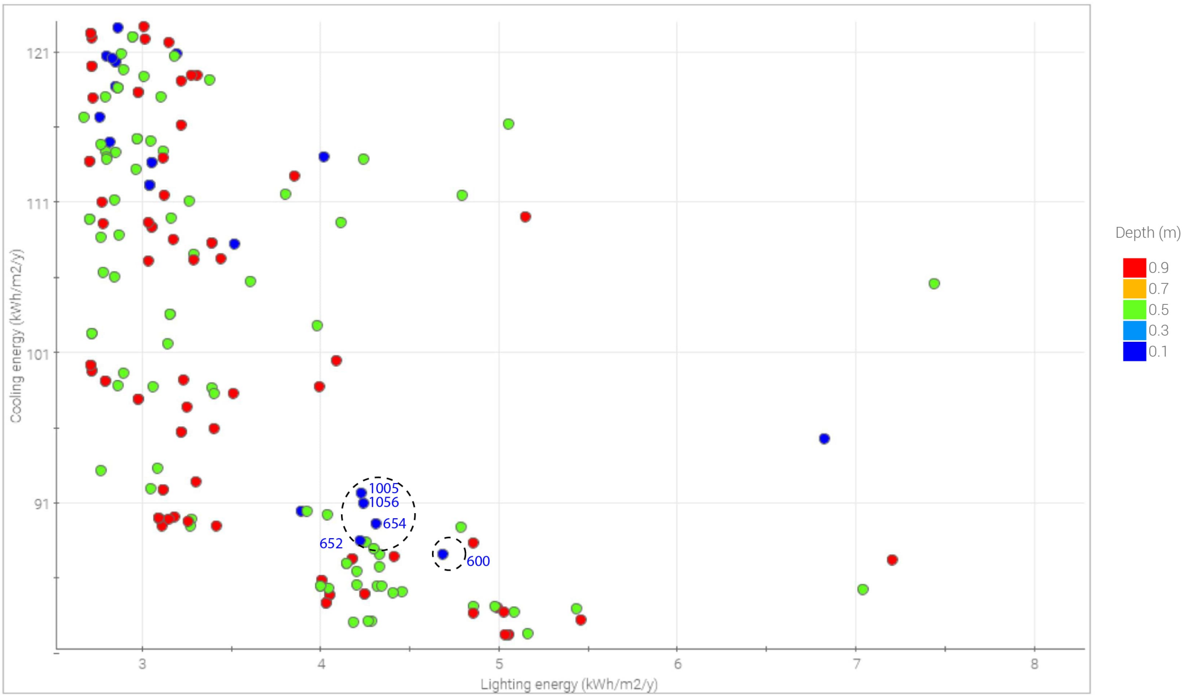

Figure 7.36: :The figure shows a zoom of the previous graph with the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the value of the depth of external shading louvers (exported by ModeFRONTIER2019R2).

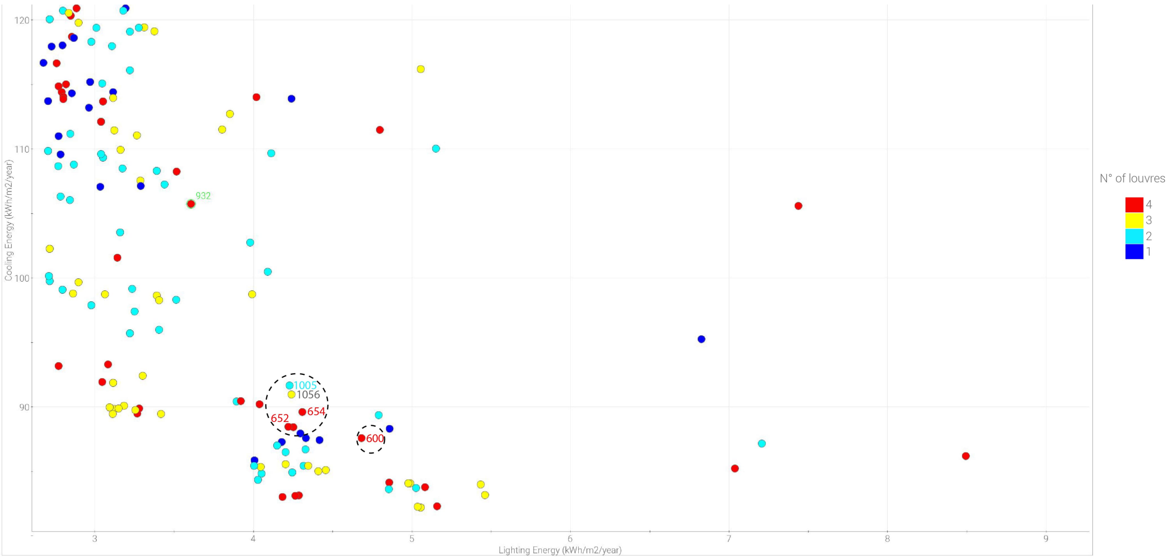

Figure 7.37: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the number of external louvers (exported by ModeFRONTIER2019R2).

In the following paragraphs there will be discussed the impact of the occupancy density, cooling set point temperature and the natural ventilation through bubble charts exported from ModeFrontier. First of all, the indoor comfort parameters with the highest impact on the cooling consumption is the cooling set point temperature. It is interesting to notice in the chart 7.44 that even the design solution with the highest cooling set point temperature lead to both low and high cooling demands. Thus, as expected the best energy performing design solutions have a cooling set point temperature of 30°C, however there are some cases which reach a cooling consumption of 111 kWh/m2/year with a cooling set point temperature of 28°C as showed in the chart 7.41.

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
1005	70%	70%	70%	70%	3	horizontal	2	0.1	0.1	3	30	92
1056	70%	70%	70%	70%	3	horizontal	3	0.1	0.1	3	30	91
654	70%	70%	60%	70%	3	horizontal	4	0.1	0.1	3	30	90
652	70%	70%	40%	70%	3	horizontal	4	0.1	0.1	3	30	88
600	70%	70%	30%	70%	3	horizontal	4	0.1	0.1	3	30	88

Figure 7.38: :Table summarizing the five design solutions with the lowest the cooling energy with an external shading system with the lowest depth.

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
921	70%	50%	30%	70%	4	horizontal	3	0.5	0.1	3	28	119
666	70%	70%	60%	70%	4	horizontal	4	0.5	0.1	3	28	114
1013	70%	70%	50%	70%	4	horizontal	4	0.5	0.1	3	28	114
953	70%	70%	70%	70%	4	horizontal	3	0.9	0.1	3	28	114
690	50%	70%	20%	70%	4	horizontal	3	0.9	0.1	3	28	113

Figure 7.39: : Table summarizing the five design solutions with the lowest the cooling energy with cooling set point temperature of 28°C.

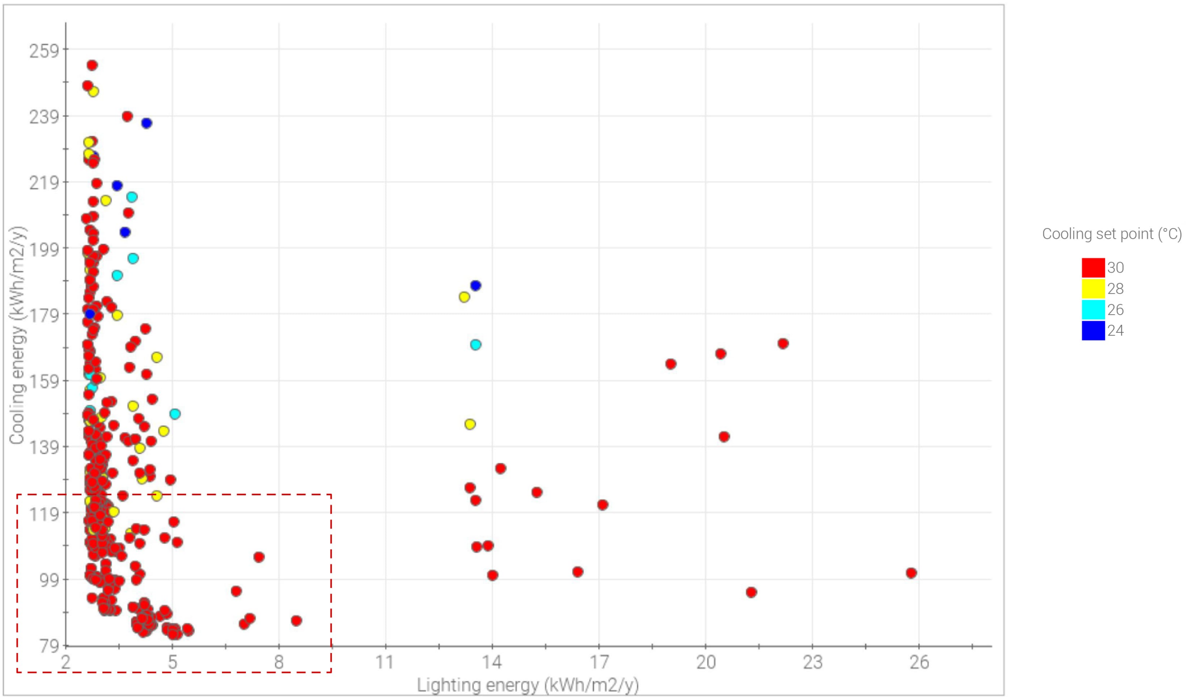

Figure 7.40: : The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the value of the cooling set point (exported by ModeFRONTIER2019R2).

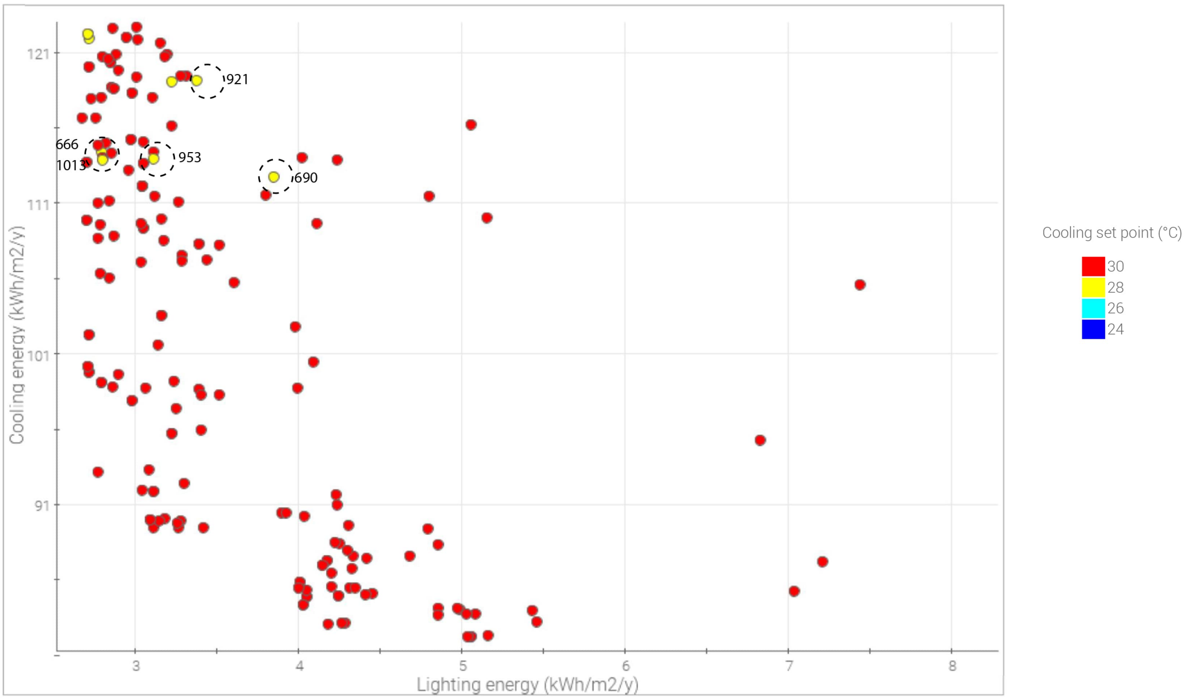

Figure 7.41: :The figure shows a zoom of the previous graph with the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the value of the cooling set point (exported by ModeFRONTIER2019R2).

Different from the previous charts, the chart 7.42 shows the position of the design solutions with respect to the cooling energy required and the mean operative temperature. This type of chart shows the ranges of cooling energy needed and the ranges of operative temperature for each temperature of cooling set point. As expected the group of design with a cooling set point of 30°C reach the lowest values of cooling energy but also the highest values of operative temperature. Thus, at this point it is important to find a trade-off between the comfort of the users and the energy consumption of the building. Three designs are highlighted in the chart 7.42 and are analysed in the table 7.43. These design have three different cooling set point temperature (26, 28 and 30°C) and differs for the cooling energy required. However, the three designs have a small difference in operative temperature between each other, 1°C difference between the design n°798 and the design n°515, and around 0.5°C between the design n°515 and the design n°1044.

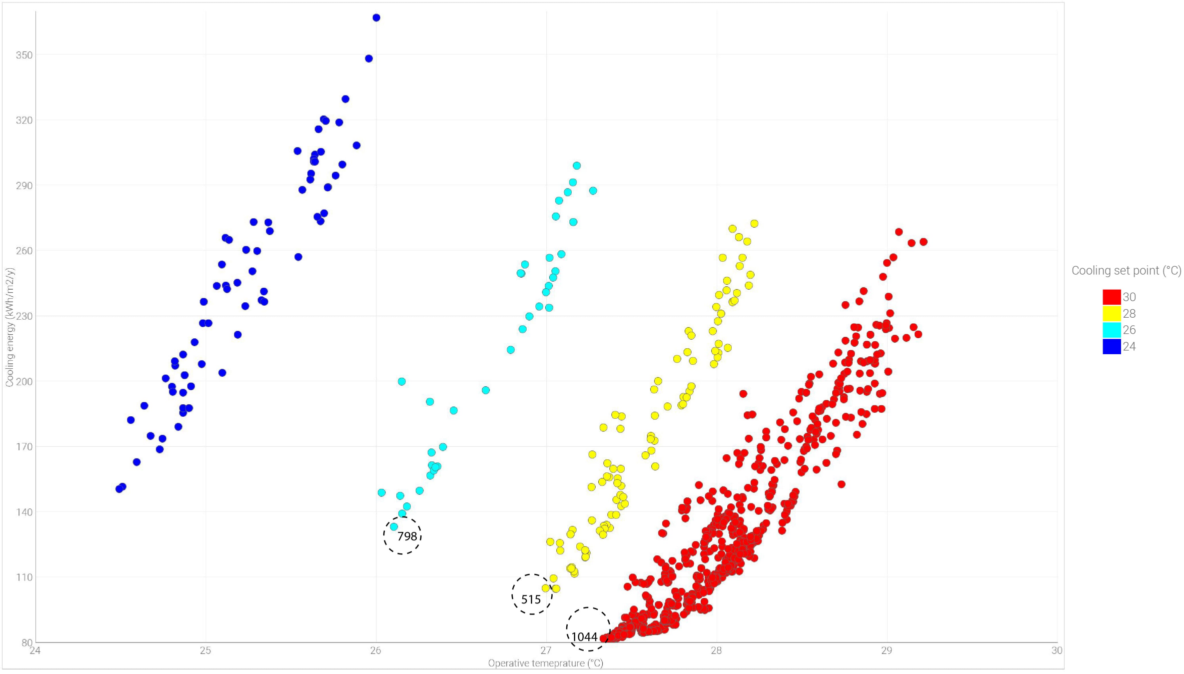

Figure 7.42: :The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the operative temperature with a color code for the value of the cooling set point (exported by ModeFRONTIER2019R2).

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
1044	70%	70%	70%	70%	3	horizontal	4	0.9	0.1	3	30	82
515	70%	70%	40%	70%	3	horizontal	2	0.5	0.1	3	28	105
798	60%	70%	70%	60%	4	horizontal	4	0.9	0.1	3	26	133

Figure 7.43: : Table summarizing the three design solutions selected with the lowest cooling energy and with different cooling set point temperature.

Another factor with a relevant impact on the cooling consumption is the occupancy density applied. Two values of occupancy density are tested: 0.15 ppl/m as the current situation of the office and 0.10 ppl/m2 as the density of a common office. As shown in figure 7.44 it is visible that the amount of blue dots (designs with the lowest density) is higher than that of red dots, meaning that the algorithm has identified the combination of values of variables near to the optimal solution with an occupancy density of 0.10 ppl/m2. Also, the right-bottom region is dense with designs with the lowest energy consumption for cooling with the lowest occupancy density value. Finally, another interesting factor to observe is the impact of the natural ventilation in the reduction of cooling consumption. In the current design of the case study, there is no natural ventilation strategy implemented. However, since during the literature research it was found that natural ventilation is one the main strategies applied in Bioclimatic architecture and since the adaptive comfort model is applied as well, it is relevant to discuss the heat loss achieved through natural ventilation means. The natural ventilation is simulated in a way that the maximum outdoor temperature for which natural ventilation is allowed is the same temperature of the cooling set point. Thus, if the cooling set point temperature is 30°C then the natural ventilation would be implemented only if the outdoor temperature is less then 30°C, and so on.

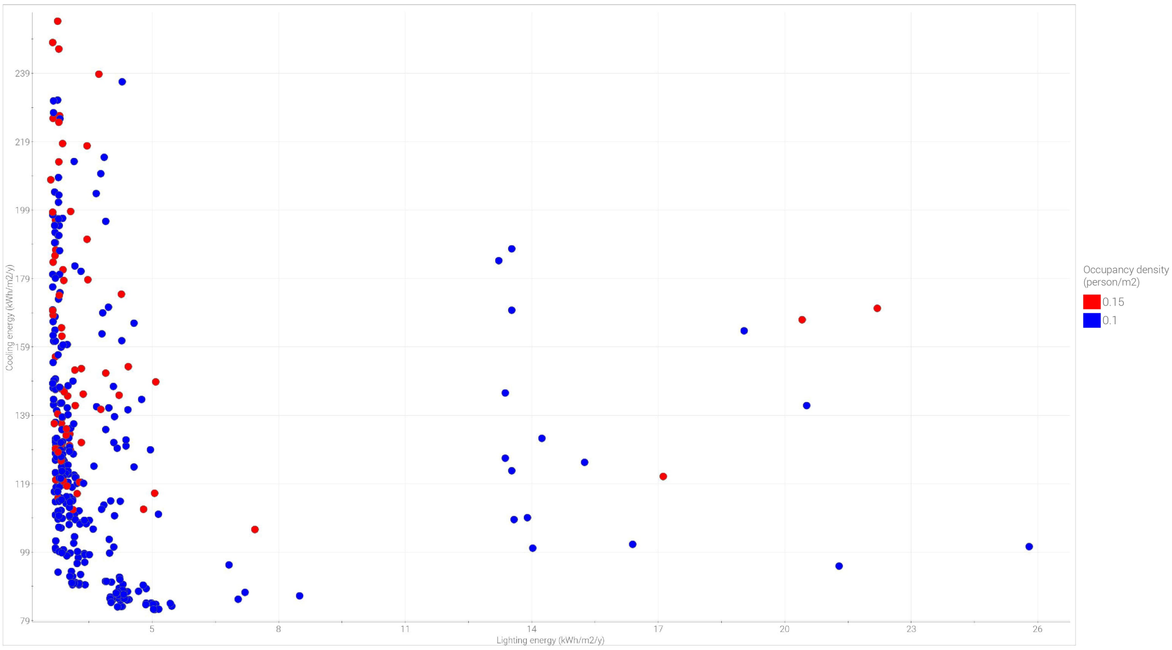

Figure 7.44: : The graph shows the landscape of design solutions and the respective position with respect to cooling energy and the lighting energy with a color code for the value of the occupancy density (exported by ModeFRONTIER2019R2).

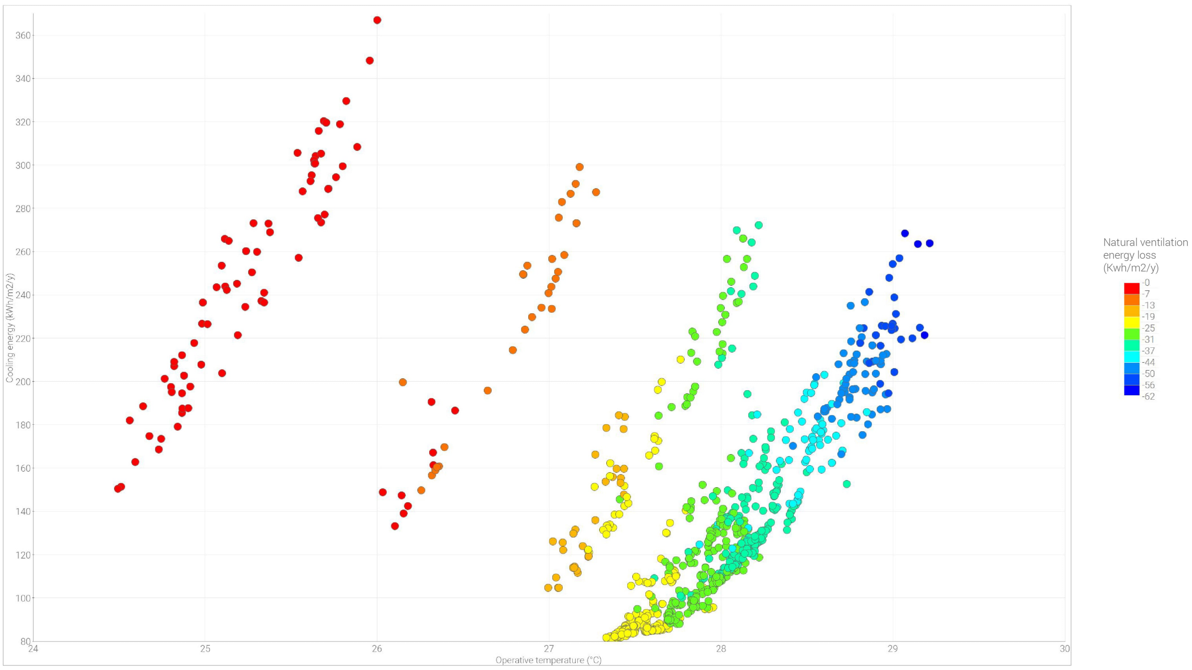

Figure 7.45: : The graph shows the landscape of design solutions and the respective position with respect to cooling energy and operative temperature with a color code for the value of the heat loss for the natural ventilation means (exported by ModeFRONTIER2019R2).

As shown in figure 7.45 the heat loss range from 0 to 62 Kwh/m2/y, where the highest values are reached in the designs plotted in the right-bottom part of the chart. In particular, it is interesting to notice that the designs with the lowest cooling consumption are not necessarily the designs with the highest heat losses through natural ventilation (yellow and green dots), meaning that the maximum contribution of natural ventilation is till 25 kWh/m2/y of heat losses. However, in later phases of the design process it is suggested to carry more complex and reliable computational fluid dynamics analysis.

The last type of chart used to observe and compare the results of the different designs tested during the optimization phase is the parallel chart. This is a chart for visualizing and analyzing high-dimensional and multivariate data. You can plot any number of variables and visualize the distribution of designs in variable sub-ranges (ModeFrontier, 2019).

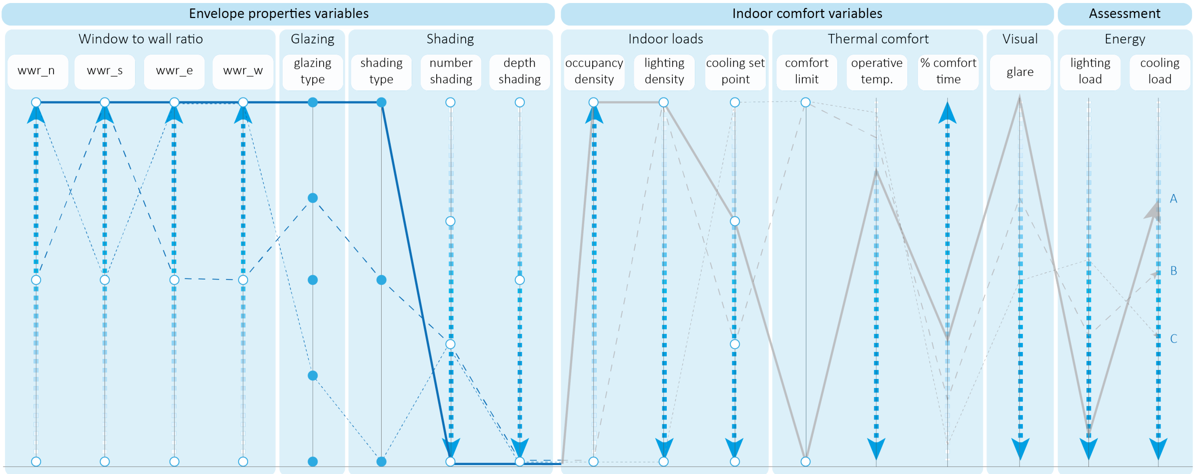

Figure 7.46: : Schematic diagram of the parallel coordinates chart showing the subdivision of the three criterias used as starting points in the guidelines in the following chapter.

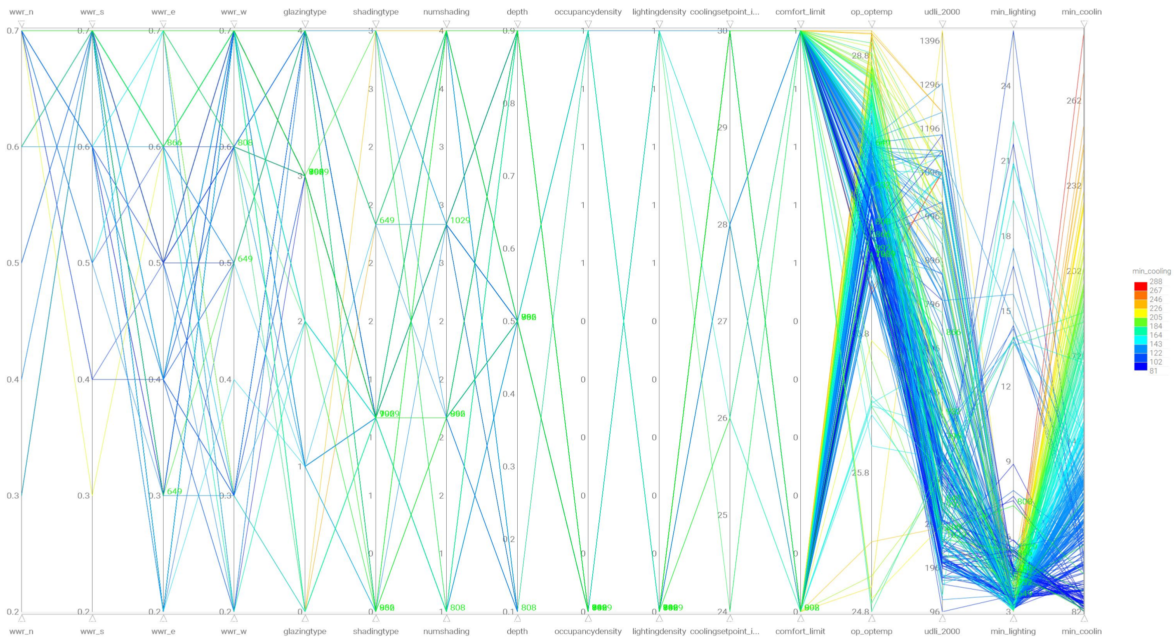

Figure 7.47: : Visualization of the parallel chart of all the 1070 design solutions calculated during the second optimization (exported by ModeFRONTIER2019R2).)

All the variables are represented and ordered horizontally, in the top horizontal line of the graph. Each variable has a vertical line in which the values of the ranges of the variables are spread, at the top and at the bottom of each axis are shown the lower and upper bounds. Then, the different designs tested are shown as horizontal polylines connecting vertices on the vertical axes, in order to highlight their values of a specific variable. In 7.46 it is shown a simplified version of the parallel coordinates chart, dividing the variables and outputs into envelope properties variables and assessment, and dividing them again into sub sections: window to wall ration, glazing, shading, comfort and energy. This subdivision highlight the freedom of the designer to filter the designs by restricting the ranges of specific set of variables focusing on the interested set of variables. In 7.47 it is shown the parallel chart with all 1070 designs tested with a color code referring to the output chosen, in this case the cooling consumption.

High values are shown in red, whereas low values are shown in blues in accordance with the color legend to the right of the chart. As is it shown in the chart, the cooling consumption of the designs tested ranges from a minimum of 81 to a maximum of 288 kWh/m2/year. This clearly proof that if the decision making of the envelope design of a building is made without taking into account the energy consumption for cooling, the latter can even be three times higher than a well thought design. Also, as shown earlier in the correlation matrix the cooling consumption and the electric lighting energy are indirectly correlated, thus at the increase of one there is the decrease of the other, and this is also clear in the parallel chart. An important feature of the Parallel Coordinates Chart is the possibility to filter designs according to a specific sub-range of variable values. In fact, it is possible to observe the filtered designs with respect to a specific parameter. In the following chapter, this type of chart will be implemented in order to filter the design space, and select specific design solutions to discuss.

7.8.3. Overall conclusion of the results

After analyzing the results of the optimization phase and discussing some cases, here are the conclusions that were drawn:

- **Cooling consumption**: In the first optimization it is observed that the cooling consumption ranges are between 368 and 193 kWh/m2/year while in the second optimization this range is definitely lower, between 288 and 81 kWh/m2/year. Thus, it is clear that the combination of envelope parameters and parameters related to the indoor comfort and internal loads leads to a more impactful solution rather than only the parameters related to the architectural design of the building.

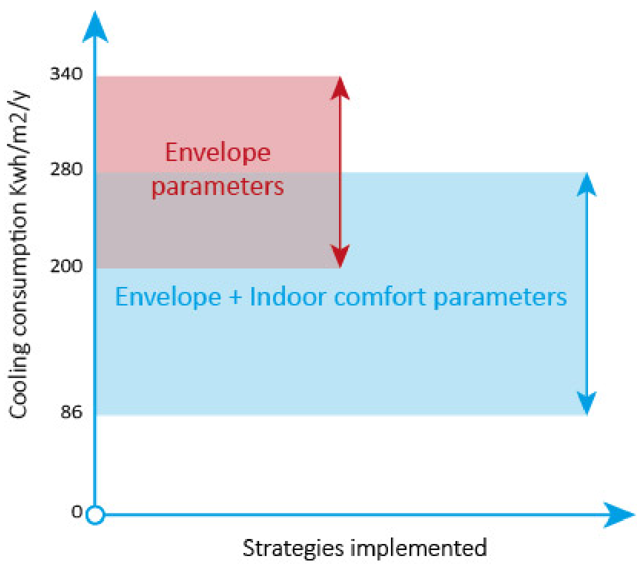

Figure 7.48: : Comparison of the ranges of cooling energy depending from envelope parameters (in red) and from envelope and indoor comfort parameters (in blue)

- **Lighting consumption**: In both the optimization it is clear that the consumption for electric lighting is definitely lower than the cooling consumption, with a range between 3 and 54 Kwh/m2/y. Thus, it is more reasonable to select a certain design for a lower cooling consumption rather than for a lower lighting consumption.

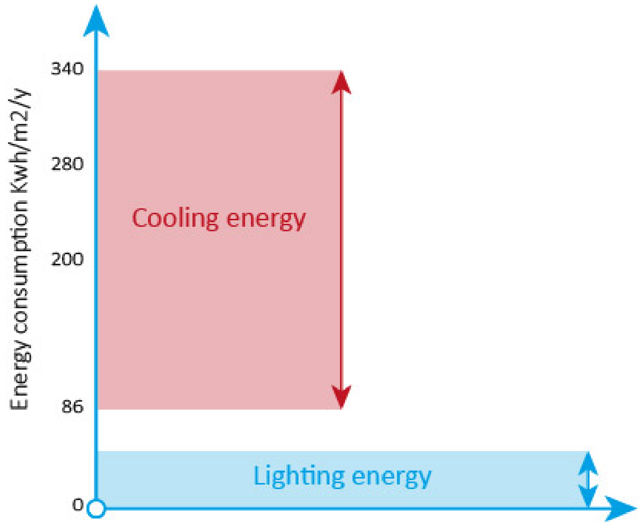

Figure 7.49: : Comparison of the ranges of cooling energy and electric lighting energy with respect to the total energy consumption.

- **Window to wall ratio**: As expected, in both the optimizations it is found out that the impact of the window to wall ration for the east and west facades is stronger than the window to wall ratio of north and south facades.
- **Glazing type** Among the five glazing type applied, from the first optimization it is found out that the most beneficial glazing types are the following:
  - Double coated glazing (ST108)
  - Double coated glazing (SKN154)
  - Single coated glazing (ST120)
- **Shading system**: From the first optimization it is clear that the external shading system is definitely more efficient than the internal blinds. As showed in the chart 7.33 the external horizontal louvres lead to the lowest cooling consumption.
- **Internal loads: Occupancy and lighting density**: Although it is predictable that lower internal loads would lead to lower energy consumption for cooling purposes, it is interesting to observe the impact of this parameter on the energy consumption of a building. As expected, the designs that lead to the lowest values of cooling consumption are the ones with the lowest occupancy density. However, it is interesting to mention that the designs with the highest occupancy density and the lowest cooling energy required, reach a cooling consumption of 120 Kwh/m2/year. Thus, if it is needed to maximize the amount of occupant per floor, it is still possible to minimize the energy consumption for cooling by implementing other strategies. The impact of the lighting density on the energy consumption for cooling purposes is the same as the occupancy density.
- **Internal schedule: cooling set point**: From the correlation matrix chart it is found out that the setting of the cooling set point is the variable with the highest correlation with the cooling consumption. Also it is clear that:
  - the amount of tested design with the highest cooling set point (30°C) is definitely higher with respect to designs with lower temperatures, meaning that the optimization algorithm has identified the optimal solution among the design with this cooling set point temperature.
  - higher cooling set point temperatures lead to lower cooling consumption. In fact, by increasing the cooling set point from 24 to 30°C and it is possible to decrease the cooling consumption from 159 to 86 Kwh/m2/y, roughly half.
  - higher cooling set point temperatures lead to higher ranges of indoor operative temperatures. However, applying the adaptive thermal comfort model is part of this research, and thus it is

one of the objectives of this study to find the optimal design that meet also indoor thermal comfort requirements. In fact, most of the designs tested turned out to reach a percentage of acceptability of 90% of the occupants, and some other design 80% of the occupants, meaning that even the highest cooling set point temperature is acceptable in tropical regions.

- **Natural ventilation**: Another objective of this research is to analyze the impact and to quantify the contribution of the implementation of a natural ventilation strategy in a tropical region. In particular, the natural ventilation strategy applied is cross ventilation through the opening area of the glazed envelope, set to 50%. It is found out that natural ventilation can lead to a minimum of 0.4 Kwh/m2/y to a maximum heat loss of 59 Kwh/m2/year. However, the figure **??** shows that the lowest values of cooling consumption are not necessarily achieved through the highest values of heat loss through natural ventilation. This result might depend on other variables, such as the window to wall ratio and thus the amount of openable area of the windows, or the values of the maximum outdoor temperature allowed to implement natural ventilation and thus to open the windows.

8

Design guideline

In the following sections some of the results of the 1070 simulations ran during the optimization phase will be shown and discussed. In order to facilitate the reading and understanding of the results of this study it was considered appropriate discuss some of the results by categorizing them in three sections: designs following architectural constraints, designs with indoor comfort limits and finally designs with constraints related to the energy performance of the building. These three sections serve as guidelines for designers, architects and building engineers, depending on the objectives of the design to be achieved. It is necessary to clarify that seen the high number of variables the number of possible combinations is definitely higher than 1070 combinations, thus the cases shown in the following paragraphs are not the only solution for specific constraints but are the cases that have been randomly selected by the optimization algorithm during the optimization phase.

8.1. Guideline: architectural parameters

The first guideline is related to architectural parameters as first design constraint. If the objective of the designer is to achieve a fully glazed building with a specific glazing type for visual comfort, or a design with the minimum size of external shading system or even with no external shading at all for aesthetical purposes, then this is the section to consult. Also, it is also possible to understand the energy consumption that derives from the combination of all the variables shown in each chart.

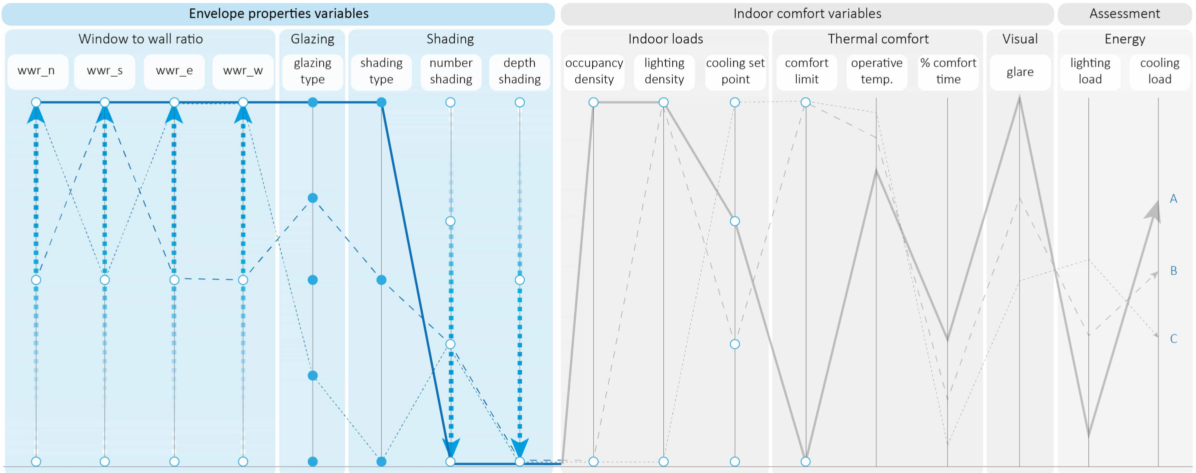

Figure 8.1: : Schematic visualization of the parallel coordinates chart, highlighting the axes taken into consideration for the guideline for a highly transparent design.

The figure 8.1 shows how the parallel charts in this section had been realized, namely by filtering the results by imposing specific constraints related solely to architectural parameters, such as window to wall ratios, glazing type or shading type. In blue are highlighted the variables taken into account during the screening of the designs. The charts 8.2 and 8.3 show two different groups of design solutions. The first shows the possible design solutions for designs with high transparency and with high occupancy density and low cooling set point temperature (24°C). While the second shows the possible design solutions with high transparency but implementing other strategies to reduce the cooling consumption such as low occupancy density and high cooling set point (30°C). By comparing these two parallel charts it is possible to notice the different range of cooling energy just by changing the internal loads and the cooling schedule. In particular, the first group of solutions has a cooling energy between 348 and 227 kWh/m2/year, while the second between 231 and 81 kWh/m2/year.

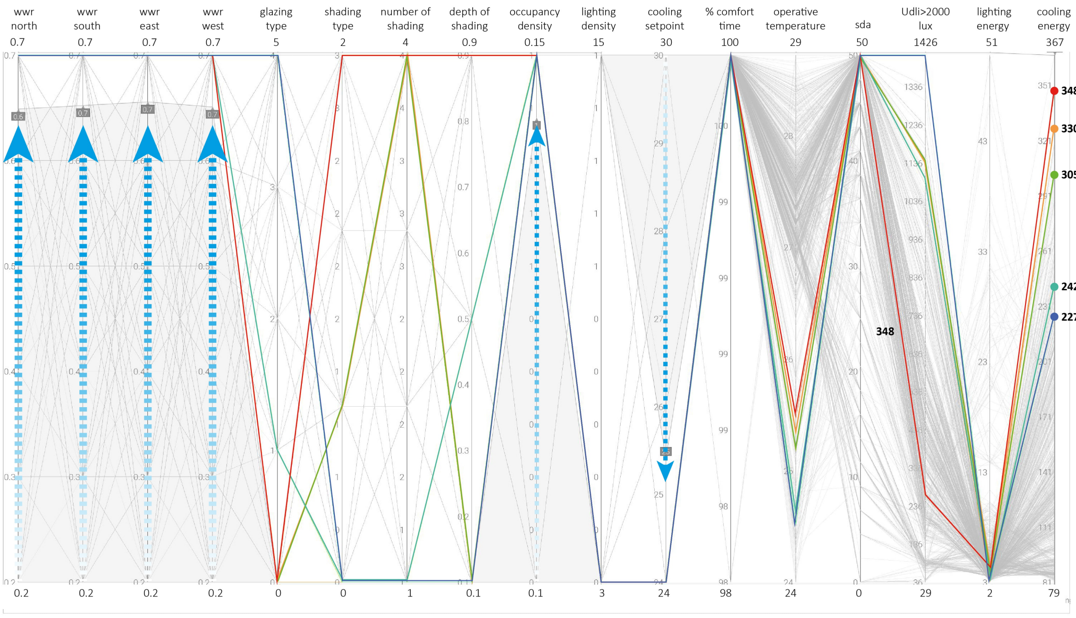

Figure 8.2: : Visualization of the parallel chart with five selected design high high transparent facade, high occupancy density and low cooling set point temperature (exported by ModeFRONTIER2019R2).

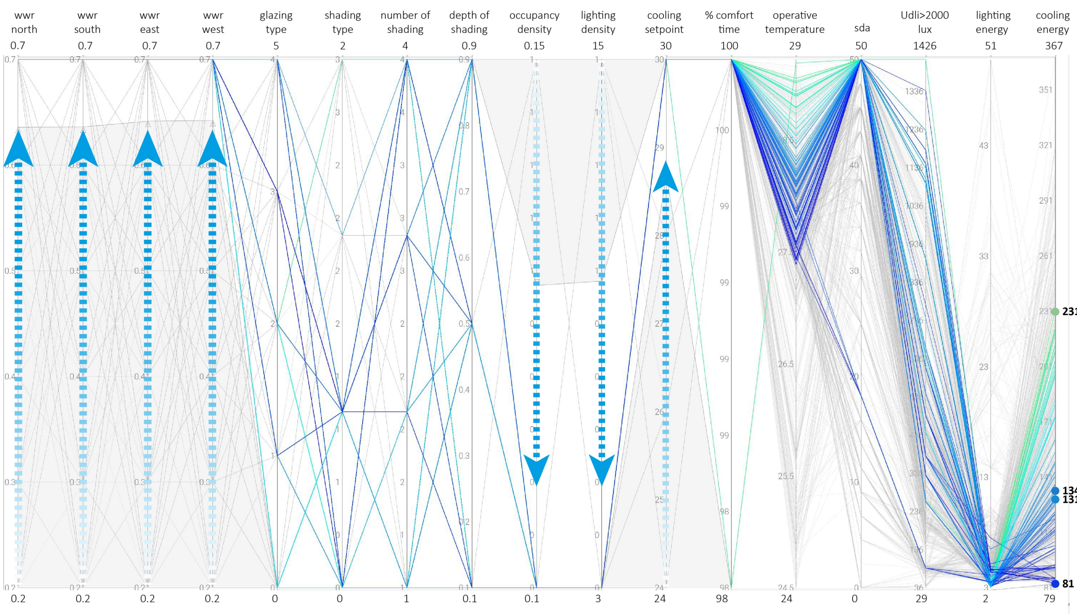

Figure 8.3: : Visualization of the parallel chart with three selected design high high transparent facade, low occupancy density and high cooling set point temperature (exported by ModeFRONTIER2019R2).

In the tables 8.4 and 8.5 are shown selected design solutions from the previous parallel charts, in order to compare the variable settings of each design and the influence on the cooling energy needed. All the design proposed are characterized by a full transparent facade, but they differ in the glazing type, shading properties and internal loads and schedule.

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
80	70%	70%	70%	70%	0	electrochromic glazing			0.15	3	24	348
343	70%	70%	70%	70%	0	vertical	1	0.5	0.15	3	24	330
175	70%	70%	70%	70%	0	horizontal	4	0.1	0.15	3	24	305
475	70%	70%	70%	70%	1	vertical	1	0.5	0.15	3	24	242
700	70%	70%	70%	70%	4	vertical	1	0.5	0.15	3	24	227

Figure 8.4: : Table summarizing the selected designs with high transparent facade, high occupancy density and low cooling set point temperature.

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
347	70%	70%	70%	70%	4	internal blinds			0.1	3	30	134
1010	70%	70%	70%	70%	4	horizontal	1	0.1	0.1	3	30	131
1044	70%	70%	70%	70%	3	horizontal	4	0.9	0.1	3	30	82

Figure 8.5: : Table summarizing the selected designs with high transparent facade, low occupancy density and high cooling set point temperature.

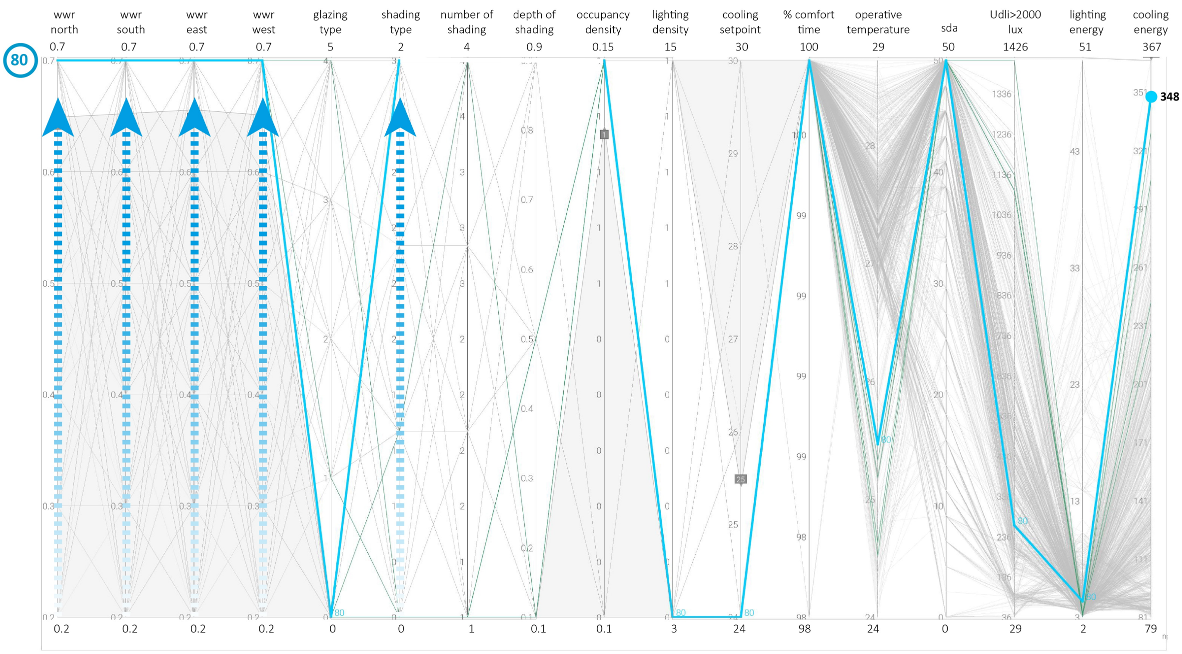

Figure 8.6: : Visualization of the parallel chart of the selected design with high transparent facade, high occupancy density and low cooling set point temperature (exported by ModeFRONTIER2019R2).

The case showed is the design n°80 found after filtering all the designs with a window to wall ratio of 70% for all the four facades and without external shading. The figure 8.6 shows the parallel chart with the input and the output of the simulation to find this design. While the figure A.27 shows a general view of the case study building with the variables of this design applied. The glazing type applied is the electrochromic glazing. Regarding the indoor loads, an occupancy density of 0.15 ppl/m2 and a lighting density of 3 W/m2 were selected. Concerning the indoor thermal comfort, a cooling set point of 24°C was set up. The outcome of this design with these variables is an indoor operative temperature of 25.5°C, a lighting consumption of 2 Kwh/m2/y and finally a cooling consumption of 348 Kwh/m2/y. The figure 8.7 shows examples of high rises office buildings with a high transparency without any external shading system.

Figure 8.7: : Examples of buildings in Singapore with high glazing areas on the facade and without external shading system. From left to right: Frasers tower (Source: https://www.fraserstower.com.sg/), Asia square tower (Source: http://www.keywordbasket.com) and Ocean Financial center (Source: https://www.keppellandlive.com/commercial/singapore/ocean-financial-centre.html).

8.2. Guideline: indoor comfort parameters

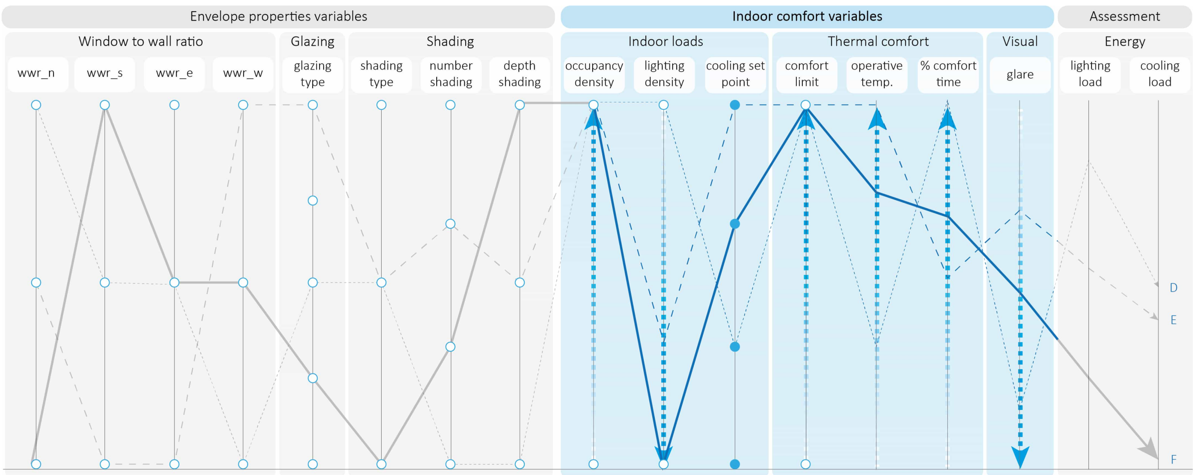

Figure 8.8: : Schematic visualization of the parallel coordinates chart, highlighting the axes taken into consideration for the guideline focused on the indoor comfort parameters.

The second guideline proposed is related to the indoor comfort variables. The latter consists of the indoor loads, namely occupancy and lighting density and the cooling set point temperature, the thermal comfort parameters, namely the comfort limit of the adaptive model. In this case also output of the simulation were taken into account in order to choose a specific design, such as indoor operative temperature or the glare probability. In the figure 8.8 it is shown the parallel chart with highlighted the variables and output filtered to achieve some of the results shown in this section.

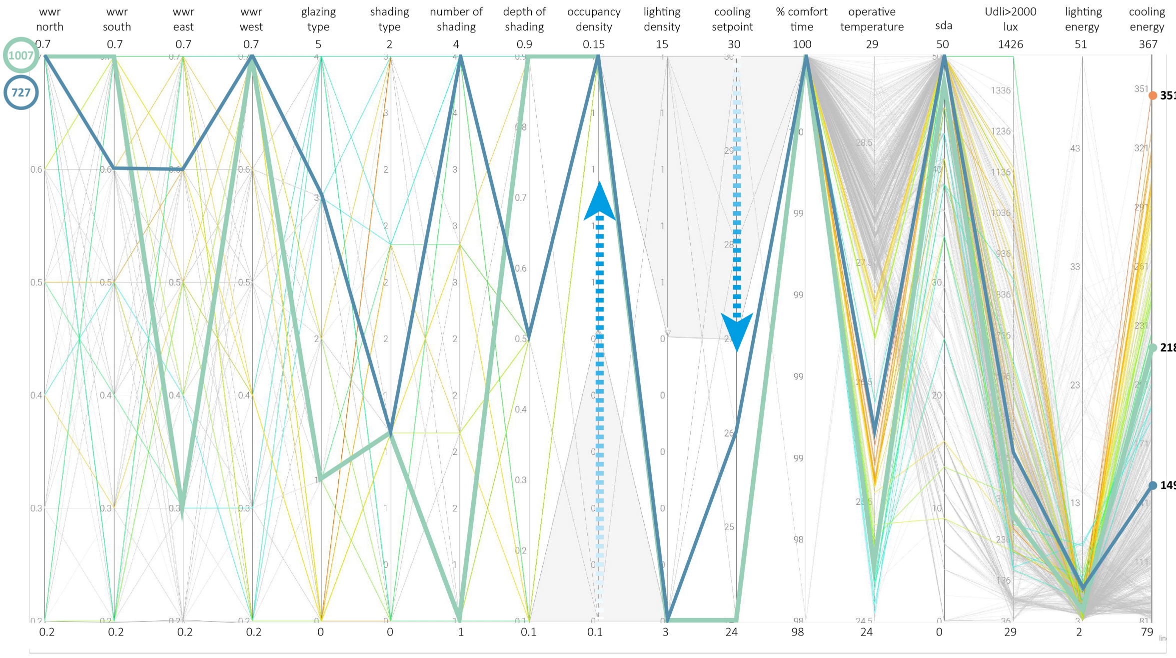

Figure 8.9: : Visualization of the parallel chart of the two selected design (n°1007 and 727) with high occupancy density and cooling set point temperature between 24 and 26°C (exported by ModeFRONTIER2019R2).

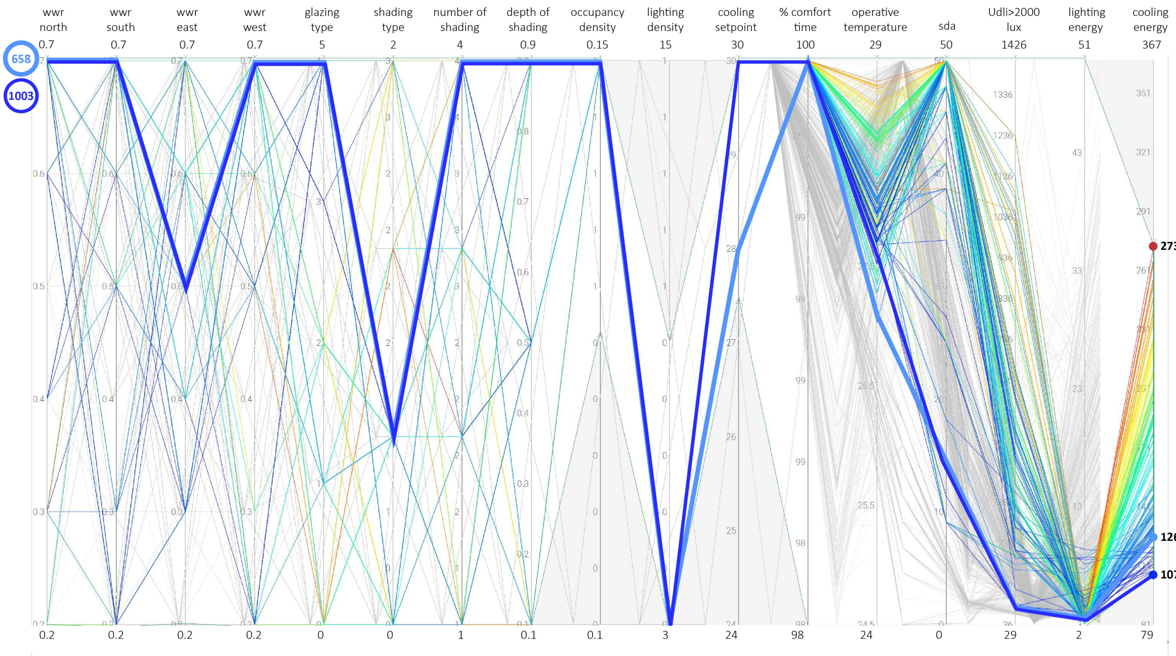

Figure 8.10: : Visualization of the parallel chart of the two selected design (n°658 and 1003) with high occupancy density and cooling set point temperature between 28 and 30°C (exported by ModeFRONTIER2019R2).

The parallel charts 8.9 and 8.10 shows the groups of possible design solutions allowing for a high occupancy density. The former group is characterized by a cooling set point temperature between 24 and 26°C, which is a preferable temperature range for the thermal comfort of the users. However, these design solutions have a range of cooling energy between a maximum of 351 kWh/m2/year and a minimum of 149 kWh/m2/year. While the second group is characterized by a cooling set point temperature between 28 and 30°C. These temperatures allows for a lower cooling energy, which ranges between 273 and 107 kWh/m2/year. Four design solutions are highlighted in the two parallel charts, each design has a different cooling set point temperature, from 24 to 30°C. The settings of the variables of these four designs are shown in the table 8.13.

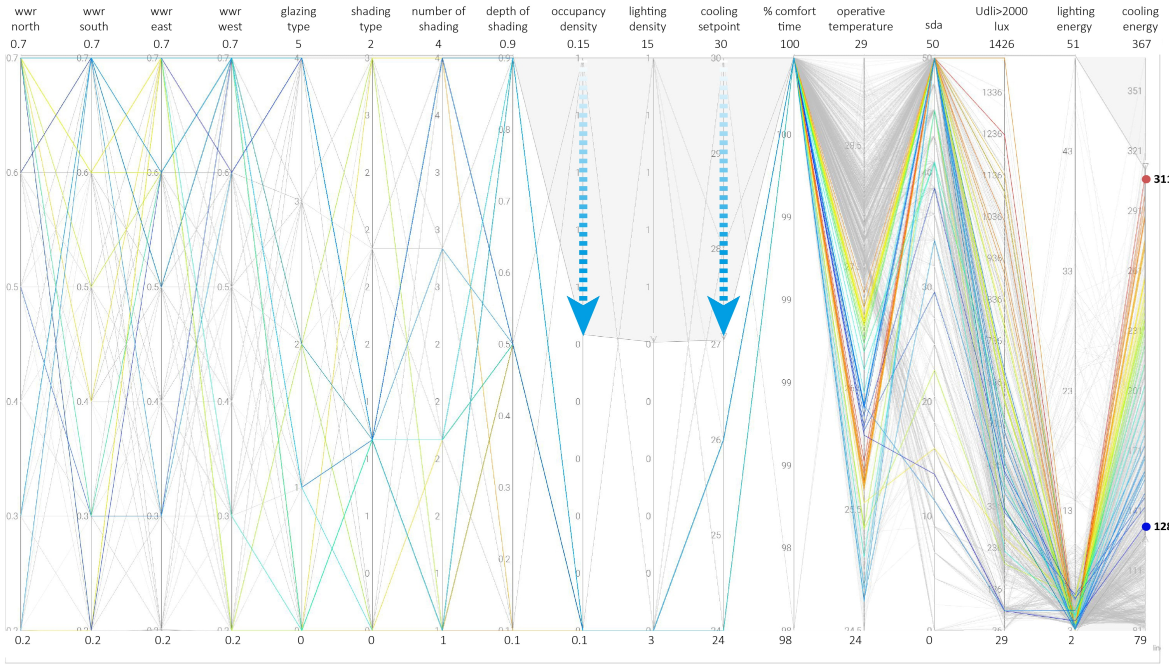

Figure 8.11: : Visualization of the parallel chart of the ranges of design solution with low occupancy density and cooling set point temperature between 24 and 26°C (exported by ModeFRONTIER2019R2).

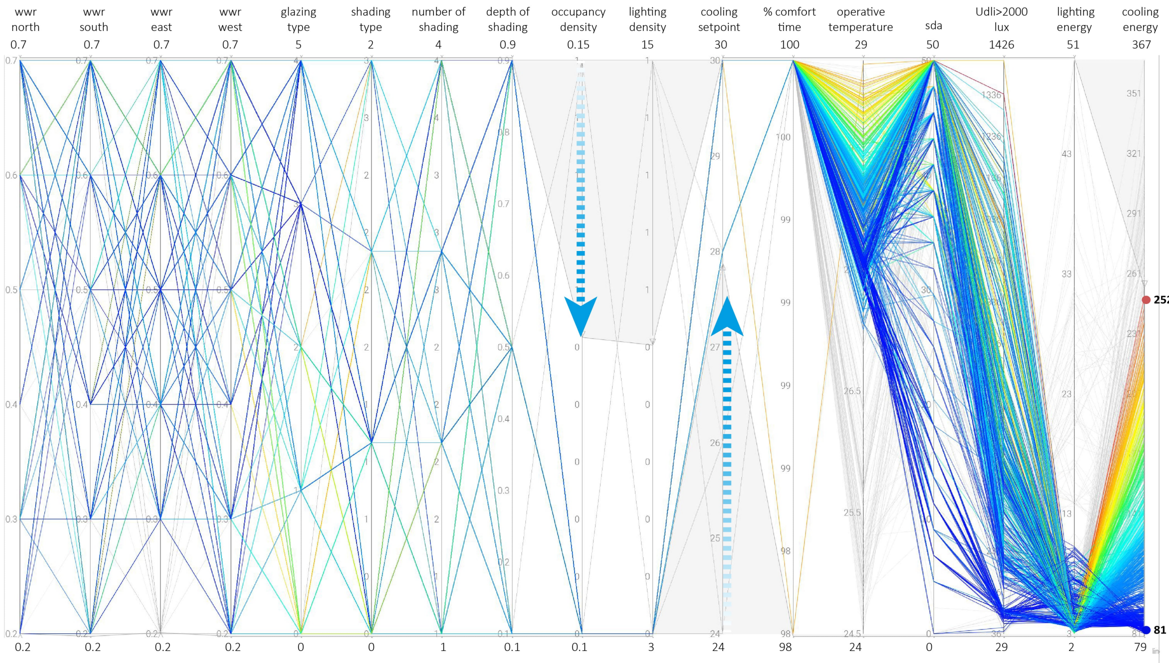

Figure 8.12: : Visualization of the parallel chart of the ranges of design solution with low occupancy density and cooling set point temperature between 28 and 30°C (exported by ModeFRONTIER2019R2)

Differently from the previous two charts, the charts 8.11 and 8.12 shows the group of the possible designs with a low occupancy density of 0.1 person/m2. Again the design solutions are divided with respect to the cooling set-point temperature, respectively the first chart for a temperature between 24 and 26°C and the second between 28 and 30°C. The table 8.14 compare the ranges of cooling energy needed with respect to the occupancy density (low/high) and with respect to the cooling set point temperature ranges (24-26°C and 28-30°C).

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
1007	70%	70%	30%	70%	1	horizontal	1	0.9	0.15	3	24	218
727	70%	60%	60%	70%	3	horizontal	4	0.5	0.15	3	26	149
658	70%	70%	50%	70%	4	horizontal	4	0.9	0.15	3	28	126
1003	70%	70%	50%	70%	4	horizontal	4	0.9	0.15	3	30	107

Figure 8.13: : Table summarizing the input variable of the four selected designs in the previous parallel charts.

Occupancy density	Cooling setpoint temperature	Maximum cooling energy	Minimum cooling energy
High (0.15 ppl/m2)	24-26	351	149
Low (0.1 ppl/m2)	24-26	311	128
High (0.15 ppl/m2)	28-30	273	107
Low (0.1 ppl/m2)	28-30	252	79

Figure 8.14: : Table summarizing the maximum and minimum ranges of cooling demand with respect to the occupancy density and to the cooling set point temperature.

8.3. Guideline: energy performance

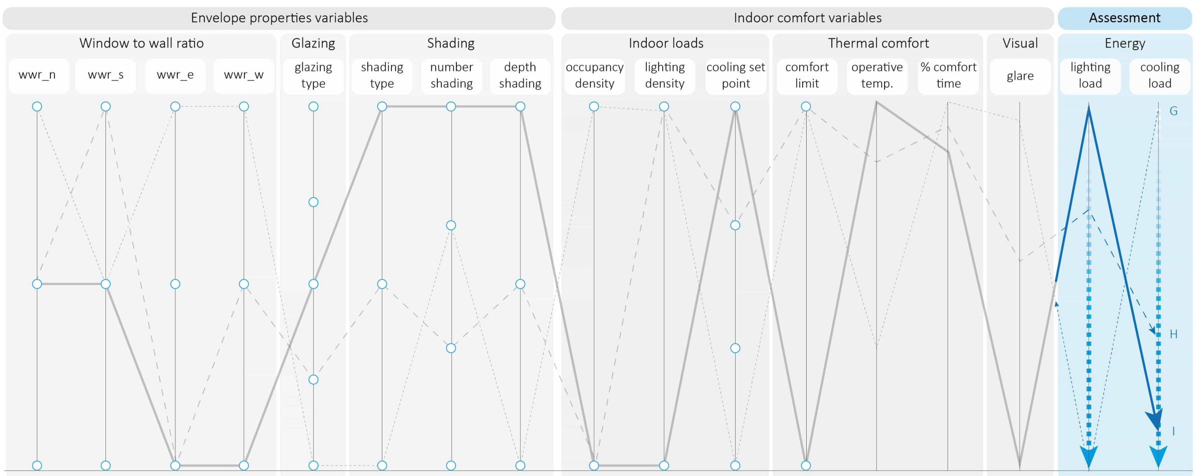

Figure 8.15: : Schematic visualization of the parallel coordinates chart, highlighting the axes taken into consideration for the guideline for low energy consuming designs.

In this last section of this chapter, the cases discussed are the result of the screening of the designs with respect to the energy performance of the building, in particular the cooling consumption. Being this the objective of this research, to find the most optimal solutions to reduce at maximum the cooling consumption of an office building, several solutions are presented and discussed. The following designs have in common the low cooling consumption, between 88 and 93 Kwh/m2/y, but they differ with respect to the window to wall ratio, glazing and shading type. By comparing different cases, it results easier to understand the impact of each variables and it shows how it is possible to achieve the same goal with different combination of variables. Thus, the design selected differs in percentage of glazed envelope, amount of louvres and depth of the shading louvres in case the objective of the design to achieve are not only related to the energy performance but also to the architectural design of the building.

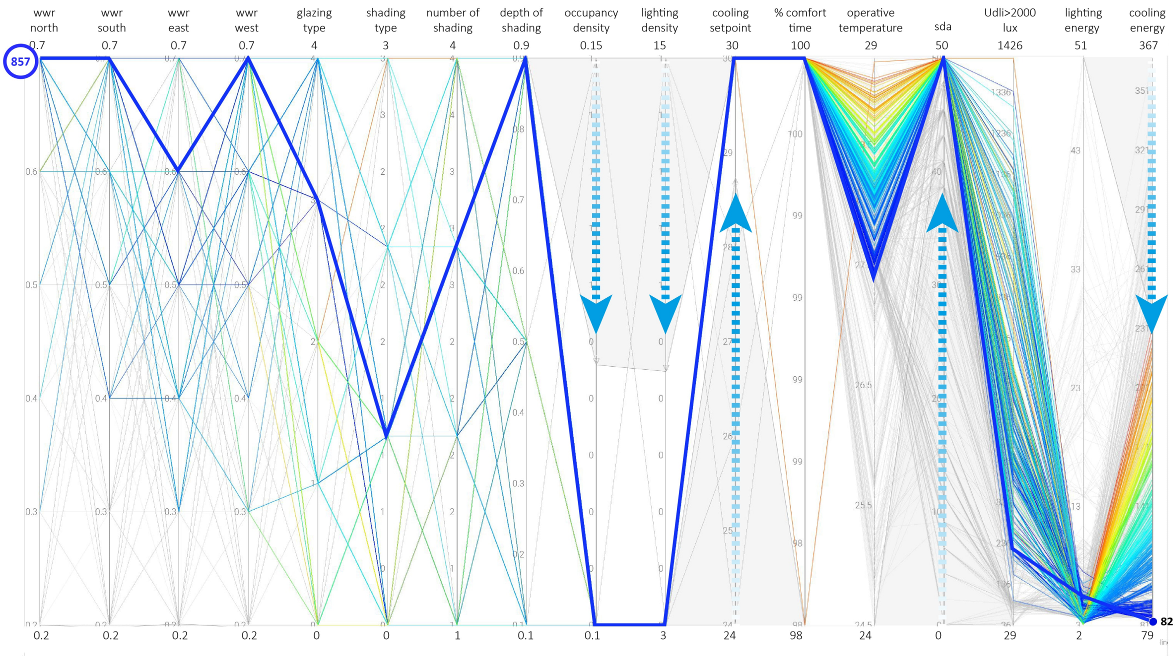

Figure 8.16: : Visualization of the parallel chart of the selected design solution (n°857) with a low cooling demand with low occupancy density and high cooling set point temperature (exported by ModeFRONTIER2019R2).

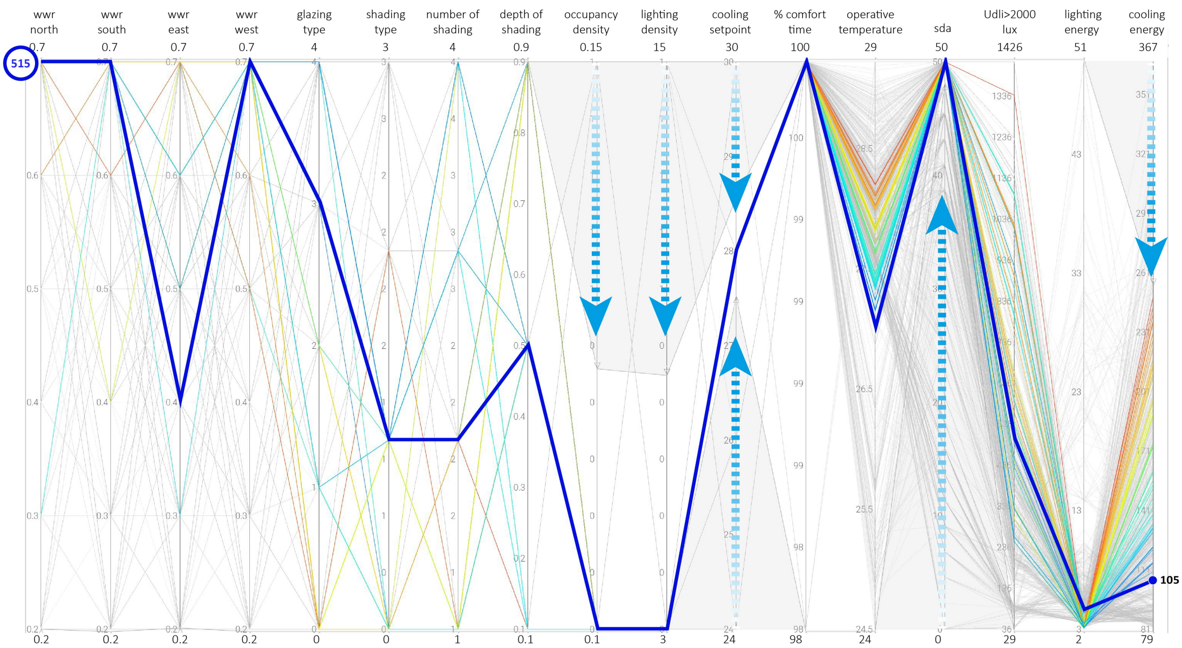

Figure 8.17: : Visualization of the parallel chart of the selected design solution (n°515) with a low cooling demand with low occupancy density and a cooling set point temperature of 28°C (exported by ModeFRONTIER2019R2).

In the following charts are proposed some design solutions with the lowest energy consumption for cooling with respect to each possible cooling set point temperature. Thus, the chart 8.16 shows the selected design n°857 for a cooling set point temperature of 30°C, the chart 8.17 shows the design n°515 for a cooling set point of 28°C and finally the chart 8.18 shows the design n°791 for a cooling set point temperature of 26°C. All the three design selected have been filtered with a low occupancy and lighting density and with the highest value of the spatial daylight autonomy (sda) equal to 50%. Finally, among the group of possible design solutions, the designs selected have been chosen for the lowest cooling energy needed.

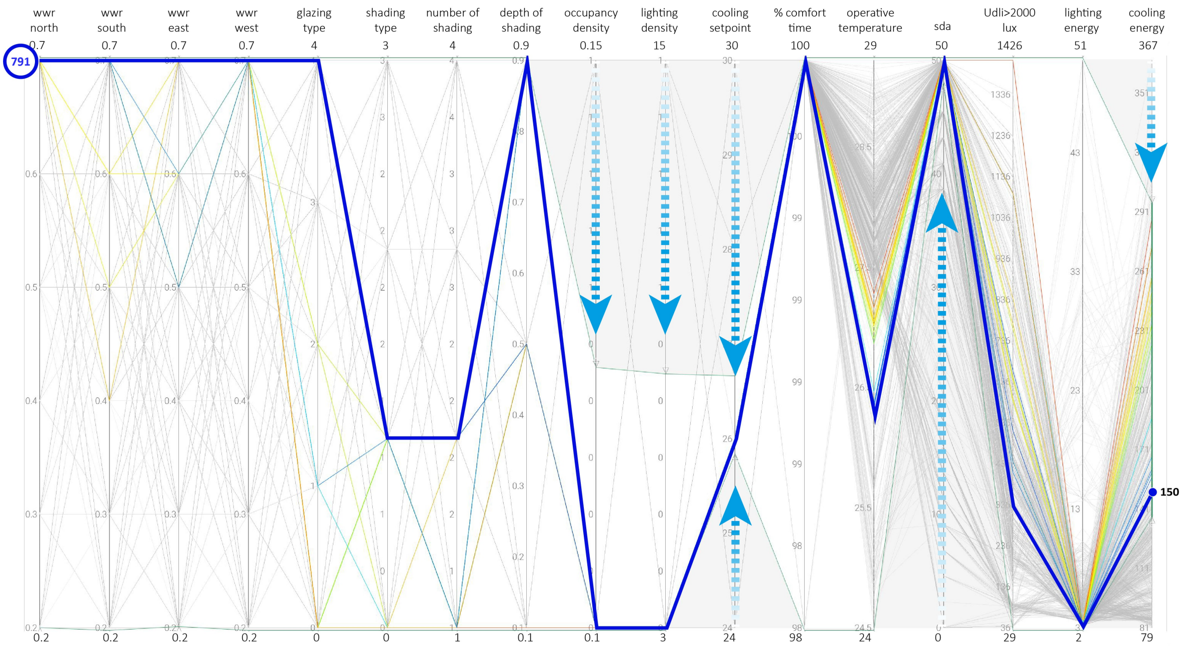

Figure 8.18: :Visualization of the parallel chart of the selected design solution (n°515) with a low cooling demand with low occupancy density and a cooling set point temperature of 26°C (exported by ModeFRONTIER2019R2).

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
791	70%	70%	70%	70%	4	horizontal	2	0.9	0.1	3	26	150
515	70%	70%	40%	70%	3	horizontal	2	0.5	0.1	3	28	105
857	70%	70%	60%	70%	3	horizontal	3	0.9	0.1	3	30	82

Figure 8.19: : Table summarizing the three designs selected in the previous parallel charts.

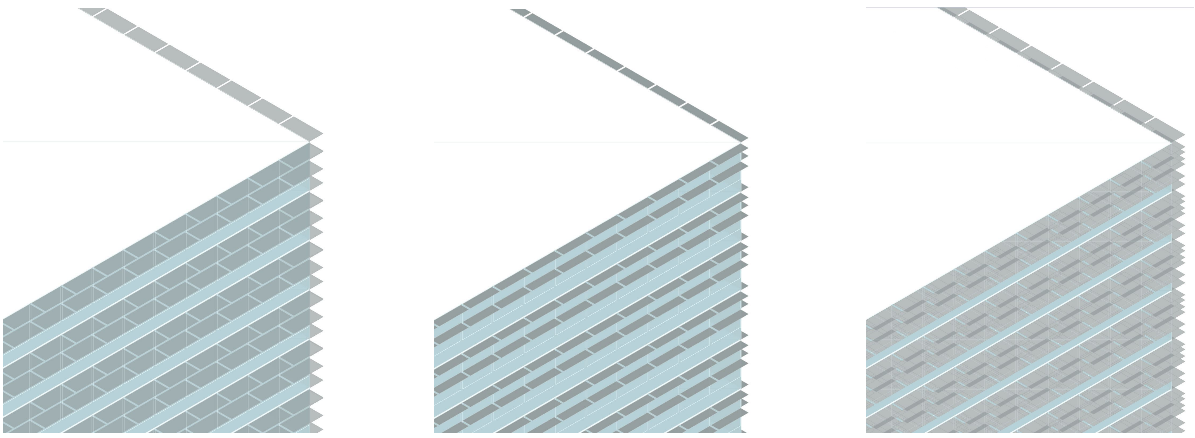

Figure 8.20: : Visualization of the three designs discussed. From the left to the right: design n°791, 515 and 857.

In the table 8.19 the main settings of the three designs proposed as best energy performing designs are summarized. As it can be noticed, the reduction of cooling demand is higher between the design with 26°C and the design with 28°C for the cooling set point temperature. The difference in temperature between the two last design with higher cooling set point temperature (from 28 to 30°C) is almost half than the difference temperature between the first two design with lower cooling set point temperature (from 26 to 28°C). Also, it can be noticed that in order to reach the lowest cooling consumption is not only needed to implement the highest cooling set point temperature but it is also important to implement a high number of external louvres and the deepest dimension of the overhang. The figure A.33 shows a view of the three designs proposed, in order the design n°791, 515 and finally on the right the design n°857. While the figures 8.21 and 8.22 show examples of building with external horizontal and vertical louvres.

Figure 8.21: : Examples of buildings in Singapore with the integration of vertical shading louvres on the facade. From left to right: Silver Tower Center (Source: https://archello.com/project/silver-tower-center), Hongkou Soho' office tower (Source: https://www.baunetz.de/meldungen) and The Maersk Tower (Source: https://architizer.com).

Figure 8.22: : Examples of buildings in Singapore with the integration of horizontal shading louvres on the facade. From left to right: Xi'an Jiaotong-Liverpool University (Source: www.archdaily.com), One George Street Singapore Source: https://architizer.com/projects/one-george-street/) and Twin Tree Tower (Source: www.archidaily.com).

8.4. Summary of the design proposed

After filtering the design solutions through the parallel chart and after analysing some cases, the table 8.23 compare all the designs discussed in this chapter. The designs are grouped with respect to the possible aimed design goals, such as high transparency, high occupancy density or high energy performance of the building. In the table it is shown the end outcome of the simulation for each design, meaning the energy needed for cooling, since the objective of this research is to reduce completely the cooling consumption. Also, for each design it was calculated the percentage of energy reduction or increase with respect to the value of cooling consumption of the current design found during the research phase. It can be observed that in order to achieve a high transparency, keeping a low cooling set point temperature and a high occupancy density (which are the internal loads and schedule of the current building), but changing the glazing type and the shading properties can lead to an increase of cooling energy up to 57%. On the other hand, by proceeding on the internal schedule, thus by increasing the cooling set point temperature while keeping a high occupancy density, it is possible to save up to 49% of the cooling energy with respect to the current design. Also, if a comparison is made between the design n° 658 and the n°1003, which differ for the cooling set point temperature (28°C and 30°C respectively), the difference of the energy reduction is equal to 9%. Thus, if the energy consumption and the thermal comfort of the users are equally important design goals, then the option n°658 is preferable. Finally, the highest energy reduction can be achieved by the last design (n°857), which has as design objective to reach the lowest cooling demand, and which is characterized by a low occupancy and lighting density and the highest cooling set point temperature.

Design goal	Constants	Design n°	Cooling energy (kWh/m2/y)	Energy reduction/increase (%)
High transparency	High wwr High occupancy density Low lighting density Low cooling set point	343	330	+57
		175	305	+45
		475	242	+15
		700	227	+8
High occupancy density	High occupancy density Low lighting density	1007	218	+4
		727	149	-29
		658	126	-40
		1003	107	-49
Low cooling demand	Low occupancy density Low lighting density	791	150	-29
		515	105	-50
		857	82	-61

Figure 8.23: Comparison of the design proposed from an energy consumption point of view. The percentage of energy reduction/increase is calculated with respect to the current energy consumption of the building.

The figure 8.24 the cooling consumption of the design proposed is shown with respect to the cooling energy consumed by the current design of the case study which was calculated during the research through Grasshopper. It can be noticed that the design solutions which implement higher cooling set point temperatures can reach half of more energy savings with respect to the current design.

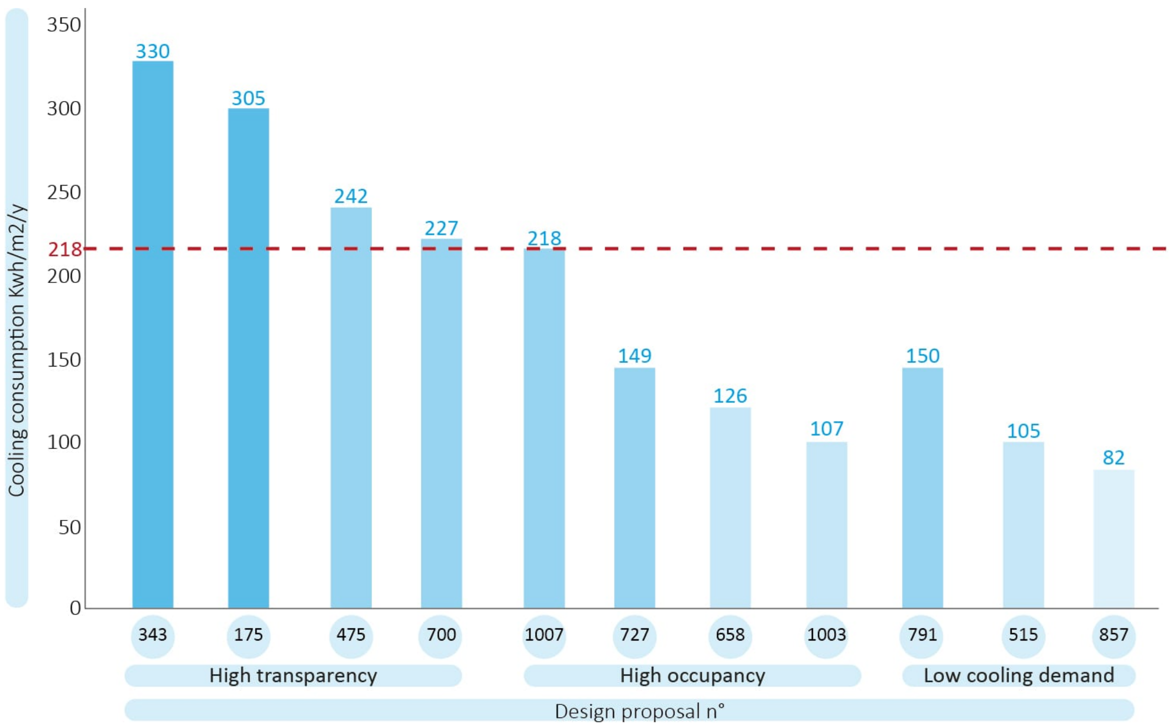

Figure 8.24: Comparison of the design proposed from an energy consumption point of view. The percentage of energy reduction/increase is calculated with respect to the current energy consumption of the building.

9 Conclusion

The main aim of this research is to understand the feasibility of a purely passive building in tropical climates by researching through the literature review the current passive design strategies and by investigating the possibility of the design of a purely passive building in tropical climate through building performance optimization. The conclusions drawn from the literature review are the following:

- The number of ZEB cases in Tropical regions are definitely low with respect to the total amount, in particular 3 out of 332 ZEBs globally. This result lead to the conclusion that it is indeed more challenging to design a zero energy building in extreme climate conditions.
- The building benchmark of certain countries might be more focused on the energy efficiency of the equipment and installations implemented rather than on the efficiency of the design it self.
- The application and study of adaptive comfort models in tropical regions is still not fully defined, however in the last couple of years the International Energy Agency has launched a research regarding this last point. The outcome of the research should be published at the beginning of 2020. The project is called ''Strategy and Practice of Adaptive Thermal Comfort in low energy buildings'' (EBC Annex 69).
- The applicable passive strategies in tropical climate are related to the building layout, envelope and devices, natural ventilation, evaporative cooling and radiative cooling. In the bioclimatic architecture of Ken Yeang are implemented the following strategies: building layout, envelope and shading strategies, natural ventilation and vertical landscape.

From the outcome of the literature review the main outline and the details of the optimization phase were defined. Starting from an existing case study based in Singapore, the optimization of the envelope parameters and the indoor comfort parameters was conducted, implementing the strategies found during the literature review such as external shading system or natural ventilation. The optimization results are observed and discussed to define the significance and influence of each factor, related to the envelope design and indoor comfort, with respect to the cooling consumption. Finally, the results of the optimization are the starting point for the definition of a guideline for designers and engineers for the achievement of a nearly purely passive building in tropical regions.

During the construction of the simulation script it was noted the complexity of the decision making for all the parameters related to the building design, from the architectural parameters to the internal load and schedules to the definition of the HVAC systems. This is a clear example of how complicated can be the entire design of a passive building by taking into account all the aspects of a building. Also, this shows how important is to start the design of a sustainable building in an integrated way. Because of the lack of information and details of the case study many assumption were made, such as the HVAC system implemented, the air infiltration rate or the lighting density.

After validating the results of one simulation in Grasshopper with Design Builder, the construction of the optimization workflow took place. This phase of the thesis turned out to take longer time than expected because of the issues faced during the connection of the optimization software, ModeFrontier, and the simulation software, Grasshopper. The difficult part of this process is related to the fact that the algorithm of the optimization tool create combination of the variables randomly during the Design of Exploration (DOE) and sometimes the combination simulated would lead to an impossible result, and thus to an error blocking the optimization process. It turned out to be fundamental to check several times the Grasshopper script before connecting it to ModeFrontier. Except for this first problematic part, ModeFrontier and in particular using PilOpt, was found to be an excellent tool for the definition of homogeneous landscape to find the most optimal solution. Also, the post processing phase of the results turned out to be clear and fast thanks to the variety of charts that is possible to create with ModeFrontier.

From the results of the second optimization the following conclusion were drawn:

- the cooling consumption can be decreased up to 58% by implementing strategies related to envelope design and indoor comfort parameters;
- as expected, in both the optimization it is found out that the impact of the window to wall ration for the east and west facades is stronger than the window to wall ratio of north and south facades;
- among the five glazing type applied, from the first optimization it is found out that the most beneficial glazing types is the double coated glazing (ST-108);
- the implementation of external shading system is needed. Depending on the architectural image of the building wanted, it is possible to implement both horizontal or vertical louvres;
- the designs that lead to the lowest values of cooling consumption are the ones with the lowest occupancy and lighting density;
- from the correlation matrix charts in the chapter 7, it is found out that the setting of the cooling set point is the variable with the highest correlation with the cooling consumption. Implementing a cooling set point temperature of 30°C lead to the lowest cooling consumption and the 100% of comfortable time is still reached with the 90% of acceptability of the users.
- the strategy of cross ventilation was found to lead to a maximum heat loss of 59 Kwh/m2/year.

The factor that can be neglected to reduce the cooling consumption are the window to wall ratio of the north and west facades and the internal blinds. Also, the electric lighting consumption turned out to have a range six times smaller than the range of the cooling consumption.

After discussing the results through several charts, different design proposal for the reference building were selected. The designs proposed are presented with the description of the different settings related to the envelope properties and indoor comfort parameters adopted, together with the performance of the building, in order to support the designer during the decision making. In fact, the designer can choose among the different solutions a specific design based on soft or hard criteria, meaning aesthetic constraints or indoor comfort or energy related respectively.

Since during the literature review it has not been found any study with the optimisation of design parameters to achieve a purely passive building in tropical climates, this study could be useful for further research. Other variables could be added and other aspects related to the energy performance of the building could be taken into account. In fact, this research focuses mainly on the optimization of envelope parameters and indoor comfort parameters of a case study, in order to achieve a nearly passive building and apply the adaptive thermal comfort model in an office building in tropical climate. However, this research could be extended by optimizing also aspects like other type of shading system such as dinamic shading, green facades, other design possibilities such as atria to implement other types of natural ventilation, or HVAC system settings and finally take into account the urban context of the case study.

10

Reflection

The objective of this research is to investigate whether it is possible or not to design a purely passive building in tropical climate and to draw a guideline for architects and engineers to achieve this goal as conclusion. Through the computational optimization of the design of a building case study it was possible to observe the impact of the envelope and indoor comfort parameters to decrease the energy consumption of an office high rise in a tropical region.

The first phase of this research consists on the literature review of the state-of-the-art of the passive cooling strategies and of the principles of the bioclimatic architecture applied in tropical regions. Also, other two important topics to research are the Zero Energy Building's in tropical regions and the benchmark applied in the location of the case study. Finally, the application of adaptive comfort models was investigated.

The second part of this research consists on the research through design. In particular, starting from a case study it was researched how to achieve a purely passive building through a building performance simulation (BPS) and building performance optimization (BPO) process. The set-up of the simulation process was done through Rhino and Grasshopper (GH) for the construction of the parametric model and through the plug-ins Honeybee and Ladybug for the performance evaluation of the tested designs. This first phase consisted of the construction of the model and the set-up of all the parameters that influence the energy performance of the building, meaning envelope parameters, parameters related to the internal loads and schedule and the definition of the HVAC system implemented in the current case study. It is important to specify that many information related to the systems implemented in the case study were not found, thus assumptions were made, such as the type of HVAC system, the air infiltration rate or the lighting density. Also, another aspect to highlight is the reliability of the results of the tools used. Grasshopper, Ladybug and Honeybee are tools in constant development, thus limitations and restrictions were faced during this face. However, an evaluation of the results of the simulations was done by testing the performance of the design also in another reliable software, which is Design Builder.

Then, the building performance optimization was carried on Modefrontier, by linking the Grasshopper script with the optimization software. ModeFrontier is a tool used mostly in the engineering design process rather than in the architectural design process. Thus, this study helps to experiment the application of this tool in this field. Because of the lack of other studies based on the application of this software, this last phase of this research turned out to be slower than expected. In particular, different complications were found during the connection of the Grasshopper script with the optimization script. It was learned to test the optimization software by testing the simulation file in different stages, by enhancing gradually the details of the script and by adding slowly the variables to be combined by the algorithm. Also, it is important to check the time needed for each simulation during the testing phase of the software and to simplify the grasshopper script in order to run a considerable amount of simulations and to approach to the optimal solution. However, once obtained the results of the optimization phase, it was easier to read and understand the outcomes of the research thanks to the advanced tools for data analysis and visualization. The post processing phase of the results in ModeFrontier turned out to be an interesting feature of this software simplifying the decision making phase. With this study hopefully it will easier to implement this optimization tool in the architecture design process to achieve easily the design objectives fixed.

During the background research it appeared the lack of research about the computational optimization of the design of passive buildings in tropical countries, thus the outcome of this study could be useful for future research on the development of zero energy buildings in tropical climates. In fact, this study establish not only the impact of the envelope properties on the energy performance of a building but also the impact of indoor comfort strategies, such as internal loads and schedules or the introduction of cross ventilation. Also, this research contains a guideline to design a high rise office building in a tropical region following three criteria: architectural constraints, indoor comfort parameters and finally the energy performance of the building. All the design proposal take into account the energy consumption of the building, in order to allow to the designers, architect or engineer to be aware of the impact of the choices made on the energy performance of the design chosen. Finally, as stated previously this research can be useful for a further development, by taking into account other parameters such as a dynamic shading system or the HVAC system parameters.

Regarding the impact on the the society or the users, it is interesting to observe how active users could have a high impact on the energy consumption of a building. In particular, by implementing the adaptive comfort standards and at the same time by acting on the indoor comfort parameters, namely internal loads and schedule. This parameters were tested by calculating the user's comfort implementing the adaptive comfort model. The latter, differently from other comfort models, allows higher ranges of temperatures thanks to the adaptability of the users. Also, the use of Adaptive Comfort Standards can increase design flexibility, reduce the capacity of installed plant for cooling purposes and save energy consumption, without affecting enormously user's satisfaction As noticed by the results of the second optimization, all the solutions simulated reach the total percentage of comfort time although the high indoor operative temperature reached. Thus, this study shows that it is still possible to increase the cooling set point temperature and achieving the highest thermal comfort levels, especially in tropical regions. Also, as stated by Francois Garde:

"The last most important key feature are the occupants of the building because the success of the process is to get active people in a passive building instead of passive people in active buildings. To do this, people need to be educated and to adapt their behavior." [21].

The challenge to the related architects/designers/researchers is to come out with effective strategies to overcome the state of discomfort with minimum energy utilization. Finally, I can conclude that in order to achieve a nearly passive building architects, designers and engineers must come out with a design proposal, not driven anymore by architectural design, but driven by comfort and energy performance in order to guarantee acceptable comfort levels with minimum energy consumption. It is thus necessary to make certain design compromises in order to reduce the harmful impact of the building industry on the environment.

A

Appendix

A.1. Calibration of the simulation

Design Builder: Input

Construction		
Exterior wall (opaque)	U-value: 0.353 W/m2K R-value: 2.8 m2K/W	Lightweight curtain wall insulated to 2000 regs (Design Builder) Metallic cladding, XPS polystyrene (88mm), gypsum plasterboard)
Glazing construction	U-value: 2.76 W/m2K g-value: 0.15 VT-value: 0.07	Dbl Ref-A-L Clr 6mm/6mm Air
Floor/Ceiling construction	U-value: 2.9 W/m2K R-value: 0.3 m2K/W	Intermediate floor- 4 in. (100mm) concrete slab (Adiabatic) Cast concrete 0.10 m (Adiabatic)
Airtightness	0.7 ac/h	
Shading system	None	
Activity		
Occupancy schedule	8.00- 17.00 5 days	
Occupancy density	0.15 people/m2	
Heating setpoint	22°C	
Heating setback	12°C	
Cooling setpoint	24°C	
Cooling setback	28°C	
Equipment load	6.9 W/m2	
Lighting		
Lighting density	15 W/m2	
Lighting control	Automate switch off occupancy sensor	
Illuminance threshold	400 lux	
HVAC		
HVAC system	Fan Coil Unit (4-Pipe), Air cooled Chiller, DOAS	
Natural ventilation	Off	

Design Builder: Output

District cooling intensity	294 kWh/m2

Figure A.1

Grasshopper: Input

Construction		
Exterior wall (opaque)	U-value: 0.353 W/m2K R-value: 2.8 m2K/W	Lightweight curtain wall insulated to 2000 regs (Design Builder) Metallic cladding, XPS polystyrene (88mm), gypsum plasterboard)
Glazing construction	U-value: 2.76 W/m2K g-value: 0.15 VT-value: 0.07	Dbl Ref-A-L Clr 6mm/6mm Air
Floor/Ceiling construction	U-value: 2.9 W/m2K R-value: 0.3 m2K/W	Intermediate floor- 4 in. (100mm) concrete slab (Adiabatic) Cast concrete 0.10 m (Adiabatic)
Airtightness	0.7 ac/h	
Shading system	None	
Activity		
Occupancy schedule	8.00- 17.00 5 days	
Occupancy density	0.15 people/m2	
Heating setpoint	22°C	
Heating setback	12°C	
Cooling setpoint	24°C	
Cooling setback	28°C	
Equipment load	6.9 W/m2	
Lighting		
Lighting density	15 W/m2	
Lighting control	Automate switch off occupancy sensor	
Illuminance threshold	400 lux	
HVAC		
HVAC system	Fan Coil Unit (4-Pipe), Air cooled Chiller, DOAS	
Natural ventilation	Off	

Grasshopper: Output

Cooling energy	218 kWh/m2/year

Figure A.2

A.2. Simulation in Design Builder

Program Version:**EnergyPlus, Version 8.5.0-c87e61b44b, YMD=2019.10.10 11:49** Table of Contents

Tabular Output Report in Format: **HTML**

Building: **Building**

Environment: **ONERAFFLESQUAY (01-01:31-12) ** SINGAPORE - SGP IWEC Data WMO#=486980**

Simulation Timestamp: **2019-10-10 11:49:17**

Report: **Annual Building Utility Performance Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	476324.26	370.23	370.23
Net Site Energy	476324.26	370.23	370.23
Total Source Energy	710443.29	552.21	552.21
Net Source Energy	710443.29	552.21	552.21

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.250
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050
Other Fuel 1	1.000
Other Fuel 2	1.000

Building Area

	Area [m2]
Total Building Area	1286.56
Net Conditioned Building Area	1286.56
Unconditioned Building Area	0.00

End Uses

	Electricity [kWh]	Natural Gas [kWh]	Additional Fuel [kWh]	District Cooling [kWh]	District Heating [kWh]	Water [m3]
Heating	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	0.00	0.00	0.00	378902.69	0.00	0.00
Interior Lighting	60442.39	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	32690.38	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	4288.80	67.16
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	93132.77	0.00	0.00	378902.69	4288.80	67.16

End Uses By Subcategory

	Subcategory	Electricity [kWh]	Natural Gas [kWh]	Additional Fuel [kWh]	District Cooling [kWh]	District Heating [kWh]	Water [m3]
Heating	General	0.00	0.00	0.00	0.00	0.00	0.00

Figure A.3

Cooling	General	0.00	0.00	0.00	378902.69	0.00	0.00
Interior Lighting	ELECTRIC EQUIPMENT#Block1:Zone1#GeneralLights	60442.39	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	ELECTRIC EQUIPMENT#Block1:Zone1#05	32690.38	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	DHW Block1:Zone1	0.00	0.00	0.00	0.00	4288.80	67.16
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [kWh/m2]	Natural Gas Intensity [kWh/m2]	Additional Fuel Intensity [kWh/m2]	District Cooling Intensity [kWh/m2]	District Heating Intensity [kWh/m2]	Water Intensity [m3/m2]
Lighting	46.98	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	294.51	3.33	0.05
Other	25.41	0.00	0.00	0.00	0.00	0.00
Total	72.39	0.00	0.00	294.51	3.33	0.05

Utility Use Per Total Floor Area

	Electricity Intensity [kWh/m2]	Natural Gas Intensity [kWh/m2]	Additional Fuel Intensity [kWh/m2]	District Cooling Intensity [kWh/m2]	District Heating Intensity [kWh/m2]	Water Intensity [m3/m2]
Lighting	46.98	0.00	0.00	0.00	0.00	0.00
HVAC	0.00	0.00	0.00	294.51	3.33	0.05
Other	25.41	0.00	0.00	0.00	0.00	0.00
Total	72.39	0.00	0.00	294.51	3.33	0.05

Electric Loads Satisfied

	Electricity [kWh]	Percent Electricity [%]
Fuel-Fired Power Generation	0.000	0.00
High Temperature Geothermal*	0.000	0.00
Photovoltaic Power	0.000	0.00
Wind Power	0.000	0.00
Power Conversion	0.000	0.00
Net Decrease in On-Site Storage	0.000	0.00
Total On-Site Electric Sources	0.000	0.00
Electricity Coming From Utility	93132.774	100.00
Surplus Electricity Going To Utility	0.000	0.00
Net Electricity From Utility	93132.774	100.00
Total On-Site and Utility Electric Sources	93132.774	100.00
Total Electricity End Uses	93132.774	100.00

On-Site Thermal Sources

	Heat [kWh]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-

Figure A.4

Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	67.16	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	67.16	100.00
Total Water End Uses	67.16	100.00

Setpoint Not Met Criteria

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	1.11
Tolerance for Zone Cooling Setpoint Not Met Time	1.11

Comfort and Setpoint Not Met Summary

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	0.00
Time Setpoint Not Met During Occupied Cooling	0.00
Time Not Comfortable Based on Simple ASHRAE 55-2004	158.50

Note 1: An asterisk (*) indicates that the feature is not yet implemented.

Table of Contents

Report: **Input Verification and Results Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

General

	Value
Program Version and Build	EnergyPlus, Version 8.5.0-c87e61b44b, YMD=2019.10.10 11:49
RunPeriod	ONERAFFLESQUAY (01-01:31-12)
Weather File	SINGAPORE - SGP IWEC Data WMO#=486980
Latitude [deg]	1.37
Longitude [deg]	103.98
Elevation [m]	16.00
Time Zone	8.00
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	459.00	135.00	94.50	135.00	94.50
Above Ground Wall Area [m2]	459.00	135.00	94.50	135.00	94.50
Window Opening Area [m2]	296.00	87.13	60.88	87.13	60.88
Gross Window-Wall Ratio [%]	64.49	64.54	64.42	64.54	64.42
Above Ground Window-Wall Ratio [%]	64.49	64.54	64.42	64.54	64.42

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	459.00	135.00	94.50	135.00	94.50
Above Ground Wall Area [m2]	459.00	135.00	94.50	135.00	94.50
Window Opening Area [m2]	296.00	87.13	60.88	87.13	60.88
Gross Window-Wall Ratio [%]	64.49	64.54	64.42	64.54	64.42

Figure A.5

Above Ground Window-Wall Ratio [%]	64.49	64.54	64.42	64.54	64.42

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	0.00
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

PERFORMANCE

Zone Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
BLOCK1:ZONE1	1286.56	Yes	Yes	3216.39	1.00	459.00	12.31	15.0000	6.67	6.9000
Total	1286.56			3216.39		459.00	12.31	15.0000	6.67	6.9000
Conditioned Total	1286.56			3216.39		459.00	12.31	15.0000	6.67	6.9000
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: **Demand End Use Components Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

End Uses

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	District Heating [W]	Water [m3/s]
Time of Peak	01-JAN-07:30	-	-	10-JUN-11:00	01-JAN-09:30	01-JAN-09:30
Heating	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	0.00	0.00	0.00	178192.86	0.00	0.00
Interior Lighting	19298.34	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	8877.24	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	1825.80	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	28175.57	0.00	0.00	178192.86	1825.80	0.00

End Uses By Subcategory

	Subcategory	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	District Heating [W]	Water [m3/s]
Heating	General	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	0.00	0.00	0.00	178192.86	0.00	0.00
Interior Lighting	ELECTRIC EQUIPMENT#Block1:Zone1#GeneralLights	19298.34	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	ELECTRIC EQUIPMENT#Block1:Zone1#05	8877.24	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	DHW Block1:Zone1	0.00	0.00	0.00	0.00	1825.80	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Report: **Climatic Data Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Figure A.6

SizingPeriod:DesignDay

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
SUMMER DESIGN DAY IN ONERAFFLESQUAY (01-01:31-12) JUL	34.10	6.10	26.50	Wetbulb [C]	0.00	0.00
WINTER DESIGN DAY IN ONERAFFLESQUAY (01-01:31-12)	23.80	0.00	23.80	Wetbulb [C]	9.20	0.00

Weather Statistics File

	Value
None	

Report: **Envelope Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Opaque Exterior

	Construction	Reflectance	U-Factor with Film [W/m2-K]	U-Factor no Film [W/m2-K]	Gross Area [m2]	Net Area [m2]	Azimuth [deg]	Tilt [deg]	Cardinal Direction
BLOCK1:ZONE1_WALL_2_0_0	LIGHTWEIGHT CURTAIN WALL INSULATED TO 2000 REGS	0.60	0.356	0.376	135.00	47.87	0.00	90.00	N
BLOCK1:ZONE1_WALL_3_0_0	LIGHTWEIGHT CURTAIN WALL INSULATED TO 2000 REGS	0.60	0.356	0.376	94.50	33.62	270.00	90.00	W
BLOCK1:ZONE1_WALL_4_0_0	LIGHTWEIGHT CURTAIN WALL INSULATED TO 2000 REGS	0.60	0.356	0.376	135.00	47.87	180.00	90.00	S
BLOCK1:ZONE1_WALL_5_0_0	LIGHTWEIGHT CURTAIN WALL INSULATED TO 2000 REGS	0.60	0.356	0.376	94.50	33.62	90.00	90.00	E

Exterior Fenestration

	Construction	Glass Area [m2]	Frame Area [m2]	Divider Area [m2]	Area of One Opening [m2]	Area of Multiplied Openings [m2]	Glass U-Factor [W/m2-K]	Glass SHGC	Glass Visible Transmittance	Frame Conductance [W/m2-K]	Divider Conductance [W/m2-K]	Shade Control	
BLOCK1:ZONE1_WALL_2_0_0_0_0_WIN	1001	2.99	0.29	0.07	3.35	87.13	2.761	0.154	0.073	9.500	9.500	No	BLOCK1:ZO
BLOCK1:ZONE1_WALL_3_0_0_0_0_WIN	1001	3.02	0.29	0.07	3.38	60.88	2.761	0.154	0.073	9.500	9.500	No	BLOCK1:ZO
BLOCK1:ZONE1_WALL_4_0_0_0_0_WIN	1001	2.99	0.29	0.07	3.35	87.13	2.761	0.154	0.073	9.500	9.500	No	BLOCK1:ZO
BLOCK1:ZONE1_WALL_5_0_0_0_0_WIN	1001	3.02	0.29	0.07	3.38	60.88	2.761	0.154	0.073	9.500	9.500	No	BLOCK1:ZO
Total or Average						296.00	2.761	0.154	0.073				
North Total or Average						87.13	2.761	0.154	0.073				
Non-North Total or Average						208.88	2.761	0.154	0.073				

Interior Fenestration

	Construction	Area of One Opening [m2]	Area of Openings [m2]	Glass U-Factor [W/m2-K]	Glass SHGC	Glass Visible Transmittance	Parent Surface
Total or Average			0.00	-	-	-	

Exterior Door

	Construction	U-Factor with Film [W/m2-K]	U-Factor no Film [W/m2-K]	Gross Area [m2]	Parent Surface
None					

Report: **Lighting Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Interior Lighting

	Zone	Lighting Power Density [W/m2]	Zone Area [m2]	Total Power [W]	End Use Subcategory	Schedule Name	Scheduled Hours/Week [hr]	Hours/Week > 1% [hr]	Full Load Hours/Week [hr]	Return Air Fraction	Cond
BLOCK1:ZONE1 GENERAL LIGHTING	BLOCK1:ZONE1	15.0000	1286.56	19298.34	ELECTRIC EQUIPMENT#Block1:Zone1#GeneralLights	OFFICE_OPENOFF_LIGHT	60.07	60.07	60.07	0.0000	
Interior Lighting Total		15.0000	1286.56	19298.34							

Daylighting

	Zone	Daylighting Type	Control Type	Fraction Controlled	Lighting Installed in Zone [W]	Lighting Controlled [W]
None						

Figure A.7

Exterior Lighting

	Total Watts	Astronomical Clock/Schedule	Schedule Name	Scheduled Hours/Week [hr]	Hours/Week > 1% [hr]	Full Load Hours/Week [hr]	Consumption [GJ]
Exterior Lighting Total	0.00						0.00

Report: **Equipment Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Central Plant

	Type	Nominal Capacity [W]	Nominal Efficiency [W/W]	IPLV in SI Units [W/W]	IPLV in IP Units [Btu/W-h]
None					

Cooling Coils

	Type	Design Coil Load [W]	Nominal Total Capacity [W]	Nominal Sensible Capacity [W]	Nominal Latent Capacity [W]	Nominal Sensible Heat Ratio	Nominal Efficiency [W/W]	Nominal Coil UA Value [W/C]	Nominal Coil Surface Area [m2]
None									

DX Cooling Coils

	DX Cooling Coil Type	Standard Rated Net Cooling Capacity [W]	Standard Rated Net COP [W/W]	EER [Btu/W-h]	SEER [Btu/W-h]	IEER [Btu/W-h]
None						

DX Cooling Coil ASHRAE 127 Standard Ratings Report

	DX Cooling Coil Type	Rated Net Cooling Capacity Test A [W]	Rated Electric Power Test A [W]	Rated Net Cooling Capacity Test B [W]	Rated Electric Power Test B [W]	Rated Net Cooling Capacity Test C [W]	Rated Electric Power Test C [W]	Rated Net Cooling Capacity Test D [W]	Rated Electric Power Test D [W]
None									

DX Heating Coils

	DX Heating Coil Type	High Temperature Heating (net) Rating Capacity [W]	Low Temperature Heating (net) Rating Capacity [W]	HSPF [Btu/W-h]	Region Number
None					

Heating Coils

	Type	Design Coil Load [W]	Nominal Total Capacity [W]	Nominal Efficiency [W/W]
None				

Fans

	Type	Total Efficiency [W/W]	Delta Pressure [pa]	Max Air Flow Rate [m3/s]	Rated Electric Power [W]	Rated Power Per Max Air Flow Rate [W-s/m3]	Motor Heat In Air Fraction	End Use
None								

Pumps

	Type	Control	Head [pa]	Water Flow [m3/s]	Electric Power [W]	Power Per Water Flow Rate [W-s/m3]	Motor Efficiency [W/W]
None							

Service Water Heating

	Type	Storage Volume [m3]	Input [W]	Thermal Efficiency [W/W]	Recovery Efficiency [W/W]	Energy Factor
None						

Report: **HVAC Sizing Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Zone Sensible Cooling

	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]	Design Day Name	Date/Time Of Peak {TIMESTAMP}	Thermostat Setpoint Temperature at Peak Load [C]	Indoor Temperature at Peak Load [C]	Indoor Humidity Ratio at Peak Load [kgWater/kgAir]	Outdoor Temperature at Peak Load [C]	Outdoo Humidity Rati at Peak Loa [kgWater/kgAir
BLOCK1:ZONE1	62823.63	72247.18	56.16	4.281	4.923	SUMMER DESIGN DAY IN ONERAFFLESQUAY (01-01:31-12) JUL	7/15 16:30:00	24.00	23.98	0.00958	33.49	0.0188

The Design Load is the zone sensible load only. It does not include any system effects or ventilation loads.

Figure A.8

Zone Sensible Heating

	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]	Design Day Name	Date/Time Of Peak {TIMESTAMP}	Thermostat Setpoint Temperature at Peak Load [C]	Indoor Temperature at Peak Load [C]	Indoor Humidity Ratio at Peak Load [kgWater/kgAir]	Outdoor Temperature at Peak Load [C]	Outdoor Humidity Ratio at Peak Load [kgWater/kgAir]
BLOCK1:ZONE1	0.00	0.00	0.00	0.000	1.930	WINTER DESIGN DAY IN ONERAFFLESQUAY (01-01:31-12)		0.00	0.00	0.00000	23.80	0.01872

The Design Load is the zone sensible load only. It does not include any system effects or ventilation loads.

System Design Air Flow Rates

	Calculated cooling [m3/s]	User cooling [m3/s]	Calculated heating [m3/s]	User heating [m3/s]
None				

Plant Loop Coincident Design Fluid Flow Rate Adjustments

	Previous Design Volume Flow Rate [m3/s]	Algorithm Volume Flow Rate [m3/s]	Coincident Design Volume Flow Rate [m3/s]	Coincident Size Adjusted	Peak Sizing Period Name	Peak Day into Period {TIMESTAMP}[day]	Peak Hour Of Day {TIMESTAMP}[hr]	Peak Step Start Minute {TIMESTAMP}[min]
None								

Report: **System Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Economizer

	High Limit Shutoff Control	Minimum Outdoor Air [m3/s]	Maximum Outdoor Air [m3/s]	Return Air Temp Limit	Return Air Enthalpy Limit	Outdoor Air Temperature Limit [C]	Outdoor Air Enthalpy Limit [C]
None							

Demand Controlled Ventilation using Controller:MechanicalVentilation

	Controller:MechanicalVentilation Name	Outdoor Air Per Person [m3/s-person]	Outdoor Air Per Area [m3/s-m2]	Air Distribution Effectiveness in Cooling Mode	Air Distribution Effectiveness in Heating Mode	Air Distribution Effectiveness Schedule
None						

Time Not Comfortable Based on Simple ASHRAE 55-2004

	Winter Clothes [hr]	Summer Clothes [hr]	Summer or Winter Clothes [hr]
BLOCK1:ZONE1	3132.00	158.50	158.50
Facility	3132.00	158.50	158.50

Aggregated over the RunPeriods for Weather

Time Setpoint Not Met

	During Heating [hr]	During Cooling [hr]	During Occupied Heating [hr]	During Occupied Cooling [hr]
BLOCK1:ZONE1	0.00	4.00	0.00	0.00
Facility	0.00	4.00	0.00	0.00

Aggregated over the RunPeriods for Weather

Report: **Outdoor Air Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Average Outdoor Air During Occupied Hours

	Average Number of Occupants	Nominal Number of Occupants	Zone Volume [m3]	Mechanical Ventilation [ach]	Infiltration [ach]	AFN Infiltration [ach]	Simple Ventilation [ach]
BLOCK1:ZONE1	144.74	192.98	3216.39	1.677	0.691	0.000	0.000

Values shown for a single zone without multipliers

Minimum Outdoor Air During Occupied Hours

	Average Number of Occupants	Nominal Number of Occupants	Zone Volume [m3]	Mechanical Ventilation [ach]	Infiltration [ach]	AFN Infiltration [ach]	Simple Ventilation [ach]
BLOCK1:ZONE1	144.74	192.98	3216.39	0.557	0.339	0.000	0.000

Values shown for a single zone without multipliers

Report: **Object Count Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Figure A.9

Surfaces by Class

	Total	Outdoors
Wall	8	4
Floor	6	0
Roof	6	0
Internal Mass	0	0
Building Detached Shading	0	0
Fixed Detached Shading	0	0
Window	4	4
Door	0	0
Glass Door	0	0
Shading	0	0
Overhang	0	0
Fin	0	0
Tubular Daylighting Device Dome	0	0
Tubular Daylighting Device Diffuser	0	0

HVAC

	Count
HVAC Air Loops	0
Conditioned Zones	1
Unconditioned Zones	0
Supply Plenums	0
Return Plenums	0

Input Fields

	Count
IDF Objects	282
Defaulted Fields	20
Fields with Defaults	785
Autosized Fields	4
Autosizable Fields	4
Autocalculated Fields	10
Autocalculatable Fields	52

Report: **Sensible Heat Gain Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2019-10-10 11:49:17**

Annual Building Sensible Heat Gain Components

	HVAC Zone Eq & Other Sensible Air Heating [GJ]	HVAC Zone Eq & Other Sensible Air Cooling [GJ]	HVAC Terminal Unit Sensible Air Heating [GJ]	HVAC Terminal Unit Sensible Air Cooling [GJ]	HVAC Input Heated Surface Heating [GJ]	HVAC Input Cooled Surface Cooling [GJ]	People Sensible Heat Addition [GJ]	Lights Sensible Heat Addition [GJ]	Equipment Sensible Heat Addition [GJ]	Window Heat Addition [GJ]	Interzone Air Transfer Heat Addition [GJ]	Infiltration Heat Addition [GJ]	Opaque Surface Conduction and Other Heat Addition [GJ]	Equipment Sensible Heat Removal [GJ]	Window Heat Removal [GJ]	Int… Tr… Re
BLOCK1:ZONE1	0.000	-558.692	0.000	0.000	0.000	0.000	111.733	217.593	117.685	134.602	0.000	43.096	0.014	0.000	-32.055	
Total Facility	0.000	-558.692	0.000	0.000	0.000	0.000	111.733	217.593	117.685	134.602	0.000	43.096	0.014	0.000	-32.055	

Peak Cooling Sensible Heat Gain Components

	Time of Peak {TIMESTAMP}	HVAC Zone Eq & Other Sensible Air Heating [W]	HVAC Zone Eq & Other Sensible Air Cooling [W]	HVAC Terminal Unit Sensible Air Heating [W]	HVAC Terminal Unit Sensible Air Cooling [W]	HVAC Input Heated Surface Heating [W]	HVAC Input Cooled Surface Cooling [W]	People Sensible Heat Addition [W]	Lights Sensible Heat Addition [W]	Equipment Sensible Heat Addition [W]	Window Heat Addition [W]	Interzone Air Transfer Heat Addition [W]	Infiltration Heat Addition [W]	Opaque Surface Conduction and Other Heat Addition [W]	Equipmen Sensibl Hea Remova [W
BLOCK1:ZONE1	22-JUL-05:11	0.00	-77421.41	0.00	0.00	0.00	0.00	0.00	0.00	478.84	0.00	0.00	1419.82	78461.75	0.0
Total Facility	22-JUL-05:11	0.00	-77421.41	0.00	0.00	0.00	0.00	0.00	0.00	478.84	0.00	0.00	1419.82	78461.75	0.0

Peak Heating Sensible Heat Gain Components

	Time of Peak {TIMESTAMP}	HVAC Zone Eq & Other Sensible Air Heating [W]	HVAC Zone Eq & Other Sensible Air Cooling [W]	HVAC Terminal Unit Sensible Air Heating [W]	HVAC Terminal Unit Sensible Air Cooling [W]	HVAC Input Heated Surface Heating [W]	HVAC Input Cooled Surface Cooling [W]	People Sensible Heat Addition [W]	Lights Sensible Heat Addition [W]	Equipment Sensible Heat Addition [W]	Window Heat Addition [W]	Interzone Air Transfer Heat Addition [W]	Infiltration Heat Addition [W]	Opaque Surface Conduction and Other Heat Addition [W]	Equipmen Sensibl Hea Remova [W
BLOCK1:ZONE1	22-AUG-05:03	74.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	478.84	0.00	0.00	0.00	1997.80	0.0

Figure A.10

A.3. Design solution of the second optimization

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
0		DOE_A...	30	0.9	2	1	2	0	3	0.6	0.6	0.4	0.6	2.9114E1	1.0000E2	3.1820E1	2.2200E2	220	24
1		DOE_A...	30	0.9	2	1	4	1	1	0.2	0.5	0.2	0.3	2.8202E1	1.0000E2	0.0000E0	9.0000E1	142	25
2		DOE_A...	30	0.1	3	1	2	0	3	0.3	0.2	0.5	0.5	2.7983E1	1.0000E2	1.1360E1	1.7100E2	134	50
3		ULH	28	0.5	1	1	1	0	1	0.7	0.7	0.7	0.5	2.7357E1	1.0000E2	5.0000E1	5.6700E2	162	18
4		DOE_A...	24	0.1	4	0	1	1	0	0.5	0.7	0.2	0.4	2.4820E1	1.0000E2	3.8640E1	6.7200E2	207	5
5		DOE_A...	28	0.9	0	0	2	0	2	0.6	0.2	0.7	0.3	2.8009E1	1.0000E2	3.6360E1	3.9600E2	213	5
6		DOE_A...	26	0.5	1	0	4	0	1	0.3	0.5	0.3	0.7	2.6143E1	1.0000E2	2.9550E1	3.2100E2	147	6
7		DOE_A...	24	0.9	0	0	3	1	2	0.5	0.4	0.3	0.7	2.5619E1	1.0000E2	4.5450E1	4.7700E2	295	4
8		DOE_A...	26	0.1	3	1	3	1	0	0.4	0.3	0.6	0.2	2.6150E1	1.0000E2	3.6360E1	2.6400E2	200	47
9		DOE_A...	24	0.1	4	0	4	1	2	0.3	0.4	0.5	0.3	2.4765E1	1.0000E2	4.5450E1	1.6200E2	201	4
10		pilOPT	28	0.5	2	1	3	1	2	0.5	0.5	0.5	0.5	2.8059E1	1.0000E2	5.0000E1	3.8700E2	242	16
11		pilOPT	24	0.1	2	0	4	1	3	0.2	0.7	0.2	0.7	2.5377E1	1.0000E2	2.5000E1	1.4700E2	269	5
12		pilOPT	30	0.1	0	1	4	0	3	0.2	0.7	0.7	0.7	2.9012E1	9.7922E1	4.0910E1	1.5900E2	224	22
13		pilOPT	24	0.1	0	0	1	1	0	0.7	0.7	0.7	0.2	2.5662E1	1.0000E2	4.5450E1	1.0110E3	316	4
14		pilOPT	24	0.1	0	0	4	1	3	0.2	0.7	0.7	0.7	2.5704E1	1.0000E2	4.0910E1	1.5900E2	319	4
15		pilOPT	30	0.1	0	0	1	1	3	0.7	0.2	0.7	0.2	2.8818E1	1.0000E2	2.5000E1	2.0400E2	221	5
16		pilOPT	24	0.1	4	1	4	0	3	0.2	0.2	0.2	0.7	2.4801E1	1.0000E2	9.0900E0	1.5300E2	197	36
17		pilOPT	24	0.9	2	0	1	0	3	0.7	0.7	0.2	0.2	2.5328E1	1.0000E2	2.2730E1	1.9800E2	237	5
18		pilOPT	24	0.9	0	1	4	0	3	0.2	0.7	0.2	0.2	2.5273E1	1.0000E2	1.5910E1	6.0000E1	250	28
19		pilOPT	30	0.1	2	0	4	0	0	0.2	0.7	0.2	0.2	2.8411E1	1.0000E2	2.0450E1	1.3800E2	136	6
20		pilOPT	24	0.9	0	0	4	1	3	0.2	0.7	0.2	0.2	2.5237E1	1.0000E2	1.5910E1	6.0000E1	260	6
21		pilOPT	24	0.9	4	1	1	0	0	0.2	0.7	0.2	0.7	2.4807E1	1.0000E2	2.9550E1	3.7200E2	195	30
22		pilOPT	24	0.9	2	0	4	1	0	0.7	0.2	0.7	0.7	2.5066E1	1.0000E2	3.4090E1	3.6300E2	244	7
23		pilOPT	24	0.1	4	1	1	1	3	0.2	0.7	0.7	0.7	2.4987E1	1.0000E2	4.0910E1	1.5900E2	236	24
24		pilOPT	30	0.9	2	1	1	0	3	0.7	0.7	0.2	0.7	2.9157E1	1.0000E2	3.4090E1	2.7300E2	225	25
25		pilOPT	30	0.5	2	0	4	0	0	0.2	0.6	0.2	0.5	2.8137E1	1.0000E2	2.5000E1	1.4400E2	127	7
26		pilOPT	30	0.9	0	1	4	1	0	0.2	0.7	0.2	0.2	2.8120E1	1.0000E2	1.5910E1	3.9000E1	167	38
27		pilOPT	30	0.5	2	0	4	0	0	0.5	0.6	0.2	0.5	2.8246E1	1.0000E2	3.4090E1	2.6100E2	140	7
28		pilOPT	30	0.1	4	1	1	0	3	0.2	0.2	0.7	0.7	2.8399E1	1.0000E2	2.5000E1	1.5000E2	144	32
29		pilOPT	28	0.5	1	0	4	1	2	0.7	0.7	0.3	0.5	2.7434E1	1.0000E2	4.7730E1	5.4000E2	178	5
30		pilOPT	30	0.9	2	1	1	0	0	0.7	0.7	0.7	0.7	2.8926E1	1.0000E2	5.0000E1	8.9700E2	208	13
31		pilOPT	28	0.5	1	0	4	0	1	0.5	0.7	0.4	0.5	2.7082E1	1.0000E2	4.0910E1	3.6300E2	122	5
32		pilOPT	24	0.1	2	0	4	0	0	0.2	0.7	0.2	0.2	2.4915E1	1.0000E2	2.0450E1	1.3800E2	198	6
33		pilOPT	28	0.5	0	0	3	1	2	0.7	0.7	0.5	0.5	2.8179E1	1.0000E2	5.0000E1	5.4900E2	264	3
34		pilOPT	24	0.9	2	0	4	0	0	0.2	0.7	0.2	0.2	2.4676E1	1.0000E2	1.5910E1	3.9000E1	175	8
35		pilOPT	30	0.5	4	0	3	0	0	0.5	0.2	0.5	0.3	2.7836E1	1.0000E2	2.5000E1	1.9800E2	96	7
36		pilOPT	24	0.9	2	0	4	0	0	0.2	0.7	0.2	0.7	2.4867E1	1.0000E2	2.5000E1	1.9200E2	195	7
37		pilOPT	28	0.5	1	0	4	1	2	0.7	0.7	0.5	0.5	2.7441E1	1.0000E2	5.0000E1	5.4900E2	184	4
38		pilOPT	24	0.9	0	0	4	1	3	0.7	0.2	0.2	0.7	2.5568E1	1.0000E2	1.5910E1	2.5800E2	288	5
39		pilOPT	24	0.1	0	1	4	1	0	0.2	0.2	0.7	0.2	2.5116E1	1.0000E2	1.8180E1	2.3700E2	266	28
40		pilOPT	24	0.1	4	0	4	1	3	0.7	0.2	0.7	0.2	2.4819E1	1.0000E2	2.5000E1	2.0400E2	209	6
41		pilOPT	30	0.9	2	1	4	1	3	0.7	0.7	0.7	0.7	2.9215E1	1.0000E2	5.0000E1	2.6400E2	264	20
42		pilOPT	24	0.1	2	0	4	1	3	0.7	0.7	0.2	0.7	2.5614E1	1.0000E2	3.4090E1	2.7300E2	293	5
43		pilOPT	30	0.1	0	1	4	0	3	0.2	0.7	0.2	0.7	2.8963E1	1.0000E2	2.5000E1	1.4700E2	213	26
44		pilOPT	30	0.9	2	0	1	1	0	0.7	0.7	0.7	0.7	2.8810E1	1.0000E2	5.0000E1	8.9700E2	218	3
45		pilOPT	30	0.5	4	0	1	0	0	0.2	0.2	0.2	0.2	2.7955E1	1.0000E2	0.0000E0	7.8000E1	96	7
46		pilOPT	24	0.1	0	0	4	1	3	0.2	0.7	0.7	0.7	2.5704E1	1.0000E2	4.0910E1	1.5900E2	319	4
47		pilOPT	24	0.1	4	1	4	0	3	0.2	0.7	0.2	0.7	2.4878E1	1.0000E2	2.5000E1	1.4700E2	203	31
48		pilOPT	24	0.9	2	0	1	0	0	0.2	0.7	0.2	0.7	2.5190E1	1.0000E2	2.9550E1	3.7200E2	221	5
49		pilOPT	30	0.1	2	1	4	0	0	0.2	0.7	0.2	0.2	2.8587E1	1.0000E2	2.0450E1	1.3800E2	159	30
50		pilOPT	30	0.1	2	0	4	0	3	0.2	0.7	0.2	0.2	2.8733E1	1.0000E2	1.5910E1	6.0000E1	153	6
51		pilOPT	24	0.9	2	1	1	1	0	0.2	0.7	0.2	0.7	2.5281E1	1.0000E2	2.9550E1	3.7200E2	273	26
52		pilOPT	30	0.9	2	0	4	1	0	0.7	0.2	0.7	0.2	2.8039E1	1.0000E2	2.5000E1	2.1900E2	150	7
53		pilOPT	30	0.5	1	0	4	1	0	0.7	0.7	0.6	0.2	2.7703E1	1.0000E2	4.0910E1	3.1500E2	135	8
54		pilOPT	24	0.9	4	1	1	1	3	0.2	0.7	0.7	0.7	2.4987E1	1.0000E2	4.0910E1	1.5900E2	236	24
55		pilOPT	30	0.5	4	0	4	1	0	0.6	0.6	0.2	0.2	2.7779E1	1.0000E2	2.5000E1	2.1600E2	115	8
56		pilOPT	30	0.9	2	1	4	0	0	0.7	0.7	0.2	0.7	2.8401E1	1.0000E2	3.4090E1	3.7800E2	178	33
57		pilOPT	30	0.5	0	0	4	1	0	0.7	0.7	0.7	0.2	2.8181E1	1.0000E2	4.0910E1	3.2400E2	184	5
58		pilOPT	24	0.1	0	0	4	1	3	0.7	0.2	0.2	0.2	2.5301E1	1.0000E2	9.0900E0	2.0700E2	260	6
59		pilOPT	30	0.5	4	0	4	0	0	0.3	0.2	0.2	0.2	2.7757E1	1.0000E2	0.0000E0	5.1000E1	92	10
60		pilOPT	24	0.9	2	0	4	0	0	0.2	0.7	0.7	0.7	2.4977E1	1.0000E2	4.0910E1	1.8900E2	208	5
61		pilOPT	24	0.1	0	1	1	1	0	0.2	0.2	0.7	0.7	2.5538E1	1.0000E2	2.9550E1	7.5000E2	306	23
62		pilOPT	30	0.9	2	1	4	1	3	0.7	0.7	0.7	0.7	2.9215E1	9.7922E1	5.0000E1	2.6400E2	264	20
63		pilOPT	30	0.9	4	0	4	0	0	0.3	0.2	0.2	0.2	2.7728E1	1.0000E2	0.0000E0	4.2000E1	91	10
64		pilOPT	30	0.1	2	0	4	1	3	0.7	0.7	0.2	0.7	2.8993E1	1.0000E2	3.4090E1	2.7300E2	224	5
65		pilOPT	30	0.1	2	0	4	0	0	0.7	0.7	0.7	0.7	2.8927E1	1.0000E2	5.0000E1	1.1070E3	199	3
66		pilOPT	30	0.9	2	0	4	0	0	0.7	0.2	0.2	0.2	2.8031E1	1.0000E2	9.0900E0	1.8300E2	124	9
67		pilOPT	24	0.9	0	0	4	1	3	0.2	0.7	0.2	0.2	2.5237E1	1.0000E2	1.5910E1	6.0000E1	260	6
68		pilOPT	30	0.9	4	0	4	0	0	0.2	0.2	0.5	0.2	2.7712E1	1.0000E2	0.0000E0	3.9000E1	89	9
69		pilOPT	24	0.9	0	0	4	1	3	0.7	0.7	0.7	0.2	2.5692E1	1.0000E2	4.0910E1	2.1000E2	320	5
70		pilOPT	30	0.9	2	1	1	0	0	0.7	0.2	0.7	0.2	2.8747E1	1.0000E2	2.9550E1	4.8600E2	193	27

Figure A.11

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
71		pilOPT	30	0.5	4	0	4	0	0	0.2	0.2	0.5	0.2	2.7746E1	1.0000E2	1.5910E1	3.9000E1	90	9
72		pilOPT	24	0.1	4	0	4	0	0	0.2	0.7	0.2	0.2	2.4595E1	1.0000E2	2.0450E1	1.3800E2	163	7
73		pilOPT	30	0.9	2	1	4	0	0	0.2	0.7	0.2	0.7	2.8322E1	1.0000E2	2.5000E1	1.9200E2	159	36
74		pilOPT	30	0.5	2	0	4	0	0	0.7	0.7	0.7	0.7	2.8488E1	1.0000E2	5.0000E1	5.4300E2	173	3
75		pilOPT	30	0.9	0	0	4	1	0	0.7	0.2	0.2	0.2	2.7976E1	1.0000E2	9.0900E0	1.8300E2	149	8
76		pilOPT	30	0.9	3	0	4	0	0	0.7	0.7	0.4	0.7	2.7457E1	1.0000E2	3.8640E1	3.4200E2	88	10
77		pilOPT	30	0.9	3	0	4	0	0	0.7	0.7	0.5	0.7	2.7444E1	1.0000E2	4.0910E1	3.4800E2	87	9
78		pilOPT	30	0.9	3	0	4	0	0	0.7	0.7	0.5	0.6	2.7444E1	1.0000E2	4.0910E1	2.9700E2	87	9
79		pilOPT	30	0.9	1	0	4	0	0	0.7	0.7	0.7	0.7	2.7652E1	1.0000E2	5.0000E1	3.8100E2	118	6
80		pilOPT	24	0.9	0	0	4	1	3	0.7	0.7	0.7	0.7	2.5959E1	1.0000E2	5.0000E1	2.6400E2	348	4
81		pilOPT	30	0.9	0	0	4	0	0	0.7	0.7	0.7	0.7	2.8188E1	1.0000E2	5.0000E1	3.8100E2	174	4
82		pilOPT	24	0.9	0	0	4	0	3	0.7	0.2	0.2	0.7	2.5544E1	1.0000E2	1.5910E1	2.5800E2	257	5
83		pilOPT	30	0.1	0	1	1	1	3	0.7	0.2	0.7	0.7	2.9069E1	1.0000E2	3.4090E1	3.0000E2	268	25
84		pilOPT	30	0.1	2	0	4	0	0	0.7	0.7	0.2	0.7	2.8789E1	1.0000E2	3.8640E1	8.7300E2	183	5
85		pilOPT	24	0.9	0	0	4	1	3	0.2	0.7	0.7	0.7	2.5704E1	1.0000E2	4.0910E1	1.5900E2	319	4
86		pilOPT	30	0.1	0	0	1	1	3	0.7	0.2	0.2	0.2	2.8713E1	1.0000E2	9.0900E0	2.0700E2	199	6
87		pilOPT	24	0.1	4	1	4	0	3	0.2	0.7	0.2	0.7	2.4878E1	1.0000E2	2.5000E1	1.4700E2	203	31
88		pilOPT	24	0.9	0	0	4	1	0	0.7	0.7	0.7	0.2	2.5096E1	1.0000E2	4.0910E1	2.2500E2	254	6
89		pilOPT	30	0.9	4	0	4	0	0	0.2	0.2	0.2	0.2	2.7740E1	1.0000E2	0.0000E0	3.9000E1	90	10
90		pilOPT	24	0.9	2	0	4	1	3	0.2	0.7	0.2	0.2	2.5118E1	1.0000E2	1.5910E1	6.0000E1	244	6
91		pilOPT	30	0.9	2	1	1	0	3	0.2	0.7	0.7	0.2	2.8959E1	1.0000E2	3.1820E1	6.6000E1	194	28
92		pilOPT	30	0.9	4	0	4	0	0	0.7	0.2	0.7	0.2	2.7745E1	1.0000E2	2.5000E1	2.1900E2	97	8
93		pilOPT	30	0.9	0	0	4	0	0	0.2	0.7	0.2	0.7	2.8048E1	1.0000E2	2.5000E1	1.9200E2	138	7
94		pilOPT	30	0.9	4	0	4	0	0	0.6	0.7	0.7	0.6	2.7735E1	1.0000E2	5.0000E1	2.7300E2	98	5
95		pilOPT	30	0.9	4	0	4	0	0	0.7	0.7	0.2	0.7	2.7793E1	1.0000E2	3.4090E1	3.7800E2	103	8
96		pilOPT	30	0.9	4	0	4	0	0	0.7	0.7	0.7	0.7	2.7757E1	1.0000E2	5.0000E1	3.8100E2	103	5
97		pilOPT	30	0.9	4	0	3	0	0	0.5	0.6	0.6	0.4	2.7763E1	1.0000E2	4.3180E1	1.5900E2	97	6
98		pilOPT	30	0.9	2	0	4	1	3	0.7	0.7	0.2	0.7	2.8993E1	1.0000E2	3.4090E1	2.7300E2	224	5
99		pilOPT	30	0.5	1	0	1	0	0	0.4	0.6	0.7	0.3	2.7951E1	1.0000E2	5.0000E1	4.9200E2	122	5
100		pilOPT	30	0.9	4	0	4	1	0	0.7	0.7	0.2	0.2	2.7740E1	1.0000E2	2.5000E1	1.9800E2	117	8
101		pilOPT	30	0.9	4	0	4	0	0	0.4	0.2	0.7	0.2	2.7710E1	1.0000E2	1.5910E1	7.2000E1	91	9
102		pilOPT	30	0.9	2	0	4	0	0	0.7	0.7	0.2	0.7	2.8220E1	1.0000E2	3.4090E1	3.7800E2	150	7
103		pilOPT	30	0.5	1	0	1	0	0	0.5	0.6	0.7	0.2	2.7960E1	1.0000E2	4.5450E1	5.2200E2	122	6
104		pilOPT	30	0.9	0	0	4	0	0	0.2	0.7	0.7	0.2	2.7965E1	1.0000E2	3.1820E1	4.2000E1	132	6
105		pilOPT	30	0.5	4	0	4	0	0	0.2	0.2	0.2	0.2	2.7764E1	1.0000E2	0.0000E0	3.9000E1	91	10
106		pilOPT	30	0.9	2	0	4	0	3	0.7	0.7	0.7	0.7	2.9184E1	9.7922E1	5.0000E1	2.6400E2	221	4
107		pilOPT	30	0.9	2	0	1	1	1	0.4	0.7	0.7	0.7	2.8576E1	1.0000E2	5.0000E1	3.0600E2	182	3
108		pilOPT	30	0.1	3	0	2	0	0	0.7	0.7	0.7	0.7	2.7582E1	1.0000E2	5.0000E1	1.3380E3	93	4
109		pilOPT	24	0.1	0	0	1	0	1	0.7	0.7	0.7	0.7	2.5885E1	1.0000E2	5.0000E1	1.2330E3	308	3
110		pilOPT	30	0.9	4	0	4	0	0	0.2	0.4	0.3	0.2	2.7686E1	1.0000E2	0.0000E0	3.6000E1	88	9
111		pilOPT	30	0.9	2	0	4	0	0	0.7	0.7	0.7	0.7	2.8271E1	1.0000E2	5.0000E1	3.8100E2	161	4
112		pilOPT	28	0.1	0	0	2	0	0	0.7	0.7	0.7	0.7	2.8198E1	1.0000E2	5.0000E1	1.3380E3	249	3
113		pilOPT	30	0.1	0	0	1	0	0	0.7	0.7	0.7	0.7	2.9046E1	1.0000E2	5.0000E1	1.4190E3	219	3
114		pilOPT	24	0.5	0	0	1	0	1	0.7	0.7	0.7	0.7	2.5696E1	1.0000E2	5.0000E1	6.4500E2	277	3
115		pilOPT	30	0.9	4	0	4	0	0	0.2	0.3	0.7	0.2	2.7697E1	1.0000E2	1.5910E1	4.2000E1	90	9
116		pilOPT	30	0.5	4	0	4	0	0	0.2	0.2	0.2	0.2	2.7764E1	1.0000E2	0.0000E0	3.9000E1	91	10
117		pilOPT	30	0.1	4	0	4	0	0	0.2	0.2	0.2	0.2	2.7906E1	1.0000E2	0.0000E0	7.5000E1	95	8
118		pilOPT	30	0.9	4	0	4	0	0	0.2	0.2	0.7	0.2	2.7720E1	1.0000E2	1.5910E1	4.2000E1	90	9
119		pilOPT	30	0.9	2	0	4	0	0	0.7	0.7	0.7	0.2	2.8134E1	1.0000E2	4.0910E1	2.2500E2	143	6
120		pilOPT	30	0.9	0	0	4	0	0	0.2	0.2	0.2	0.2	2.7896E1	1.0000E2	0.0000E0	3.9000E1	105	9
121		pilOPT	30	0.9	4	0	4	0	0	0.7	0.7	0.7	0.2	2.7722E1	1.0000E2	4.0910E1	2.2500E2	99	7
122		pilOPT	30	0.9	4	0	1	0	0	0.2	0.2	0.2	0.2	2.7929E1	1.0000E2	0.0000E0	6.6000E1	95	8
123		pilOPT	30	0.9	0	0	1	0	0	0.7	0.7	0.7	0.7	2.8788E1	1.0000E2	5.0000E1	8.9700E2	212	3
124		pilOPT	24	0.1	3	0	4	1	2	0.4	0.5	0.5	0.2	2.4562E1	1.0000E2	4.3180E1	1.6800E2	182	9
125		pilOPT	30	0.1	4	0	2	0	0	0.6	0.7	0.7	0.6	2.8192E1	1.0000E2	5.0000E1	1.1700E3	127	3
126		pilOPT	28	0.5	1	0	4	0	2	0.6	0.7	0.3	0.6	2.7419E1	1.0000E2	4.0910E1	5.3700E2	155	5
127		pilOPT	30	0.1	4	0	2	0	0	0.7	0.7	0.7	0.6	2.8208E1	1.0000E2	5.0000E1	1.2180E3	129	3
128		pilOPT	30	0.5	1	0	1	0	1	0.4	0.6	0.7	0.3	2.7925E1	1.0000E2	5.0000E1	3.3600E2	120	5
129		pilOPT	30	0.1	4	0	4	0	0	0.7	0.3	0.2	0.2	2.7962E1	1.0000E2	1.8180E1	4.2000E2	105	7
130		pilOPT	30	0.1	4	0	4	0	0	0.2	0.2	0.2	0.2	2.7906E1	1.0000E2	0.0000E0	7.5000E1	95	8
131		pilOPT	30	0.9	3	0	3	0	1	0.7	0.7	0.4	0.5	2.7427E1	1.0000E2	4.0910E1	1.9200E2	84	6
132		pilOPT	24	0.5	0	0	1	0	1	0.7	0.7	0.6	0.7	2.5675E1	1.0000E2	5.0000E1	6.3900E2	273	3
133		pilOPT	26	0.5	0	0	1	0	1	0.7	0.7	0.7	0.7	2.7053E1	1.0000E2	5.0000E1	6.4500E2	251	3
134		pilOPT	26	0.5	0	0	2	1	2	0.7	0.7	0.6	0.4	2.7179E1	1.0000E2	5.0000E1	5.0100E2	299	3
135		pilOPT	30	0.9	0	0	2	0	2	0.6	0.2	0.7	0.5	2.8930E1	1.0000E2	3.8640E1	5.4300E2	208	5
136		pilOPT	24	0.5	0	0	3	1	2	0.6	0.5	0.5	0.7	2.5785E1	1.0000E2	5.0000E1	5.4000E2	319	3
137		pilOPT	30	0.9	3	0	3	0	1	0.6	0.7	0.5	0.5	2.7423E1	1.0000E2	4.7730E1	1.6800E2	83	6
138		pilOPT	24	0.9	0	1	4	1	3	0.7	0.7	0.7	0.7	2.6002E1	1.0000E2	5.0000E1	2.6400E2	367	20
139		pilOPT	30	0.9	3	0	2	0	0	0.7	0.7	0.7	0.6	2.7490E1	1.0000E2	5.0000E1	5.8200E2	89	6
140		pilOPT	24	0.1	0	0	2	1	1	0.5	0.7	0.7	0.4	2.5642E1	1.0000E2	5.0000E1	8.3100E2	304	3
141		pilOPT	30	0.9	4	0	3	0	1	0.6	0.6	0.3	0.5	2.7734E1	1.0000E2	3.6360E1	1.5600E2	90	4

Figure A.12

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
142		pilOPT	30	0.1	3	1	1	0	3	0.3	0.2	0.5	0.5	2.7983E1	1.0000E2	1.1360E1	1.7100E2	134	50
143		pilOPT	30	0.9	4	0	1	0	0	0.2	0.3	0.2	0.2	2.7921E1	1.0000E2	1.1360E1	6.6000E1	95	7
144		pilOPT	30	0.9	4	0	2	0	0	0.6	0.7	0.6	0.4	2.7890E1	1.0000E2	5.0000E1	4.2300E2	104	5
145		pilOPT	30	0.9	4	0	4	0	0	0.5	0.3	0.7	0.2	2.7695E1	1.0000E2	2.5000E1	1.2000E2	92	8
146		pilOPT	28	0.9	0	0	1	0	0	0.7	0.7	0.7	0.7	2.8025E1	1.0000E2	5.0000E1	8.9700E2	231	3
147		pilOPT	30	0.1	4	0	4	0	0	0.4	0.2	0.2	0.2	2.7929E1	1.0000E2	9.0900E0	2.0400E2	99	8
148		pilOPT	28	0.9	1	0	1	0	0	0.7	0.7	0.7	0.5	2.7328E1	1.0000E2	5.0000E1	7.9800E2	154	4
149		pilOPT	30	0.9	0	0	1	0	0	0.7	0.7	0.7	0.6	2.8776E1	1.0000E2	5.0000E1	8.3700E2	210	3
150		pilOPT	30	0.5	2	0	1	0	0	0.7	0.7	0.7	0.7	2.9008E1	1.0000E2	5.0000E1	1.0950E3	204	3
151		pilOPT	24	0.9	3	0	4	0	0	0.2	0.7	0.7	0.7	2.4512E1	1.0000E2	4.0910E1	1.8900E2	151	8
152		pilOPT	30	0.9	2	0	3	0	1	0.7	0.7	0.3	0.5	2.8226E1	1.0000E2	3.6360E1	1.9800E2	126	4
153		pilOPT	30	0.5	3	0	1	0	0	0.7	0.7	0.7	0.7	2.7560E1	1.0000E2	5.0000E1	1.0950E3	91	4
154		pilOPT	26	0.5	0	0	1	0	1	0.7	0.7	0.6	0.7	2.7039E1	1.0000E2	5.0000E1	6.3900E2	248	3
155		pilOPT	26	0.5	2	0	1	0	1	0.7	0.7	0.7	0.7	2.7016E1	1.0000E2	5.0000E1	6.4500E2	234	3
156		pilOPT	30	0.9	3	0	3	0	1	0.6	0.7	0.4	0.5	2.7436E1	1.0000E2	4.3180E1	1.7100E2	84	7
157		pilOPT	28	0.5	0	0	1	0	2	0.7	0.7	0.6	0.5	2.8189E1	1.0000E2	5.0000E1	5.6400E2	244	3
158		pilOPT	28	0.5	0	0	1	0	1	0.7	0.7	0.7	0.7	2.8011E1	1.0000E2	5.0000E1	6.4500E2	217	3
159		pilOPT	28	0.5	0	0	1	0	0	0.7	0.7	0.7	0.6	2.8092E1	1.0000E2	5.0000E1	1.0140E3	236	3
160		pilOPT	30	0.5	4	0	2	0	0	0.6	0.7	0.7	0.5	2.8010E1	1.0000E2	5.0000E1	6.0900E2	111	3
161		pilOPT	30	0.5	4	0	2	0	0	0.6	0.7	0.6	0.5	2.7995E1	1.0000E2	5.0000E1	5.2800E2	110	4
162		pilOPT	30	0.5	4	0	1	0	0	0.6	0.7	0.7	0.6	2.8140E1	1.0000E2	5.0000E1	9.1200E2	124	3
163		pilOPT	30	0.5	4	0	2	0	0	0.6	0.7	0.6	0.6	2.8017E1	1.0000E2	5.0000E1	6.0000E2	112	3
164		pilOPT	30	0.5	4	0	2	1	1	0.2	0.7	0.5	0.7	2.7925E1	1.0000E2	4.3180E1	3.4800E2	124	3
165		pilOPT	30	0.9	0	0	1	0	2	0.6	0.2	0.7	0.4	2.8900E1	1.0000E2	3.6360E1	4.5000E2	204	5
166		pilOPT	30	0.5	4	0	4	1	1	0.3	0.4	0.6	0.6	2.7727E1	1.0000E2	3.8640E1	3.2400E2	113	4
167		pilOPT	24	0.1	0	0	1	1	0	0.5	0.2	0.2	0.2	2.5186E1	1.0000E2	1.3640E1	3.4200E2	245	5
168		pilOPT	30	0.5	4	0	4	1	1	0.3	0.3	0.5	0.5	2.7740E1	1.0000E2	2.7270E1	2.9100E2	110	5
169		pilOPT	24	0.5	0	0	3	1	2	0.3	0.5	0.5	0.7	2.5634E1	1.0000E2	5.0000E1	3.6900E2	302	3
170		pilOPT	30	0.9	4	0	4	1	2	0.2	0.3	0.5	0.6	2.8099E1	1.0000E2	3.4090E1	2.4000E2	134	5
171		pilOPT	30	0.5	3	0	4	1	3	0.7	0.7	0.2	0.7	2.7675E1	1.0000E2	3.4090E1	2.7300E2	117	9
172		pilOPT	30	0.5	2	0	2	0	0	0.6	0.7	0.7	0.6	2.8758E1	1.0000E2	5.0000E1	6.7200E2	184	3
173		pilOPT	24	0.9	1	1	4	1	3	0.7	0.7	0.7	0.3	2.5138E1	1.0000E2	4.0910E1	2.1300E2	265	31
174		pilOPT	30	0.9	4	0	3	0	1	0.6	0.6	0.4	0.4	2.7720E1	1.0000E2	3.8640E1	1.5900E2	89	4
175		pilOPT	24	0.1	0	0	4	1	1	0.7	0.7	0.7	0.7	2.5676E1	1.0000E2	5.0000E1	1.1340E3	305	3
176		pilOPT	30	0.9	4	0	3	0	1	0.5	0.6	0.5	0.4	2.7714E1	1.0000E2	3.8640E1	1.4700E2	89	4
177		pilOPT	24	0.1	0	0	3	1	1	0.6	0.7	0.7	0.4	2.5636E1	1.0000E2	5.0000E1	8.8800E2	301	3
178		pilOPT	30	0.5	0	0	2	1	1	0.6	0.7	0.7	0.7	2.8484E1	1.0000E2	5.0000E1	5.9400E2	192	3
179		pilOPT	30	0.5	3	1	1	0	3	0.6	0.7	0.6	0.3	2.7876E1	1.0000E2	3.8640E1	2.1900E2	125	46
180		pilOPT	30	0.9	2	0	1	1	1	0.6	0.7	0.7	0.7	2.8619E1	1.0000E2	5.0000E1	4.1400E2	188	3
181		pilOPT	30	0.1	1	0	1	0	0	0.4	0.5	0.2	0.2	2.8009E1	1.0000E2	2.9550E1	2.4900E2	119	7
182		pilOPT	30	0.1	4	1	4	0	0	0.3	0.3	0.7	0.2	2.8175E1	1.0000E2	2.5000E1	3.3000E2	125	31
183		pilOPT	30	0.9	0	0	1	1	0	0.7	0.3	0.7	0.2	2.8545E1	1.0000E2	4.0910E1	5.1000E2	199	5
184		pilOPT	30	0.1	4	0	4	0	0	0.4	0.2	0.2	0.7	2.8033E1	1.0000E2	2.2730E1	4.8300E2	110	7
185		pilOPT	28	0.5	0	0	2	1	2	0.5	0.7	0.7	0.7	2.8221E1	1.0000E2	5.0000E1	6.0000E2	272	3
186		pilOPT	30	0.5	3	0	4	0	0	0.2	0.2	0.3	0.2	2.7641E1	1.0000E2	0.0000E0	3.9000E1	88	11
187		pilOPT	24	0.9	3	0	4	0	0	0.2	0.6	0.6	0.6	2.4493E1	1.0000E2	4.0910E1	1.4700E2	150	9
188		pilOPT	30	0.9	2	0	1	0	0	0.7	0.6	0.7	0.7	2.8881E1	1.0000E2	5.0000E1	8.5800E2	195	3
189		pilOPT	28	0.9	2	0	2	1	0	0.7	0.7	0.7	0.7	2.7835E1	1.0000E2	5.0000E1	6.2700E2	223	3
190		pilOPT	30	0.9	4	0	3	0	1	0.5	0.6	0.4	0.4	2.7720E1	1.0000E2	3.6360E1	1.4700E2	89	4
191		pilOPT	30	0.1	3	0	2	0	2	0.6	0.6	0.7	0.7	2.7601E1	1.0000E2	5.0000E1	6.4500E2	93	4
192		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.4	0.4	2.7605E1	1.0000E2	6.8200E0	8.7000E1	85	4
193		pilOPT	28	0.9	2	0	1	0	0	0.7	0.7	0.7	0.7	2.8005E1	1.0000E2	5.0000E1	8.9700E2	211	3
194		pilOPT	28	0.9	0	0	2	0	1	0.7	0.7	0.7	0.7	2.7614E1	1.0000E2	5.0000E1	3.3000E2	175	3
195		pilOPT	30	0.5	0	0	2	0	1	0.6	0.7	0.7	0.7	2.8525E1	1.0000E2	5.0000E1	5.9400E2	170	3
196		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.4	0.5	2.7596E1	1.0000E2	1.5910E1	7.2000E1	85	4
197		pilOPT	30	0.5	0	0	3	0	1	0.6	0.7	0.7	0.7	2.8333E1	1.0000E2	5.0000E1	5.3400E2	152	3
198		pilOPT	30	0.9	4	0	4	0	0	0.6	0.7	0.4	0.5	2.7709E1	1.0000E2	3.4090E1	2.1000E2	96	7
199		pilOPT	28	0.5	2	0	1	0	0	0.6	0.7	0.7	0.7	2.8064E1	1.0000E2	5.0000E1	1.0230E3	215	3
200		pilOPT	30	0.5	3	0	1	0	0	0.6	0.7	0.7	0.7	2.7559E1	1.0000E2	5.0000E1	1.0230E3	91	4
201		pilOPT	30	0.9	4	0	4	0	0	0.6	0.7	0.4	0.6	2.7733E1	1.0000E2	3.4090E1	2.6100E2	97	7
202		pilOPT	30	0.9	2	0	1	1	0	0.7	0.7	0.7	0.7	2.8810E1	1.0000E2	5.0000E1	8.9700E2	218	3
203		pilOPT	28	0.5	2	0	4	0	0	0.7	0.7	0.7	0.7	2.7713E1	1.0000E2	5.0000E1	5.4300E2	188	3
204		pilOPT	28	0.5	1	0	1	0	0	0.5	0.7	0.7	0.7	2.7371E1	1.0000E2	5.0000E1	9.2100E2	156	3
205		pilOPT	24	0.5	1	0	3	1	2	0.3	0.5	0.4	0.7	2.4983E1	1.0000E2	4.7730E1	3.6900E2	227	4
206		pilOPT	30	0.9	4	0	3	0	1	0.6	0.7	0.4	0.5	2.7714E1	1.0000E2	4.3180E1	1.7100E2	90	4
207		pilOPT	30	0.5	4	0	4	0	2	0.7	0.7	0.3	0.6	2.8216E1	1.0000E2	4.5450E1	5.9700E2	127	4
208		pilOPT	28	0.5	0	0	2	0	1	0.7	0.7	0.7	0.7	2.7804E1	1.0000E2	5.0000E1	6.6300E2	193	3
209		pilOPT	30	0.9	2	0	4	1	3	0.7	0.7	0.7	0.3	2.8999E1	1.0000E2	4.0910E1	2.1300E2	227	5
210		pilOPT	30	0.1	4	0	1	0	2	0.2	0.6	0.6	0.7	2.8179E1	1.0000E2	4.5450E1	3.3900E2	120	3
211		pilOPT	26	0.1	0	0	2	1	1	0.6	0.7	0.7	0.4	2.7075E1	1.0000E2	5.0000E1	9.1800E2	283	3
212		pilOPT	30	0.5	4	0	1	0	1	0.2	0.7	0.7	0.6	2.8057E1	1.0000E2	4.5450E1	3.3300E2	112	3

Figure A.13

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
212		pilOPT	30	0.5	4	0	1	0	1	0.2	0.7	0.7	0.6	2.8057E1	1.0000E2	4.5450E1	3.3300E2	112	3
213		pilOPT	30	0.5	4	1	3	0	0	0.5	0.5	0.5	0.6	2.8029E1	1.0000E2	5.0000E1	3.2100E2	120	22
214		pilOPT	30	0.1	4	0	4	0	1	0.2	0.4	0.7	0.6	2.8006E1	1.0000E2	4.5450E1	5.5500E2	108	4
215		pilOPT	30	0.5	4	0	2	0	1	0.5	0.6	0.6	0.4	2.7926E1	1.0000E2	5.0000E1	3.8100E2	104	4
216		pilOPT	30	0.5	4	0	1	1	1	0.2	0.6	0.2	0.4	2.7986E1	1.0000E2	2.9550E1	2.1600E2	123	5
217		pilOPT	24	0.1	0	0	4	1	1	0.7	0.7	0.7	0.6	2.5641E1	1.0000E2	5.0000E1	1.0620E3	301	3
218		pilOPT	26	0.5	4	0	4	0	1	0.2	0.2	0.7	0.6	2.6155E1	1.0000E2	2.7270E1	2.7000E2	139	6
219		pilOPT	30	0.9	4	0	4	0	0	0.4	0.6	0.7	0.7	2.7716E1	1.0000E2	4.0910E1	2.1600E2	97	6
220		pilOPT	30	0.1	3	0	4	0	0	0.2	0.7	0.7	0.7	2.7569E1	1.0000E2	4.5450E1	7.3200E2	88	5
221		pilOPT	24	0.9	3	0	4	1	3	0.7	0.7	0.2	0.7	2.4639E1	1.0000E2	3.4090E1	2.7300E2	189	9
222		pilOPT	30	0.1	3	0	2	0	2	0.6	0.7	0.7	0.7	2.7599E1	1.0000E2	5.0000E1	6.5100E2	93	4
223		pilOPT	30	0.9	2	0	1	1	1	0.3	0.7	0.7	0.7	2.8557E1	1.0000E2	4.7730E1	2.9400E2	178	3
224		pilOPT	30	0.9	2	0	1	1	0	0.5	0.7	0.7	0.7	2.8752E1	1.0000E2	5.0000E1	7.6500E2	209	3
225		pilOPT	30	0.9	2	0	4	0	0	0.7	0.6	0.7	0.7	2.8256E1	1.0000E2	5.0000E1	3.5100E2	159	4
226		pilOPT	30	0.9	2	0	1	1	1	0.6	0.7	0.5	0.7	2.8609E1	1.0000E2	5.0000E1	3.9300E2	186	3
227		pilOPT	30	0.5	1	0	1	0	0	0.5	0.7	0.7	0.7	2.7993E1	1.0000E2	5.0000E1	9.2100E2	136	3
228		pilOPT	30	0.9	4	0	1	0	1	0.7	0.7	0.5	0.2	2.7973E1	1.0000E2	4.3180E1	2.8800E2	107	5
229		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.6	0.5	2.7372E1	1.0000E2	1.5910E1	7.8000E1	82	6
230		pilOPT	30	0.9	4	0	1	0	1	0.7	0.7	0.2	0.4	2.7996E1	1.0000E2	3.6360E1	3.1800E2	108	5
231		pilOPT	30	0.9	3	1	2	0	0	0.7	0.7	0.7	0.6	2.7613E1	1.0000E2	5.0000E1	5.8200E2	109	29
232		pilOPT	30	0.9	0	0	3	0	1	0.7	0.7	0.2	0.2	2.8175E1	1.0000E2	2.7270E1	1.7100E2	126	5
233		pilOPT	30	0.9	0	0	1	0	0	0.6	0.7	0.7	0.7	2.8774E1	1.0000E2	5.0000E1	8.2800E2	208	3
234		pilOPT	28	0.9	2	0	1	0	0	0.6	0.7	0.7	0.7	2.7985E1	1.0000E2	5.0000E1	8.2800E2	208	3
235		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.5	0.5	2.7585E1	1.0000E2	1.5910E1	7.5000E1	85	3
236		pilOPT	30	0.5	3	0	2	1	1	0.2	0.7	0.4	0.7	2.7557E1	1.0000E2	4.3180E1	3.3600E2	107	6
237		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.5	0.5	2.7379E1	1.0000E2	1.5910E1	7.5000E1	81	6
238		pilOPT	30	0.5	4	0	4	1	1	0.2	0.5	0.6	0.6	2.7731E1	1.0000E2	3.8640E1	2.6400E2	112	4
239		pilOPT	30	0.5	2	0	3	0	1	0.6	0.7	0.6	0.6	2.8444E1	1.0000E2	5.0000E1	4.5300E2	145	3
240		pilOPT	30	0.5	2	0	3	0	1	0.5	0.7	0.6	0.6	2.8436E1	1.0000E2	5.0000E1	4.2600E2	143	3
241		pilOPT	30	0.5	4	0	3	0	1	0.5	0.6	0.7	0.7	2.7851E1	1.0000E2	5.0000E1	4.8000E2	101	3
242		pilOPT	30	0.9	3	0	3	0	0	0.6	0.7	0.3	0.5	2.7505E1	1.0000E2	3.4090E1	2.0700E2	88	10
243		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.5	0.4	2.7594E1	1.0000E2	1.3640E1	9.0000E1	85	4
244		pilOPT	30	0.5	2	0	2	0	1	0.6	0.7	0.7	0.7	2.8645E1	1.0000E2	5.0000E1	5.9400E2	162	3
245		pilOPT	30	0.9	4	0	3	0	1	0.6	0.7	0.5	0.5	2.7707E1	1.0000E2	4.7730E1	1.6800E2	89	4
246		pilOPT	30	0.5	2	0	3	0	1	0.6	0.7	0.3	0.7	2.8448E1	1.0000E2	3.8640E1	4.9500E2	144	4
247		pilOPT	30	0.5	4	0	3	0	1	0.5	0.7	0.7	0.7	2.7845E1	1.0000E2	5.0000E1	4.8900E2	100	3
248		pilOPT	30	0.5	3	0	1	0	0	0.6	0.7	0.7	0.6	2.7556E1	1.0000E2	5.0000E1	9.1200E2	90	4
249		pilOPT	30	0.9	4	0	3	0	1	0.5	0.7	0.4	0.5	2.7714E1	1.0000E2	3.6360E1	1.4700E2	90	4
250		pilOPT	30	0.5	0	0	3	0	0	0.6	0.7	0.7	0.3	2.8378E1	1.0000E2	4.0910E1	3.3900E2	173	5
251		pilOPT	30	0.5	4	0	4	0	1	0.2	0.4	0.7	0.6	2.7737E1	1.0000E2	3.6360E1	2.7000E2	90	4
252		pilOPT	30	0.5	4	0	2	0	0	0.6	0.7	0.4	0.7	2.8030E1	1.0000E2	5.0000E1	6.3300E2	113	4
253		pilOPT	30	0.5	4	0	1	0	1	0.2	0.7	0.7	0.7	2.8070E1	1.0000E2	4.5450E1	3.9300E2	113	3
254		pilOPT	30	0.5	4	0	1	0	1	0.3	0.7	0.6	0.6	2.8062E1	1.0000E2	5.0000E1	3.7500E2	113	3
255		pilOPT	28	0.5	0	0	1	1	1	0.7	0.7	0.6	0.7	2.8013E1	1.0000E2	5.0000E1	6.3900E2	240	3
256		pilOPT	30	0.5	4	0	4	0	1	0.2	0.5	0.6	0.7	2.7735E1	1.0000E2	4.0910E1	2.8500E2	90	4
257		pilOPT	30	0.9	4	0	3	0	1	0.7	0.7	0.5	0.5	2.7701E1	1.0000E2	4.3180E1	1.9800E2	89	4
258		pilOPT	30	0.5	4	0	2	0	0	0.6	0.7	0.6	0.7	2.8040E1	1.0000E2	5.0000E1	6.4800E2	114	3
259		pilOPT	30	0.5	4	0	1	0	1	0.6	0.7	0.7	0.6	2.8095E1	1.0000E2	5.0000E1	5.6400E2	119	3
260		pilOPT	30	0.5	2	0	1	0	1	0.4	0.7	0.7	0.7	2.8823E1	1.0000E2	5.0000E1	5.1300E2	175	3
261		pilOPT	30	0.1	4	0	3	0	1	0.6	0.7	0.4	0.5	2.8102E1	1.0000E2	5.0000E1	6.5700E2	117	3
262		pilOPT	30	0.5	4	0	2	0	0	0.5	0.7	0.6	0.6	2.8003E1	1.0000E2	5.0000E1	5.1600E2	111	3
263		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.7	0.5	2.7364E1	1.0000E2	1.8180E1	7.8000E1	82	6
264		pilOPT	30	0.5	2	0	3	0	1	0.6	0.7	0.7	0.7	2.8455E1	1.0000E2	5.0000E1	5.3400E2	147	3
265		pilOPT	30	0.9	1	0	2	1	1	0.6	0.7	0.7	0.7	2.7686E1	1.0000E2	5.0000E1	2.4900E2	130	3
266		pilOPT	30	0.9	2	0	1	1	1	0.5	0.7	0.7	0.7	2.8598E1	1.0000E2	5.0000E1	3.3300E2	186	3
267		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.3	0.4	2.7440E1	1.0000E2	9.0900E0	8.4000E1	83	8
268		pilOPT	30	0.1	4	0	4	0	0	0.6	0.7	0.7	0.6	2.8089E1	1.0000E2	5.0000E1	9.7200E2	121	3
269		pilOPT	28	0.5	0	0	3	0	1	0.6	0.7	0.7	0.7	2.7635E1	1.0000E2	5.0000E1	5.3400E2	173	3
270		pilOPT	30	0.1	3	0	4	0	0	0.3	0.7	0.7	0.7	2.7549E1	1.0000E2	4.7730E1	8.1300E2	89	5
271		pilOPT	28	0.5	1	0	3	0	1	0.6	0.7	0.7	0.7	2.7154E1	1.0000E2	5.0000E1	5.3400E2	132	3
272		pilOPT	30	0.9	1	0	1	0	0	0.7	0.7	0.7	0.7	2.7954E1	1.0000E2	5.0000E1	8.9700E2	129	3
273		pilOPT	30	0.9	0	0	1	1	1	0.7	0.7	0.7	0.7	2.8553E1	1.0000E2	5.0000E1	4.4100E2	202	3
274		pilOPT	24	0.9	2	0	1	0	0	0.2	0.7	0.7	0.7	2.5343E1	1.0000E2	4.5450E1	5.2200E2	241	3
275		pilOPT	30	0.5	1	0	2	1	1	0.6	0.7	0.7	0.7	2.7796E1	1.0000E2	5.0000E1	5.9400E2	140	3
276		pilOPT	28	0.5	0	0	1	0	1	0.6	0.7	0.7	0.7	2.7991E1	1.0000E2	5.0000E1	6.2100E2	214	3
277		pilOPT	30	0.9	0	0	3	0	1	0.7	0.7	0.2	0.6	2.8158E1	1.0000E2	3.6360E1	2.0700E2	131	5
278		pilOPT	28	0.5	3	0	1	0	0	0.5	0.7	0.7	0.7	2.7042E1	1.0000E2	5.0000E1	9.2100E2	109	4
279		pilOPT	30	0.9	1	0	4	0	1	0.7	0.7	0.2	0.6	2.7566E1	1.0000E2	9.0900E0	8.4000E1	93	7
280		pilOPT	30	0.9	4	0	1	0	0	0.7	0.7	0.7	0.7	2.8104E1	1.0000E2	5.0000E1	8.9700E2	118	3
281		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.4	0.2	2.7644E1	1.0000E2	1.1360E1	9.3000E1	85	5
282		pilOPT	28	0.9	2	0	1	1	0	0.6	0.7	0.7	0.7	2.7998E1	1.0000E2	5.0000E1	8.2800E2	234	3

Figure A.14

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
283		pilOPT	30	0.9	4	0	4	0	1	0.7	0.7	0.4	0.3	2.7613E1	1.0000E2	9.0900E0	9.6000E1	87	5
284		pilOPT	30	0.5	0	0	1	0	0	0.6	0.7	0.6	0.6	2.8848E1	1.0000E2	5.0000E1	7.5300E2	209	3
285		pilOPT	30	0.1	1	0	3	0	1	0.6	0.7	0.7	0.7	2.7997E1	1.0000E2	5.0000E1	1.0980E3	134	3
286		pilOPT	30	0.5	4	0	2	0	0	0.5	0.7	0.7	0.6	2.8018E1	1.0000E2	5.0000E1	5.8500E2	112	3
287		pilOPT	30	0.1	0	0	3	0	1	0.7	0.7	0.7	0.7	2.8884E1	1.0000E2	5.0000E1	1.1460E3	209	3
288		pilOPT	30	0.5	3	0	1	0	1	0.4	0.7	0.7	0.7	2.7542E1	1.0000E2	5.0000E1	5.1300E2	89	4
289		pilOPT	30	0.5	4	0	2	0	1	0.4	0.7	0.7	0.7	2.7962E1	1.0000E2	5.0000E1	4.9800E2	107	3
290		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.2	0.2	2.7691E1	1.0000E2	4.5500E0	9.0000E1	86	6
291		pilOPT	30	0.9	0	0	1	0	1	0.5	0.7	0.7	0.7	2.8569E1	1.0000E2	5.0000E1	3.3300E2	173	3
292		pilOPT	30	0.1	4	0	3	0	1	0.2	0.4	0.7	0.7	2.8092E1	1.0000E2	4.3180E1	6.6000E2	114	4
293		pilOPT	28	0.5	0	0	2	0	1	0.7	0.7	0.4	0.7	2.7793E1	1.0000E2	5.0000E1	5.9700E2	189	3
294		pilOPT	30	0.9	4	0	4	0	1	0.7	0.7	0.2	0.2	2.7685E1	1.0000E2	4.5500E0	9.0000E1	87	6
295		pilOPT	30	0.5	0	0	1	0	0	0.7	0.7	0.7	0.7	2.8902E1	1.0000E2	5.0000E1	1.0950E3	221	3
296		pilOPT	30	0.5	1	0	1	0	0	0.7	0.7	0.7	0.7	2.8012E1	1.0000E2	5.0000E1	1.0950E3	141	3
297		pilOPT	30	0.5	4	0	1	1	1	0.7	0.3	0.7	0.7	2.8066E1	1.0000E2	4.7730E1	6.5400E2	138	4
298		pilOPT	30	0.5	4	0	1	1	1	0.7	0.3	0.3	0.5	2.8015E1	1.0000E2	3.8640E1	5.0400E2	130	4
299		pilOPT	30	0.1	4	0	4	0	1	0.7	0.5	0.7	0.7	2.8064E1	1.0000E2	5.0000E1	9.9000E2	119	3
300		pilOPT	30	0.1	4	0	4	0	1	0.7	0.6	0.7	0.6	2.8052E1	1.0000E2	5.0000E1	9.6300E2	118	3
301		pilOPT	24	0.1	4	0	1	0	1	0.2	0.7	0.7	0.7	2.4867E1	1.0000E2	4.5450E1	8.2500E2	185	3
302		pilOPT	28	0.9	0	0	1	0	0	0.5	0.7	0.7	0.7	2.7977E1	1.0000E2	5.0000E1	7.6500E2	223	3
303		pilOPT	30	0.9	4	0	4	0	1	0.7	0.5	0.7	0.6	2.7574E1	1.0000E2	1.5910E1	9.0000E1	86	4
304		pilOPT	26	0.9	2	0	1	0	0	0.5	0.7	0.7	0.7	2.6957E1	1.0000E2	5.0000E1	7.6500E2	234	3
305		pilOPT	30	0.5	0	0	1	1	0	0.7	0.7	0.6	0.6	2.8836E1	1.0000E2	5.0000E1	8.2200E2	237	3
306		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.3	0.2	2.7660E1	1.0000E2	4.5500E0	9.0000E1	85	5
307		pilOPT	28	0.5	0	0	3	1	1	0.7	0.7	0.6	0.7	2.7656E1	1.0000E2	5.0000E1	5.8800E2	200	3
308		pilOPT	26	0.5	0	0	1	0	1	0.6	0.7	0.6	0.7	2.7014E1	1.0000E2	5.0000E1	5.9400E2	244	3
309		pilOPT	28	0.5	0	0	1	0	0	0.6	0.7	0.7	0.7	2.8093E1	1.0000E2	5.0000E1	1.0230E3	236	3
310		pilOPT	30	0.5	3	0	2	0	0	0.5	0.7	0.7	0.6	2.7521E1	1.0000E2	5.0000E1	5.8500E2	89	5
311		pilOPT	30	0.9	0	0	1	0	0	0.5	0.7	0.7	0.7	2.8749E1	1.0000E2	5.0000E1	7.6500E2	203	3
312		pilOPT	30	0.1	4	0	3	0	1	0.3	0.3	0.7	0.7	2.8100E1	1.0000E2	5.0000E1	7.1700E2	115	4
313		pilOPT	30	0.5	0	0	2	0	1	0.6	0.7	0.7	0.6	2.8516E1	1.0000E2	5.0000E1	5.1600E2	169	3
314		pilOPT	26	0.5	0	0	1	1	1	0.7	0.6	0.7	0.7	2.7057E1	1.0000E2	5.0000E1	6.5100E2	276	3
315		pilOPT	30	0.5	4	0	1	0	2	0.3	0.7	0.7	0.7	2.8213E1	1.0000E2	5.0000E1	4.4700E2	125	3
316		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.5	0.6	2.7370E1	1.0000E2	1.3640E1	8.7000E1	82	6
317		pilOPT	24	0.5	0	0	1	0	0	0.5	0.7	0.7	0.7	2.5719E1	1.0000E2	5.0000E1	9.2100E2	289	3
318		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.7	0.6	2.7571E1	1.0000E2	1.3640E1	8.1000E1	85	3
319		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.5	0.6	2.7580E1	1.0000E2	1.3640E1	8.7000E1	85	3
320		pilOPT	28	0.5	0	0	1	1	0	0.7	0.7	0.7	0.7	2.8129E1	1.0000E2	5.0000E1	1.0950E3	266	3
321		pilOPT	26	0.5	0	0	1	0	1	0.6	0.7	0.5	0.7	2.6997E1	1.0000E2	5.0000E1	5.8800E2	241	3
322		pilOPT	30	0.9	4	0	2	0	0	0.6	0.7	0.7	0.7	2.7952E1	1.0000E2	5.0000E1	5.5800E2	110	3
323		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.6	0.4	2.7592E1	1.0000E2	1.3640E1	8.1000E1	85	4
324		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.6	0.5	2.7584E1	1.0000E2	1.5910E1	6.6000E1	85	4
325		pilOPT	26	0.9	0	0	1	0	1	0.7	0.7	0.7	0.7	2.6901E1	1.0000E2	5.0000E1	4.4100E2	230	3
326		pilOPT	30	0.5	4	0	4	0	1	0.6	0.7	0.7	0.7	2.7698E1	1.0000E2	5.0000E1	4.5300E2	93	3
327		pilOPT	30	0.5	4	0	2	0	1	0.3	0.5	0.7	0.7	2.7954E1	1.0000E2	4.7730E1	4.3200E2	105	3
328		pilOPT	30	0.9	0	0	1	0	1	0.7	0.6	0.7	0.7	2.8596E1	1.0000E2	5.0000E1	4.3800E2	177	3
329		pilOPT	28	0.5	4	0	1	0	1	0.2	0.7	0.7	0.7	2.7372E1	1.0000E2	4.5450E1	3.9300E2	132	3
330		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.5	0.7	2.7572E1	1.0000E2	1.3640E1	9.0000E1	85	3
331		pilOPT	30	0.5	0	0	4	0	1	0.6	0.7	0.7	0.6	2.8098E1	1.0000E2	5.0000E1	4.2900E2	133	3
332		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.3	0.7	2.7602E1	1.0000E2	1.1360E1	8.4000E1	85	4
333		pilOPT	30	0.5	4	0	3	0	1	0.4	0.7	0.7	0.7	2.7844E1	1.0000E2	5.0000E1	4.5900E2	100	3
334		pilOPT	26	0.5	0	0	1	0	0	0.7	0.7	0.7	0.7	2.7159E1	1.0000E2	5.0000E1	1.0950E3	273	3
335		pilOPT	30	0.5	1	0	2	0	2	0.6	0.7	0.7	0.6	2.8084E1	1.0000E2	5.0000E1	6.5100E2	142	3
336		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.4	0.7	2.7591E1	1.0000E2	9.0900E0	7.5000E1	85	4
337		pilOPT	24	0.5	0	0	1	0	0	0.7	0.7	0.7	0.7	2.5801E1	1.0000E2	5.0000E1	1.0950E3	299	3
338		pilOPT	30	0.9	4	0	4	0	1	0.7	0.7	0.2	0.7	2.7628E1	1.0000E2	6.8200E0	8.7000E1	87	5
339		pilOPT	30	0.9	1	0	1	1	1	0.7	0.7	0.7	0.7	2.7827E1	1.0000E2	5.0000E1	4.4100E2	145	3
340		pilOPT	30	0.9	1	0	1	1	1	0.5	0.7	0.7	0.7	2.7826E1	1.0000E2	5.0000E1	3.3300E2	142	3
341		pilOPT	30	0.9	4	0	4	0	1	0.7	0.7	0.3	0.2	2.7652E1	1.0000E2	4.5500E0	9.0000E1	85	5
342		pilOPT	26	0.9	0	0	1	0	1	0.5	0.7	0.7	0.7	2.6861E1	1.0000E2	5.0000E1	3.3300E2	224	3
343		pilOPT	24	0.5	0	0	1	1	0	0.7	0.7	0.7	0.7	2.5821E1	1.0000E2	5.0000E1	1.0950E3	330	3
344		pilOPT	30	0.5	2	0	1	0	1	0.6	0.7	0.7	0.7	2.8878E1	1.0000E2	5.0000E1	6.2100E2	185	3
345		pilOPT	30	0.5	0	0	2	1	1	0.7	0.7	0.7	0.7	2.8498E1	1.0000E2	5.0000E1	6.6300E2	195	3
346		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.6	0.6	2.7571E1	1.0000E2	1.1360E1	9.0000E1	85	3
347		pilOPT	30	0.9	4	0	4	0	2	0.7	0.7	0.7	0.7	2.8275E1	1.0000E2	5.0000E1	7.4100E2	134	3
348		pilOPT	30	0.5	0	0	3	0	1	0.2	0.7	0.7	0.7	2.8303E1	1.0000E2	4.5450E1	3.4500E2	141	3
349		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.6	0.5	2.7584E1	1.0000E2	1.5910E1	6.6000E1	85	4
350		pilOPT	30	0.5	1	0	4	0	1	0.6	0.7	0.7	0.7	2.7587E1	1.0000E2	5.0000E1	4.5300E2	101	3
351		pilOPT	30	0.9	4	0	3	0	2	0.7	0.7	0.5	0.7	2.8249E1	1.0000E2	5.0000E1	6.5700E2	131	3
352		pilOPT	30	0.9	4	0	1	0	1	0.6	0.7	0.5	0.4	2.7970E1	1.0000E2	5.0000E1	2.7000E2	108	3
353		pilOPT	26	0.1	0	0	1	0	0	0.7	0.7	0.7	0.7	2.7274E1	1.0000E2	5.0000E1	1.4190E3	287	3

Figure A.15

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
354		pilOPT	30	0.1	0	0	3	0	1	0.6	0.7	0.7	0.7	2.8862E1	1.0000E2	5.0000E1	1.0980E3	208	3
355		pilOPT	30	0.1	4	0	4	0	0	0.7	0.7	0.7	0.6	2.8104E1	1.0000E2	5.0000E1	1.1130E3	123	3
356		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.5	0.6	2.7588E1	1.0000E2	1.3640E1	7.2000E1	85	4
357		pilOPT	30	0.5	4	0	3	0	1	0.6	0.7	0.6	0.6	2.7841E1	1.0000E2	5.0000E1	4.5300E2	100	3
358		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.3	0.7	2.7607E1	1.0000E2	1.1360E1	7.2000E1	85	4
359		pilOPT	28	0.5	0	0	1	0	0	0.7	0.7	0.7	0.7	2.8119E1	1.0000E2	5.0000E1	1.0950E3	240	3
360		pilOPT	26	0.5	0	0	1	0	0	0.7	0.7	0.4	0.7	2.7089E1	1.0000E2	5.0000E1	8.4000E2	258	3
361		pilOPT	28	0.5	0	0	1	0	0	0.7	0.6	0.7	0.7	2.8104E1	1.0000E2	5.0000E1	1.0170E3	237	3
362		pilOPT	26	0.5	0	0	2	1	1	0.7	0.7	0.7	0.7	2.6874E1	1.0000E2	5.0000E1	6.6300E2	253	3
363		pilOPT	24	0.5	0	0	1	0	0	0.6	0.7	0.7	0.7	2.5763E1	1.0000E2	5.0000E1	1.0230E3	294	3
364		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.6	0.6	2.7577E1	1.0000E2	1.5910E1	7.8000E1	85	3
365		pilOPT	30	0.5	0	0	1	1	0	0.7	0.6	0.7	0.7	2.8863E1	1.0000E2	5.0000E1	1.0170E3	241	3
366		pilOPT	30	0.9	4	0	1	0	1	0.6	0.7	0.7	0.7	2.8012E1	1.0000E2	5.0000E1	4.1400E2	112	3
367		pilOPT	30	0.1	4	0	4	0	1	0.6	0.7	0.7	0.7	2.8067E1	1.0000E2	5.0000E1	1.0110E3	119	3
368		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.2	0.7	2.7633E1	1.0000E2	1.1360E1	8.7000E1	86	5
369		pilOPT	30	0.9	4	0	1	0	1	0.5	0.7	0.7	0.7	2.8002E1	1.0000E2	5.0000E1	3.3300E2	111	3
370		pilOPT	30	0.9	4	0	4	1	1	0.5	0.7	0.6	0.5	2.7591E1	1.0000E2	1.5910E1	6.6000E1	107	4
371		pilOPT	30	0.9	4	0	4	0	1	0.4	0.7	0.6	0.5	2.7590E1	1.0000E2	1.3640E1	7.8000E1	85	4
372		pilOPT	30	0.5	4	0	2	0	1	0.5	0.7	0.7	0.7	2.7967E1	1.0000E2	5.0000E1	5.1600E2	109	3
373		pilOPT	30	0.9	3	0	4	0	1	0.5	0.7	0.7	0.6	2.7356E1	1.0000E2	1.3640E1	8.1000E1	81	5
374		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.7	0.7	2.7557E1	1.0000E2	1.8180E1	9.0000E1	85	3
375		pilOPT	30	0.1	4	0	1	0	1	0.5	0.2	0.7	0.2	2.8093E1	1.0000E2	2.9550E1	5.9700E2	112	5
376		pilOPT	30	0.1	4	0	1	0	1	0.5	0.2	0.7	0.4	2.8134E1	1.0000E2	3.8640E1	7.2600E2	117	5
377		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.5	0.7	2.7361E1	1.0000E2	1.3640E1	9.0000E1	82	6
378		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.2	0.2	2.7696E1	1.0000E2	4.5500E0	7.8000E1	86	6
379		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.7	0.7	2.7557E1	1.0000E2	1.8180E1	9.0000E1	85	3
380		pilOPT	30	0.5	2	0	3	0	1	0.5	0.7	0.7	0.7	2.8441E1	1.0000E2	5.0000E1	4.8900E2	144	3
381		pilOPT	30	0.9	2	0	4	0	1	0.5	0.7	0.7	0.6	2.7965E1	1.0000E2	1.3640E1	8.1000E1	108	3
382		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.5	0.6	2.7580E1	1.0000E2	1.3640E1	8.7000E1	85	3
383		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.7	0.7	2.7341E1	1.0000E2	1.8180E1	9.0000E1	82	5
384		pilOPT	30	0.9	4	0	1	0	0	0.6	0.7	0.7	0.7	2.8093E1	1.0000E2	5.0000E1	8.2800E2	117	3
385		pilOPT	30	0.5	0	0	2	0	1	0.4	0.2	0.7	0.7	2.8498E1	1.0000E2	3.6360E1	4.6200E2	158	5
386		pilOPT	30	0.9	0	0	1	1	1	0.6	0.7	0.7	0.7	2.8543E1	1.0000E2	5.0000E1	4.1400E2	198	3
387		pilOPT	30	0.9	0	0	1	1	1	0.5	0.7	0.7	0.7	2.8525E1	1.0000E2	5.0000E1	3.3300E2	195	3
388		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.3	0.7	2.7602E1	1.0000E2	1.1360E1	8.4000E1	85	4
389		pilOPT	30	0.9	3	0	1	1	1	0.3	0.7	0.7	0.7	2.7524E1	1.0000E2	4.7730E1	2.9400E2	108	5
390		pilOPT	30	0.5	4	0	1	1	1	0.5	0.7	0.6	0.7	2.8062E1	1.0000E2	5.0000E1	5.1300E2	137	3
391		pilOPT	30	0.5	2	0	1	0	0	0.7	0.7	0.7	0.7	2.9008E1	1.0000E2	5.0000E1	1.0950E3	204	3
392		pilOPT	30	0.5	4	0	4	0	1	0.4	0.7	0.6	0.7	2.7702E1	1.0000E2	4.5450E1	3.9300E2	92	3
393		pilOPT	30	0.9	0	0	1	0	0	0.6	0.7	0.5	0.5	2.8716E1	1.0000E2	5.0000E1	5.7000E2	195	3
394		pilOPT	30	0.5	1	0	3	1	2	0.6	0.6	0.7	0.7	2.8058E1	1.0000E2	5.0000E1	6.4500E2	165	3
395		pilOPT	30	0.5	3	0	2	0	0	0.7	0.7	0.7	0.7	2.7527E1	1.0000E2	5.0000E1	7.7700E2	90	5
396		pilOPT	30	0.5	0	0	3	0	1	0.6	0.7	0.7	0.7	2.8333E1	1.0000E2	5.0000E1	5.3400E2	152	3
397		pilOPT	30	0.5	4	0	4	0	1	0.4	0.7	0.7	0.7	2.7699E1	1.0000E2	4.5450E1	4.1100E2	92	3
398		pilOPT	30	0.9	0	0	1	0	1	0.6	0.7	0.6	0.7	2.8585E1	1.0000E2	5.0000E1	4.1400E2	176	3
399		pilOPT	26	0.5	0	0	2	0	0	0.7	0.7	0.7	0.7	2.7018E1	1.0000E2	5.0000E1	7.7700E2	257	3
400		pilOPT	30	0.9	4	0	4	0	1	0.7	0.7	0.2	0.2	2.7685E1	1.0000E2	4.5500E0	9.0000E1	87	6
401		pilOPT	30	0.5	1	0	1	0	0	0.6	0.7	0.7	0.7	2.8004E1	1.0000E2	5.0000E1	1.0230E3	139	3
402		pilOPT	28	0.9	0	0	1	0	1	0.7	0.7	0.7	0.7	2.7851E1	1.0000E2	5.0000E1	4.4100E2	198	3
403		pilOPT	30	0.5	4	0	4	0	1	0.2	0.7	0.6	0.7	2.7727E1	1.0000E2	4.0910E1	2.8200E2	90	3
404		pilOPT	30	0.9	4	0	2	0	1	0.4	0.7	0.7	0.7	2.7828E1	1.0000E2	4.7730E1	2.1300E2	98	3
405		pilOPT	28	0.9	0	0	1	1	0	0.7	0.7	0.7	0.7	2.8036E1	1.0000E2	5.0000E1	8.9700E2	257	3
406		pilOPT	30	0.9	4	0	1	0	0	0.2	0.7	0.7	0.7	2.8042E1	1.0000E2	4.5450E1	5.2200E2	113	3
407		pilOPT	30	0.5	3	0	2	0	1	0.4	0.7	0.7	0.7	2.7496E1	1.0000E2	5.0000E1	4.9800E2	87	4
408		pilOPT	30	0.9	2	0	1	1	0	0.2	0.7	0.7	0.7	2.8645E1	1.0000E2	4.5450E1	5.2200E2	190	3
409		pilOPT	30	0.9	0	0	1	0	1	0.6	0.7	0.7	0.7	2.8582E1	1.0000E2	5.0000E1	4.1400E2	177	3
410		pilOPT	30	0.9	2	0	4	0	0	0.7	0.7	0.7	0.7	2.8271E1	1.0000E2	5.0000E1	3.8100E2	161	4
411		pilOPT	30	0.5	4	0	2	0	1	0.4	0.7	0.6	0.7	2.7963E1	1.0000E2	5.0000E1	4.7400E2	107	3
412		pilOPT	30	0.9	0	0	1	1	0	0.7	0.7	0.7	0.7	2.8755E1	1.0000E2	5.0000E1	8.9700E2	235	3
413		pilOPT	30	0.5	4	0	2	0	1	0.4	0.7	0.7	0.7	2.7962E1	1.0000E2	5.0000E1	4.9800E2	107	3
414		pilOPT	30	0.9	0	0	1	1	0	0.2	0.7	0.7	0.7	2.8601E1	1.0000E2	4.5450E1	5.2200E2	203	3
415		pilOPT	30	0.5	4	0	3	0	1	0.3	0.7	0.7	0.7	2.7844E1	1.0000E2	4.5450E1	4.2300E2	99	3
416		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.7	0.7	2.7565E1	1.0000E2	1.3640E1	8.1000E1	85	3
417		pilOPT	30	0.9	2	0	1	0	0	0.7	0.7	0.7	0.7	2.8888E1	1.0000E2	5.0000E1	8.9700E2	196	3
418		pilOPT	24	0.9	0	0	1	0	0	0.7	0.7	0.7	0.7	2.5716E1	1.0000E2	5.0000E1	8.9700E2	289	3
419		pilOPT	30	0.9	0	0	1	0	1	0.7	0.7	0.7	0.7	2.8591E1	1.0000E2	5.0000E1	4.4100E2	180	3
420		pilOPT	24	0.9	2	0	1	1	0	0.2	0.7	0.7	0.7	2.5368E1	1.0000E2	4.5450E1	5.2200E2	273	3
421		pilOPT	30	0.5	4	0	4	0	1	0.5	0.7	0.6	0.7	2.7704E1	1.0000E2	5.0000E1	4.2000E2	93	3
422		pilOPT	30	0.5	4	0	4	0	1	0.3	0.7	0.7	0.7	2.7702E1	1.0000E2	4.5450E1	3.6600E2	90	3
423		pilOPT	30	0.5	4	0	4	0	1	0.5	0.7	0.7	0.7	2.7697E1	1.0000E2	5.0000E1	4.3200E2	92	3
424		pilOPT	30	0.5	4	0	4	0	1	0.2	0.7	0.7	0.7	2.7718E1	1.0000E2	4.3180E1	3.0300E2	90	3

Figure A.16

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
425		pilOPT	28	0.9	0	0	1	0	1	0.6	0.7	0.7	0.7	2.7839E1	1.0000E2	5.0000E1	4.1400E2	195	3
426		pilOPT	28	0.9	0	0	1	1	1	0.6	0.7	0.7	0.7	2.7850E1	1.0000E2	5.0000E1	4.1400E2	221	3
427		pilOPT	30	0.9	4	0	4	0	0	0.2	0.7	0.7	0.7	2.7736E1	1.0000E2	4.0910E1	1.8900E2	98	6
428		pilOPT	30	0.9	4	0	4	0	0	0.2	0.2	0.7	0.7	2.7771E1	1.0000E2	2.5000E1	1.8600E2	97	8
429		pilOPT	30	0.1	4	0	4	0	0	0.7	0.7	0.7	0.7	2.8122E1	1.0000E2	5.0000E1	1.1070E3	125	3
430		pilOPT	30	0.9	2	0	1	0	0	0.7	0.7	0.7	0.7	2.8888E1	1.0000E2	5.0000E1	8.9700E2	196	3
431		pilOPT	30	0.9	0	0	1	0	0	0.7	0.2	0.7	0.7	2.8719E1	1.0000E2	3.8640E1	8.5800E2	197	5
432		pilOPT	30	0.9	0	0	4	1	0	0.7	0.7	0.7	0.7	2.8155E1	1.0000E2	5.0000E1	3.8100E2	194	4
433		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.4	0.5	2.7607E1	1.0000E2	1.1360E1	6.0000E1	85	4
434		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.5	0.5	2.7591E1	1.0000E2	1.3640E1	6.0000E1	85	4
435		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.7	0.6	2.7571E1	1.0000E2	1.3640E1	8.1000E1	85	3
436		pilOPT	30	0.9	0	0	1	0	0	0.7	0.7	0.7	0.7	2.8788E1	1.0000E2	5.0000E1	8.9700E2	212	3
437		pilOPT	30	0.5	4	0	4	0	2	0.5	0.7	0.7	0.7	2.8249E1	1.0000E2	5.0000E1	6.0000E2	129	3
438		pilOPT	30	0.5	3	0	4	0	1	0.6	0.7	0.7	0.7	2.7389E1	1.0000E2	5.0000E1	4.5300E2	83	4
439		pilOPT	30	0.5	4	0	4	0	1	0.4	0.6	0.7	0.7	2.7704E1	1.0000E2	4.7730E1	4.0200E2	92	3
440		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.6	0.6	2.7577E1	1.0000E2	1.5910E1	7.8000E1	85	3
441		pilOPT	30	0.9	2	0	1	0	0	0.2	0.7	0.7	0.7	2.8708E1	1.0000E2	4.5450E1	5.2200E2	168	3
442		pilOPT	30	0.9	0	1	1	0	3	0.7	0.7	0.7	0.7	2.9145E1	1.0000E2	5.0000E1	2.6400E2	263	20
443		pilOPT	30	0.9	4	0	4	0	0	0.7	0.7	0.7	0.7	2.7757E1	1.0000E2	5.0000E1	3.8100E2	103	5
444		pilOPT	30	0.9	2	0	1	0	0	0.2	0.7	0.7	0.7	2.8708E1	1.0000E2	4.5450E1	5.2200E2	168	3
445		pilOPT	30	0.9	2	0	4	0	0	0.2	0.7	0.7	0.7	2.8145E1	1.0000E2	4.0910E1	1.8900E2	141	5
446		pilOPT	30	0.9	4	0	4	0	1	0.4	0.6	0.5	0.5	2.7607E1	1.0000E2	1.1360E1	6.6000E1	85	4
447		pilOPT	30	0.9	0	0	1	0	0	0.7	0.7	0.2	0.7	2.8722E1	1.0000E2	3.8640E1	7.2000E2	195	5
448		pilOPT	28	0.1	4	0	4	0	1	0.3	0.7	0.7	0.7	2.7353E1	1.0000E2	5.0000E1	8.0400E2	134	3
449		pilOPT	30	0.9	4	0	4	0	0	0.2	0.7	0.7	0.7	2.7736E1	1.0000E2	4.0910E1	1.8900E2	98	6
450		pilOPT	30	0.9	0	1	1	0	0	0.7	0.7	0.7	0.7	2.8829E1	1.0000E2	5.0000E1	8.9700E2	225	13
451		pilOPT	30	0.1	4	0	4	0	1	0.7	0.6	0.7	0.7	2.8070E1	1.0000E2	5.0000E1	1.0530E3	119	3
452		pilOPT	30	0.1	4	0	4	1	1	0.7	0.4	0.7	0.7	2.8034E1	1.0000E2	5.0000E1	1.0380E3	137	3
453		pilOPT	30	0.1	4	0	1	1	1	0.7	0.7	0.7	0.7	2.8185E1	1.0000E2	5.0000E1	1.2330E3	151	3
454		pilOPT	24	0.1	0	0	4	0	1	0.7	0.7	0.7	0.7	2.5655E1	1.0000E2	5.0000E1	1.1340E3	275	3
455		pilOPT	30	0.5	1	0	1	0	1	0.4	0.7	0.7	0.7	2.7931E1	1.0000E2	5.0000E1	5.1300E2	126	3
456		pilOPT	30	0.5	4	0	3	0	1	0.6	0.7	0.7	0.7	2.7854E1	1.0000E2	5.0000E1	5.3400E2	102	3
457		pilOPT	30	0.5	4	0	3	0	1	0.5	0.7	0.7	0.7	2.7845E1	1.0000E2	5.0000E1	4.8900E2	100	3
458		pilOPT	30	0.9	4	0	1	1	1	0.6	0.7	0.7	0.7	2.7974E1	1.0000E2	5.0000E1	4.1400E2	132	3
459		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.6	0.4	2.7390E1	1.0000E2	1.1360E1	9.0000E1	83	7
460		pilOPT	30	0.9	1	0	1	0	1	0.6	0.7	0.5	0.7	2.7860E1	1.0000E2	5.0000E1	3.9300E2	121	4
461		pilOPT	30	0.9	4	0	4	0	1	0.2	0.7	0.3	0.7	2.7651E1	1.0000E2	6.8200E0	8.1000E1	86	5
462		pilOPT	30	0.5	0	0	1	0	0	0.6	0.7	0.7	0.7	2.8881E1	1.0000E2	5.0000E1	1.0230E3	217	3
463		pilOPT	28	0.1	0	0	1	1	1	0.7	0.2	0.7	0.7	2.8134E1	1.0000E2	3.8640E1	1.0500E3	253	4
464		pilOPT	30	0.5	4	0	4	0	1	0.6	0.7	0.7	0.7	2.7698E1	1.0000E2	5.0000E1	4.5300E2	93	3
465		pilOPT	28	0.1	0	0	1	1	1	0.7	0.3	0.7	0.7	2.8151E1	1.0000E2	5.0000E1	1.0470E3	257	4
466		pilOPT	30	0.5	0	0	4	1	1	0.2	0.7	0.7	0.6	2.8065E1	1.0000E2	4.3180E1	2.7600E2	148	3
467		pilOPT	30	0.5	2	0	3	1	1	0.5	0.2	0.7	0.7	2.8354E1	1.0000E2	3.6360E1	4.6500E2	162	5
468		pilOPT	30	0.5	4	0	4	0	1	0.6	0.7	0.6	0.6	2.7701E1	1.0000E2	5.0000E1	4.1700E2	92	3
469		pilOPT	30	0.5	0	0	1	0	1	0.3	0.7	0.7	0.7	2.8699E1	1.0000E2	5.0000E1	4.5900E2	181	3
470		pilOPT	30	0.9	0	0	2	1	1	0.7	0.7	0.7	0.7	2.8259E1	1.0000E2	5.0000E1	3.3000E2	170	3
471		pilOPT	30	0.5	4	0	1	0	1	0.6	0.7	0.7	0.7	2.8116E1	1.0000E2	5.0000E1	6.2100E2	120	3
472		pilOPT	26	0.9	1	0	1	0	1	0.6	0.7	0.7	0.7	2.6326E1	1.0000E2	5.0000E1	4.1400E2	167	3
473		pilOPT	30	0.9	2	0	1	1	1	0.6	0.7	0.7	0.3	2.8550E1	1.0000E2	4.7730E1	2.7000E2	178	4
474		pilOPT	26	0.5	1	0	1	0	0	0.7	0.7	0.7	0.7	2.6455E1	1.0000E2	5.0000E1	1.0950E3	186	3
475		pilOPT	24	0.5	1	0	1	1	0	0.7	0.7	0.7	0.7	2.5126E1	1.0000E2	5.0000E1	1.0950E3	242	3
476		pilOPT	28	0.5	0	0	2	1	1	0.4	0.7	0.7	0.7	2.7766E1	1.0000E2	5.0000E1	4.9800E2	210	3
477		pilOPT	28	0.9	2	0	1	1	1	0.6	0.7	0.7	0.7	2.7860E1	1.0000E2	5.0000E1	4.1400E2	209	3
478		pilOPT	30	0.9	0	0	1	1	2	0.6	0.7	0.7	0.7	2.9038E1	1.0000E2	5.0000E1	6.5100E2	257	3
479		pilOPT	28	0.9	3	0	1	1	1	0.6	0.7	0.7	0.7	2.7023E1	1.0000E2	5.0000E1	4.1400E2	126	4
480		pilOPT	30	0.5	4	0	2	0	1	0.7	0.7	0.7	0.7	2.7987E1	1.0000E2	5.0000E1	6.6300E2	111	3
481		pilOPT	24	0.5	4	0	3	0	1	0.5	0.7	0.7	0.7	2.4731E1	1.0000E2	5.0000E1	4.8900E2	169	3
482		pilOPT	28	0.9	0	0	3	0	1	0.7	0.7	0.7	0.7	2.7439E1	1.0000E2	5.0000E1	2.6100E2	152	3
483		pilOPT	30	0.9	3	0	1	1	1	0.7	0.7	0.6	0.7	2.7507E1	1.0000E2	5.0000E1	4.5000E2	110	4
484		pilOPT	30	0.5	3	0	4	0	1	0.5	0.7	0.7	0.7	2.7396E1	1.0000E2	5.0000E1	4.3200E2	83	4
485		pilOPT	30	0.5	4	0	1	0	1	0.6	0.7	0.7	0.7	2.8116E1	1.0000E2	5.0000E1	6.2100E2	120	3
486		pilOPT	30	0.9	1	0	4	0	1	0.3	0.7	0.7	0.6	2.7514E1	1.0000E2	9.0900E0	8.7000E1	92	4
487		pilOPT	30	0.9	2	0	4	0	1	0.6	0.7	0.7	0.7	2.7949E1	1.0000E2	1.8180E1	9.0000E1	108	3
488		pilOPT	30	0.9	0	0	4	0	2	0.2	0.7	0.7	0.7	2.8929E1	1.0000E2	4.5450E1	3.9000E2	210	3
489		pilOPT	30	0.9	0	0	4	0	2	0.3	0.7	0.7	0.6	2.8942E1	1.0000E2	4.7730E1	4.0800E2	212	3
490		pilOPT	30	0.9	2	0	4	0	2	0.2	0.7	0.7	0.6	2.8968E1	9.7922E1	4.5450E1	3.2700E2	187	3
491		pilOPT	30	0.5	4	0	4	0	1	0.3	0.7	0.7	0.7	2.7702E1	1.0000E2	4.5450E1	3.6600E2	90	3
492		pilOPT	30	0.5	4	0	4	0	1	0.7	0.7	0.7	0.7	2.7698E1	1.0000E2	5.0000E1	4.8600E2	93	3
493		pilOPT	26	0.9	0	0	1	1	1	0.4	0.7	0.7	0.7	2.6852E1	1.0000E2	5.0000E1	3.0600E2	249	3
494		pilOPT	28	0.9	0	0	4	0	1	0.6	0.7	0.7	0.7	2.7268E1	1.0000E2	1.8180E1	9.0000E1	136	3

Figure A.17

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
495		pilOPT	30	0.1	4	0	1	0	1	0.6	0.7	0.7	0.7	2.8225E1	1.0000E2	5.0000E1	1.1490E3	129	3
496		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.6	0.7	2.7562E1	1.0000E2	1.8180E1	9.0000E1	84	3
497		pilOPT	30	0.9	2	0	4	0	1	0.6	0.7	0.3	0.7	2.7992E1	1.0000E2	1.1360E1	8.4000E1	108	4
498		pilOPT	28	0.9	1	0	1	1	1	0.6	0.7	0.7	0.7	2.7270E1	1.0000E2	5.0000E1	4.1400E2	166	3
499		pilOPT	30	0.5	4	0	3	0	2	0.4	0.7	0.7	0.7	2.8233E1	1.0000E2	5.0000E1	5.1600E2	128	3
500		pilOPT	30	0.5	4	0	3	0	1	0.6	0.7	0.7	0.7	2.7854E1	1.0000E2	5.0000E1	5.3400E2	102	3
501		pilOPT	30	0.5	0	0	4	0	1	0.6	0.7	0.7	0.7	2.8098E1	1.0000E2	5.0000E1	4.5300E2	134	3
502		pilOPT	28	0.5	0	0	3	0	1	0.5	0.3	0.7	0.7	2.7617E1	1.0000E2	3.8640E1	4.7100E2	168	4
503		pilOPT	30	0.5	3	0	4	0	1	0.3	0.7	0.7	0.7	2.7419E1	1.0000E2	4.5450E1	3.6600E2	82	5
504		pilOPT	30	0.5	4	0	4	0	1	0.6	0.7	0.5	0.7	2.7710E1	1.0000E2	5.0000E1	4.2900E2	94	3
505		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.6	0.6	2.7571E1	1.0000E2	1.1360E1	9.0000E1	85	3
506		pilOPT	30	0.5	2	0	3	0	1	0.3	0.7	0.7	0.7	2.8408E1	1.0000E2	4.5450E1	4.2300E2	140	3
507		pilOPT	30	0.5	0	0	1	0	0	0.7	0.7	0.7	0.7	2.8902E1	1.0000E2	5.0000E1	1.0950E3	221	3
508		pilOPT	30	0.5	2	0	3	0	1	0.6	0.7	0.7	0.7	2.8455E1	1.0000E2	5.0000E1	5.3400E2	147	3
509		pilOPT	28	0.9	4	0	1	0	1	0.6	0.7	0.7	0.7	2.7337E1	1.0000E2	5.0000E1	4.1400E2	133	3
510		pilOPT	30	0.9	3	0	4	0	0	0.7	0.7	0.7	0.7	2.7419E1	1.0000E2	5.0000E1	3.8100E2	85	7
511		pilOPT	30	0.5	4	0	4	0	1	0.5	0.7	0.7	0.7	2.7697E1	1.0000E2	5.0000E1	4.3200E2	92	3
512		pilOPT	28	0.5	4	0	3	0	1	0.5	0.7	0.7	0.7	2.7234E1	1.0000E2	5.0000E1	4.8900E2	121	3
513		pilOPT	30	0.9	0	0	3	0	1	0.5	0.7	0.7	0.7	2.8095E1	1.0000E2	5.0000E1	2.1900E2	129	3
514		pilOPT	28	0.5	0	0	1	1	0	0.7	0.7	0.7	0.7	2.8129E1	1.0000E2	5.0000E1	1.0950E3	266	3
515		pilOPT	28	0.5	3	0	2	0	1	0.4	0.7	0.7	0.7	2.6996E1	1.0000E2	5.0000E1	4.9800E2	105	4
516		pilOPT	30	0.5	4	0	3	0	1	0.3	0.7	0.6	0.7	2.7846E1	1.0000E2	4.5450E1	3.8700E2	99	3
517		pilOPT	30	0.5	4	0	2	1	1	0.4	0.7	0.7	0.7	2.7932E1	1.0000E2	5.0000E1	4.9800E2	127	3
518		pilOPT	30	0.5	4	0	1	0	1	0.4	0.7	0.7	0.7	2.8092E1	1.0000E2	5.0000E1	5.1300E2	117	3
519		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.4	0.3	2.7441E1	1.0000E2	6.8200E0	9.6000E1	84	9
520		pilOPT	30	0.9	3	0	4	0	1	0.5	0.7	0.7	0.7	2.7351E1	1.0000E2	1.3640E1	8.1000E1	81	5
521		pilOPT	30	0.9	4	0	4	0	1	0.3	0.7	0.6	0.7	2.7590E1	1.0000E2	1.1360E1	9.3000E1	85	4
522		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.3	0.7	2.7403E1	1.0000E2	1.1360E1	8.4000E1	83	7
523		pilOPT	30	0.5	3	0	4	0	1	0.6	0.7	0.5	0.5	2.7417E1	1.0000E2	5.0000E1	3.9000E2	82	5
524		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.2	0.3	2.7500E1	1.0000E2	6.8200E0	9.6000E1	85	9
525		pilOPT	30	0.5	4	0	4	1	0	0.5	0.3	0.3	0.7	2.7815E1	1.0000E2	1.8180E1	3.6000E2	120	8
526		pilOPT	30	0.9	4	0	4	0	1	0.2	0.7	0.6	0.7	2.7615E1	1.0000E2	6.8200E0	8.7000E1	85	4
527		pilOPT	30	0.5	4	0	4	0	1	0.4	0.7	0.3	0.2	2.7745E1	1.0000E2	2.2730E1	2.0700E2	88	5
528		pilOPT	30	0.9	1	0	4	0	1	0.6	0.7	0.3	0.7	2.7529E1	1.0000E2	1.1360E1	8.4000E1	92	6
529		pilOPT	30	0.5	4	0	4	0	1	0.2	0.6	0.5	0.2	2.7758E1	1.0000E2	3.1820E1	1.1400E2	88	5
530		pilOPT	30	0.5	0	0	2	0	1	0.7	0.7	0.7	0.7	2.8537E1	1.0000E2	5.0000E1	6.6300E2	173	3
531		pilOPT	30	0.5	4	0	4	0	1	0.2	0.5	0.5	0.2	2.7758E1	1.0000E2	3.1820E1	1.1700E2	88	5
532		pilOPT	30	0.5	3	0	4	0	1	0.2	0.7	0.7	0.7	2.7447E1	1.0000E2	4.3180E1	3.0300E2	82	5
533		pilOPT	30	0.9	3	0	4	0	1	0.3	0.7	0.7	0.7	2.7377E1	1.0000E2	9.0900E0	9.3000E1	81	5
534		pilOPT	30	0.5	4	0	4	0	1	0.6	0.7	0.6	0.7	2.7704E1	1.0000E2	5.0000E1	4.4400E2	93	3
535		pilOPT	30	0.5	2	0	4	0	1	0.2	0.7	0.7	0.7	2.8184E1	1.0000E2	4.3180E1	3.0300E2	120	3
536		pilOPT	26	0.1	0	0	3	1	1	0.7	0.7	0.7	0.7	2.7155E1	1.0000E2	5.0000E1	1.1460E3	291	3
537		pilOPT	30	0.5	4	0	4	0	1	0.4	0.7	0.7	0.7	2.7699E1	1.0000E2	4.5450E1	4.1100E2	92	3
538		pilOPT	30	0.9	4	0	2	0	1	0.6	0.7	0.6	0.7	2.7838E1	1.0000E2	5.0000E1	2.4300E2	100	3
539		pilOPT	26	0.9	0	0	4	0	1	0.2	0.7	0.7	0.7	2.6328E1	1.0000E2	1.1360E1	8.4000E1	161	3
540		pilOPT	30	0.5	4	0	4	0	1	0.6	0.7	0.6	0.7	2.7704E1	1.0000E2	5.0000E1	4.4400E2	93	3
541		pilOPT	30	0.9	0	0	4	0	0	0.5	0.7	0.7	0.7	2.8139E1	1.0000E2	5.0000E1	2.7000E2	164	4
542		pilOPT	30	0.9	0	0	4	0	0	0.5	0.7	0.6	0.7	2.8131E1	1.0000E2	5.0000E1	2.7000E2	162	4
543		pilOPT	30	0.9	4	0	1	1	1	0.5	0.7	0.7	0.7	2.7969E1	1.0000E2	5.0000E1	3.3300E2	131	3
544		pilOPT	30	0.9	0	0	4	0	1	0.4	0.6	0.7	0.7	2.7884E1	1.0000E2	1.1360E1	8.7000E1	111	3
545		pilOPT	30	0.5	4	0	1	0	1	0.6	0.6	0.7	0.6	2.8091E1	1.0000E2	5.0000E1	5.5200E2	118	3
546		pilOPT	30	0.5	1	0	4	0	1	0.3	0.7	0.7	0.7	2.7605E1	1.0000E2	4.5450E1	3.6600E2	97	3
547		pilOPT	30	0.9	3	0	1	0	0	0.6	0.7	0.7	0.7	2.7535E1	1.0000E2	5.0000E1	8.2800E2	89	4
548		pilOPT	30	0.5	4	0	3	0	1	0.6	0.2	0.7	0.7	2.7894E1	1.0000E2	3.6360E1	4.9500E2	102	5
549		pilOPT	30	0.5	0	0	1	0	0	0.6	0.7	0.7	0.7	2.8881E1	1.0000E2	5.0000E1	1.0230E3	217	3
550		pilOPT	30	0.5	4	0	4	0	1	0.6	0.4	0.7	0.7	2.7715E1	1.0000E2	4.5450E1	4.4400E2	93	4
551		pilOPT	30	0.1	4	0	4	0	1	0.4	0.2	0.7	0.7	2.8054E1	1.0000E2	3.8640E1	7.7700E2	113	5
552		pilOPT	30	0.5	4	0	1	0	0	0.2	0.2	0.7	0.7	2.8089E1	1.0000E2	2.9550E1	5.4900E2	112	6
553		pilOPT	26	0.5	0	0	2	1	1	0.6	0.6	0.7	0.7	2.6849E1	1.0000E2	5.0000E1	5.8500E2	250	3
554		pilOPT	28	0.9	0	0	2	0	1	0.6	0.7	0.7	0.7	2.7612E1	1.0000E2	5.0000E1	2.4900E2	173	3
555		pilOPT	30	0.1	4	0	3	0	1	0.7	0.6	0.7	0.7	2.8166E1	1.0000E2	5.0000E1	1.0320E3	125	3
556		pilOPT	30	0.9	2	0	2	1	1	0.6	0.7	0.7	0.7	2.8342E1	1.0000E2	5.0000E1	2.4900E2	163	3
557		pilOPT	28	0.5	1	0	1	1	0	0.7	0.7	0.7	0.7	2.7406E1	1.0000E2	5.0000E1	1.0950E3	184	3
558		pilOPT	28	0.5	0	1	1	1	0	0.7	0.3	0.7	0.7	2.8092E1	1.0000E2	4.7730E1	9.7500E2	270	21
559		pilOPT	30	0.9	1	0	1	0	0	0.6	0.7	0.7	0.7	2.7950E1	1.0000E2	5.0000E1	8.2800E2	128	3
560		pilOPT	30	0.5	3	0	2	0	1	0.4	0.7	0.7	0.7	2.7496E1	1.0000E2	5.0000E1	4.9800E2	87	4
561		pilOPT	30	0.5	3	0	4	0	1	0.7	0.7	0.7	0.7	2.7383E1	1.0000E2	5.0000E1	4.8600E2	83	4
562		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.5	0.7	2.7580E1	1.0000E2	1.3640E1	7.5000E1	85	4
563		pilOPT	30	0.5	1	0	2	0	1	0.6	0.7	0.7	0.7	2.7818E1	1.0000E2	5.0000E1	5.9400E2	119	3
564		pilOPT	30	0.9	4	0	1	0	1	0.6	0.7	0.7	0.7	2.8012E1	1.0000E2	5.0000E1	4.1400E2	112	3
565		pilOPT	30	0.9	4	0	4	0	1	0.5	0.6	0.6	0.7	2.7575E1	1.0000E2	1.8180E1	7.2000E1	85	3

Figure A.18

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
566		pilOPT	30	0.9	3	0	4	0	1	0.2	0.7	0.7	0.7	2.7417E1	1.0000E2	1.1360E1	8.4000E1	82	6
567		pilOPT	28	0.1	4	0	4	0	1	0.6	0.7	0.7	0.7	2.7381E1	1.0000E2	5.0000E1	1.0110E3	138	3
568		pilOPT	30	0.1	4	0	4	0	1	0.5	0.7	0.7	0.7	2.8057E1	1.0000E2	5.0000E1	9.9000E2	117	3
569		pilOPT	30	0.1	0	0	2	0	1	0.6	0.7	0.7	0.7	2.8930E1	1.0000E2	5.0000E1	1.0800E3	217	3
570		pilOPT	30	0.9	4	0	4	0	1	0.7	0.7	0.7	0.7	2.7551E1	1.0000E2	1.8180E1	8.7000E1	86	3
571		pilOPT	30	0.5	4	0	2	0	1	0.6	0.7	0.7	0.7	2.7976E1	1.0000E2	5.0000E1	5.9400E2	110	3
572		pilOPT	30	0.9	4	0	3	0	1	0.7	0.7	0.7	0.7	2.7688E1	1.0000E2	5.0000E1	2.6100E2	92	3
573		pilOPT	30	0.5	3	0	3	0	1	0.4	0.7	0.7	0.7	2.7452E1	1.0000E2	5.0000E1	4.5900E2	85	4
574		pilOPT	30	0.5	4	0	1	0	1	0.4	0.7	0.7	0.7	2.8092E1	1.0000E2	5.0000E1	5.1300E2	117	3
575		pilOPT	30	0.9	3	0	2	0	1	0.5	0.7	0.7	0.7	2.7442E1	1.0000E2	5.0000E1	2.0700E2	85	4
576		pilOPT	30	0.9	3	0	4	0	1	0.6	0.7	0.7	0.6	2.7354E1	1.0000E2	1.8180E1	9.0000E1	82	6
577		pilOPT	30	0.9	4	0	4	0	1	0.7	0.7	0.7	0.7	2.7551E1	1.0000E2	1.8180E1	8.7000E1	86	3
578		pilOPT	30	0.5	4	0	1	0	1	0.5	0.7	0.7	0.7	2.8104E1	1.0000E2	5.0000E1	5.4900E2	119	3
579		pilOPT	30	0.5	3	0	2	0	1	0.5	0.7	0.7	0.7	2.7491E1	1.0000E2	5.0000E1	5.1600E2	87	4
580		pilOPT	30	0.5	4	0	1	0	0	0.7	0.7	0.7	0.7	2.8164E1	1.0000E2	5.0000E1	1.0950E3	128	3
581		pilOPT	30	0.1	1	0	3	0	1	0.7	0.2	0.2	0.7	2.8030E1	1.0000E2	2.7270E1	6.9900E2	126	7
582		pilOPT	30	0.9	4	0	3	0	1	0.6	0.6	0.7	0.7	2.7697E1	1.0000E2	5.0000E1	2.1900E2	90	3
583		pilOPT	30	0.5	3	0	1	0	3	0.4	0.7	0.7	0.3	2.7632E1	1.0000E2	3.1820E1	1.8600E2	93	9
584		pilOPT	30	0.9	4	0	4	1	1	0.4	0.6	0.5	0.7	2.7600E1	1.0000E2	1.1360E1	8.1000E1	107	4
585		pilOPT	24	0.5	0	0	2	0	0	0.2	0.2	0.7	0.7	2.5233E1	1.0000E2	2.5000E1	3.9300E2	234	6
586		pilOPT	24	0.5	4	0	1	0	1	0.3	0.2	0.7	0.6	2.4746E1	1.0000E2	3.4090E1	3.6900E2	173	5
587		pilOPT	30	0.9	1	0	4	0	1	0.2	0.4	0.3	0.7	2.7630E1	1.0000E2	4.5500E0	7.8000E1	93	7
588		pilOPT	30	0.5	2	0	4	0	1	0.2	0.2	0.5	0.7	2.8222E1	1.0000E2	2.7270E1	2.7000E2	119	5
589		pilOPT	30	0.5	0	0	1	1	1	0.7	0.7	0.7	0.7	2.8756E1	1.0000E2	5.0000E1	6.4500E2	218	3
590		pilOPT	30	0.5	4	0	2	1	1	0.3	0.7	0.7	0.7	2.7925E1	1.0000E2	4.7730E1	4.4700E2	126	3
591		pilOPT	30	0.9	1	0	2	1	1	0.7	0.7	0.7	0.7	2.7680E1	1.0000E2	5.0000E1	3.3000E2	130	3
592		pilOPT	30	0.5	4	0	4	0	2	0.5	0.7	0.7	0.7	2.8249E1	1.0000E2	5.0000E1	6.0000E2	129	3
593		pilOPT	30	0.5	4	0	4	0	1	0.3	0.7	0.7	0.3	2.7706E1	1.0000E2	4.0910E1	2.5500E2	88	4
594		pilOPT	28	0.9	0	1	2	0	1	0.7	0.7	0.7	0.7	2.7638E1	1.0000E2	5.0000E1	3.3000E2	184	13
595		pilOPT	30	0.5	0	0	2	0	1	0.5	0.7	0.7	0.7	2.8511E1	1.0000E2	5.0000E1	5.1600E2	168	3
596		pilOPT	30	0.9	2	0	2	1	1	0.2	0.7	0.6	0.7	2.8325E1	1.0000E2	4.3180E1	2.0700E2	153	3
597		pilOPT	30	0.9	3	0	4	0	1	0.3	0.6	0.7	0.6	2.7399E1	1.0000E2	1.1360E1	8.4000E1	82	6
598		pilOPT	30	0.5	0	0	3	0	1	0.5	0.7	0.7	0.7	2.8324E1	1.0000E2	5.0000E1	4.8900E2	149	3
599		pilOPT	28	0.5	1	0	2	1	0	0.7	0.7	0.7	0.7	2.7334E1	1.0000E2	5.0000E1	7.7700E2	179	3
600		pilOPT	30	0.1	3	0	4	0	1	0.3	0.7	0.7	0.7	2.7536E1	1.0000E2	5.0000E1	8.0400E2	88	5
601		pilOPT	30	0.5	4	0	4	0	1	0.7	0.7	0.7	0.7	2.7698E1	1.0000E2	5.0000E1	4.8600E2	93	3
602		pilOPT	30	0.5	3	0	2	0	1	0.6	0.7	0.7	0.7	2.7488E1	1.0000E2	5.0000E1	5.9400E2	85	4
603		pilOPT	30	0.5	0	0	2	0	1	0.6	0.7	0.7	0.7	2.8525E1	1.0000E2	5.0000E1	5.9400E2	170	3
604		pilOPT	28	0.5	4	0	4	0	1	0.3	0.7	0.3	0.7	2.7166E1	1.0000E2	2.9550E1	3.2700E2	112	4
605		pilOPT	30	0.5	4	0	3	0	1	0.3	0.7	0.3	0.3	2.7824E1	1.0000E2	2.5000E1	2.2800E2	94	4
606		pilOPT	30	0.5	4	0	1	0	1	0.3	0.7	0.7	0.7	2.8083E1	1.0000E2	5.0000E1	4.5900E2	115	3
607		pilOPT	30	0.9	4	0	2	0	1	0.7	0.3	0.7	0.7	2.7853E1	1.0000E2	4.0910E1	3.0600E2	100	4
608		pilOPT	30	0.5	4	0	3	0	1	0.5	0.7	0.4	0.6	2.7840E1	1.0000E2	5.0000E1	3.9900E2	99	3
609		pilOPT	30	0.9	4	0	2	0	1	0.7	0.7	0.7	0.7	2.7829E1	1.0000E2	5.0000E1	3.3000E2	100	3
610		pilOPT	30	0.5	4	0	4	0	1	0.2	0.7	0.7	0.7	2.7718E1	1.0000E2	4.3180E1	3.0300E2	90	3
611		pilOPT	30	0.5	1	0	3	0	1	0.7	0.7	0.7	0.7	2.7710E1	1.0000E2	5.0000E1	6.1200E2	112	3
612		pilOPT	30	0.5	4	0	1	0	0	0.7	0.7	0.7	0.7	2.8164E1	1.0000E2	5.0000E1	1.0950E3	128	3
613		pilOPT	30	0.9	4	1	4	0	1	0.6	0.6	0.7	0.7	2.7657E1	1.0000E2	1.3640E1	8.7000E1	97	17
614		pilOPT	30	0.5	4	0	3	0	1	0.2	0.7	0.7	0.7	2.7854E1	1.0000E2	4.5450E1	3.4500E2	98	3
615		pilOPT	28	0.5	0	0	3	1	1	0.5	0.7	0.7	0.7	2.7634E1	1.0000E2	5.0000E1	4.8900E2	196	3
616		pilOPT	30	0.5	4	0	3	0	1	0.7	0.7	0.7	0.7	2.7855E1	1.0000E2	5.0000E1	6.1200E2	102	3
617		pilOPT	30	0.9	4	0	1	0	1	0.7	0.7	0.7	0.7	2.8017E1	1.0000E2	5.0000E1	4.4100E2	114	3
618		pilOPT	30	0.9	3	0	3	0	1	0.5	0.7	0.7	0.7	2.7397E1	1.0000E2	5.0000E1	2.1900E2	84	5
619		pilOPT	30	0.1	0	0	1	0	1	0.7	0.7	0.7	0.7	2.9019E1	1.0000E2	5.0000E1	1.2330E3	231	3
620		pilOPT	28	0.9	1	0	2	0	1	0.7	0.7	0.7	0.7	2.7141E1	1.0000E2	5.0000E1	3.3000E2	130	3
621		pilOPT	30	0.5	0	0	3	0	1	0.5	0.7	0.7	0.3	2.8303E1	1.0000E2	4.5450E1	3.4200E2	141	4
622		pilOPT	30	0.9	3	0	1	0	1	0.6	0.7	0.7	0.7	2.7502E1	1.0000E2	5.0000E1	4.1400E2	86	4
623		pilOPT	30	0.9	3	0	2	0	1	0.6	0.7	0.7	0.7	2.7435E1	1.0000E2	5.0000E1	2.4900E2	85	4
624		pilOPT	30	0.5	0	0	4	0	1	0.3	0.7	0.7	0.7	2.8088E1	1.0000E2	4.5450E1	3.6600E2	123	3
625		pilOPT	30	0.9	3	0	3	0	1	0.5	0.7	0.7	0.6	2.7404E1	1.0000E2	4.7730E1	1.7400E2	83	5
626		pilOPT	28	0.9	1	0	3	0	3	0.6	0.7	0.3	0.7	2.7437E1	1.0000E2	3.4090E1	2.5500E2	160	7
627		pilOPT	28	0.9	4	0	1	1	1	0.6	0.7	0.7	0.7	2.7355E1	1.0000E2	5.0000E1	4.1400E2	156	3
628		pilOPT	30	0.9	4	0	1	1	1	0.6	0.7	0.3	0.7	2.7978E1	1.0000E2	3.8640E1	3.8400E2	130	4
629		pilOPT	30	0.5	0	0	4	0	1	0.4	0.7	0.7	0.7	2.8093E1	1.0000E2	4.5450E1	4.1100E2	130	3
630		pilOPT	28	0.9	1	0	3	0	3	0.6	0.3	0.3	0.7	2.7417E1	1.0000E2	1.5910E1	2.2800E2	153	8
631		pilOPT	30	0.5	0	0	3	1	1	0.6	0.7	0.7	0.7	2.8290E1	1.0000E2	5.0000E1	5.3400E2	174	3
632		pilOPT	26	0.5	4	0	2	0	1	0.5	0.7	0.7	0.7	2.6319E1	1.0000E2	5.0000E1	5.1600E2	157	3
633		pilOPT	30	0.9	1	0	1	1	1	0.7	0.7	0.7	0.7	2.7827E1	1.0000E2	5.0000E1	4.4100E2	145	3
634		pilOPT	28	0.9	4	0	1	0	1	0.7	0.7	0.7	0.7	2.7343E1	1.0000E2	5.0000E1	4.4100E2	132	3
635		pilOPT	30	0.5	4	0	2	0	1	0.6	0.7	0.7	0.7	2.7976E1	1.0000E2	5.0000E1	5.9400E2	110	3

Figure A.19

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
636		pilOPT	30	0.9	3	0	4	0	1	0.7	0.7	0.7	0.7	2.7334E1	1.0000E2	1.8180E1	8.7000E1	82	5
637		pilOPT	30	0.9	4	0	3	0	1	0.6	0.7	0.7	0.7	2.7691E1	1.0000E2	5.0000E1	2.2200E2	90	3
638		pilOPT	30	0.5	4	0	2	0	1	0.7	0.7	0.7	0.7	2.7987E1	1.0000E2	5.0000E1	6.6300E2	111	3
639		pilOPT	30	0.9	0	0	1	1	1	0.5	0.7	0.7	0.7	2.8525E1	1.0000E2	5.0000E1	3.3300E2	195	3
640		pilOPT	30	0.5	1	0	2	0	1	0.5	0.7	0.7	0.7	2.7814E1	1.0000E2	5.0000E1	5.1600E2	118	3
641		pilOPT	30	0.1	0	0	3	0	1	0.6	0.7	0.7	0.7	2.8862E1	1.0000E2	5.0000E1	1.0980E3	208	3
642		pilOPT	30	0.1	4	0	4	0	1	0.6	0.7	0.7	0.7	2.8067E1	1.0000E2	5.0000E1	1.0110E3	119	3
643		pilOPT	30	0.5	3	0	4	0	1	0.5	0.7	0.7	0.7	2.7396E1	1.0000E2	5.0000E1	4.3200E2	83	4
644		pilOPT	30	0.9	4	0	3	0	1	0.6	0.7	0.6	0.5	2.7701E1	1.0000E2	4.7730E1	1.7400E2	89	3
645		pilOPT	30	0.5	0	0	2	0	1	0.5	0.7	0.7	0.7	2.8511E1	1.0000E2	5.0000E1	5.1600E2	168	3
646		pilOPT	30	0.5	4	0	1	0	1	0.2	0.7	0.7	0.7	2.8070E1	1.0000E2	4.5450E1	3.9300E2	113	3
647		pilOPT	30	0.1	2	0	3	0	1	0.6	0.7	0.7	0.7	2.8973E1	1.0000E2	5.0000E1	1.0980E3	194	3
648		pilOPT	30	0.9	0	0	4	0	1	0.6	0.3	0.7	0.7	2.7910E1	1.0000E2	1.1360E1	8.4000E1	114	4
649		pilOPT	30	0.9	4	0	4	0	2	0.3	0.7	0.7	0.5	2.8184E1	1.0000E2	4.7730E1	3.4500E2	122	3
650		pilOPT	30	0.1	4	0	1	0	1	0.2	0.7	0.7	0.7	2.8171E1	1.0000E2	4.5450E1	8.2500E2	121	3
651		pilOPT	30	0.9	0	0	2	1	1	0.3	0.7	0.7	0.7	2.8244E1	1.0000E2	4.5450E1	2.1600E2	162	3
652		pilOPT	30	0.1	3	0	4	0	1	0.4	0.7	0.7	0.7	2.7526E1	1.0000E2	5.0000E1	8.6400E2	88	4
653		pilOPT	30	0.9	2	0	1	1	1	0.6	0.7	0.7	0.6	2.8602E1	1.0000E2	5.0000E1	3.7800E2	187	3
654		pilOPT	30	0.1	3	0	4	0	1	0.6	0.7	0.7	0.7	2.7522E1	1.0000E2	5.0000E1	1.0110E3	90	4
655		pilOPT	30	0.5	0	0	3	0	1	0.7	0.7	0.7	0.7	2.8340E1	1.0000E2	5.0000E1	6.1200E2	154	3
656		pilOPT	30	0.9	2	0	1	1	1	0.3	0.7	0.7	0.7	2.8557E1	1.0000E2	4.7730E1	2.9400E2	178	3
657		pilOPT	30	0.1	0	0	4	0	1	0.5	0.7	0.7	0.7	2.8689E1	1.0000E2	5.0000E1	9.9000E2	192	3
658		pilOPT	28	0.9	4	0	4	1	1	0.5	0.7	0.7	0.7	2.7079E1	1.0000E2	1.3640E1	8.1000E1	126	3
659		pilOPT	30	0.9	2	0	1	1	1	0.6	0.7	0.7	0.2	2.8532E1	1.0000E2	4.5450E1	2.4000E2	174	4
660		pilOPT	30	0.9	1	0	4	0	1	0.3	0.7	0.7	0.7	2.7505E1	1.0000E2	9.0900E0	9.3000E1	93	4
661		pilOPT	30	0.5	1	0	1	0	0	0.7	0.7	0.7	0.7	2.8012E1	1.0000E2	5.0000E1	1.0950E3	141	3
662		pilOPT	30	0.1	0	0	4	0	1	0.6	0.7	0.7	0.7	2.8709E1	1.0000E2	5.0000E1	1.0110E3	196	3
663		pilOPT	30	0.9	3	0	1	0	1	0.5	0.7	0.7	0.6	2.7505E1	1.0000E2	5.0000E1	2.8800E2	87	4
664		pilOPT	30	0.9	1	0	1	1	1	0.6	0.7	0.7	0.5	2.7822E1	1.0000E2	5.0000E1	3.0000E2	141	4
665		pilOPT	30	0.1	4	0	4	0	1	0.7	0.7	0.7	0.7	2.8076E1	1.0000E2	5.0000E1	1.1340E3	120	3
666		pilOPT	28	0.5	4	0	4	0	1	0.6	0.7	0.7	0.7	2.7149E1	1.0000E2	5.0000E1	4.5300E2	114	3
667		pilOPT	30	0.9	4	0	2	0	1	0.6	0.7	0.7	0.7	2.7828E1	1.0000E2	5.0000E1	2.4900E2	100	3
668		pilOPT	30	0.5	3	0	4	0	1	0.7	0.3	0.7	0.7	2.7447E1	1.0000E2	3.8640E1	4.7100E2	86	7
669		pilOPT	30	0.9	3	0	4	0	1	0.4	0.6	0.6	0.7	2.7377E1	1.0000E2	1.1360E1	8.4000E1	82	6
670		pilOPT	30	0.5	4	1	4	0	1	0.4	0.7	0.7	0.7	2.7776E1	1.0000E2	4.5450E1	4.1100E2	100	14
671		pilOPT	30	0.1	4	0	4	0	1	0.3	0.7	0.7	0.7	2.8042E1	1.0000E2	5.0000E1	8.0400E2	114	3
672		pilOPT	30	0.1	4	0	4	1	1	0.3	0.7	0.7	0.7	2.8011E1	1.0000E2	5.0000E1	8.0400E2	134	3
673		pilOPT	30	0.1	4	0	4	0	1	0.2	0.7	0.6	0.5	2.8001E1	1.0000E2	4.5450E1	3.8400E2	108	4
674		pilOPT	30	0.5	0	0	3	0	1	0.5	0.7	0.7	0.7	2.8324E1	1.0000E2	5.0000E1	4.8900E2	149	3
675		pilOPT	30	0.9	4	0	4	0	1	0.7	0.6	0.7	0.7	2.7557E1	1.0000E2	1.3640E1	9.0000E1	86	3
676		pilOPT	30	0.9	4	0	3	0	1	0.7	0.6	0.7	0.7	2.7694E1	1.0000E2	5.0000E1	2.4300E2	92	3
677		pilOPT	30	0.5	3	0	4	0	1	0.6	0.7	0.7	0.7	2.7389E1	1.0000E2	5.0000E1	4.5300E2	83	4
678		pilOPT	30	0.9	0	0	1	0	3	0.2	0.2	0.6	0.7	2.8849E1	1.0000E2	2.5000E1	1.6500E2	186	5
679		pilOPT	30	0.5	0	0	4	0	1	0.5	0.7	0.7	0.7	2.8095E1	1.0000E2	5.0000E1	4.3200E2	132	3
680		pilOPT	30	0.9	3	0	4	0	1	0.5	0.6	0.4	0.7	2.7397E1	1.0000E2	6.8200E0	7.2000E1	83	7
681		pilOPT	30	0.5	1	0	3	0	1	0.6	0.7	0.7	0.7	2.7713E1	1.0000E2	5.0000E1	5.3400E2	111	3
682		pilOPT	30	0.9	3	0	2	0	1	0.5	0.7	0.7	0.7	2.7442E1	1.0000E2	5.0000E1	2.0700E2	85	4
683		pilOPT	28	0.9	4	0	1	0	1	0.7	0.7	0.7	0.7	2.7343E1	1.0000E2	5.0000E1	4.4100E2	132	3
684		pilOPT	30	0.5	3	0	1	0	1	0.5	0.7	0.7	0.7	2.7540E1	1.0000E2	5.0000E1	5.4900E2	88	4
685		pilOPT	30	0.9	4	0	4	0	1	0.6	0.6	0.7	0.6	2.7570E1	1.0000E2	1.5910E1	8.4000E1	87	3
686		pilOPT	30	0.9	4	0	1	0	1	0.7	0.7	0.7	0.7	2.8017E1	1.0000E2	5.0000E1	4.4100E2	114	3
687		pilOPT	30	0.9	4	0	2	0	1	0.6	0.7	0.7	0.7	2.7828E1	1.0000E2	5.0000E1	2.4900E2	100	3
688		pilOPT	30	0.9	4	0	2	1	1	0.6	0.7	0.7	0.7	2.7817E1	1.0000E2	5.0000E1	2.4900E2	120	3
689		pilOPT	28	0.9	4	0	2	0	1	0.2	0.7	0.7	0.7	2.7228E1	1.0000E2	4.3180E1	2.0700E2	119	3
690		pilOPT	28	0.9	4	0	3	0	1	0.2	0.5	0.7	0.7	2.7163E1	1.0000E2	4.0910E1	1.6800E2	113	4
691		pilOPT	30	0.9	3	0	4	0	1	0.5	0.7	0.7	0.5	2.7369E1	1.0000E2	1.5910E1	6.6000E1	81	6
692		pilOPT	28	0.9	4	0	3	0	0	0.3	0.7	0.7	0.7	2.7197E1	1.0000E2	4.0910E1	2.5800E2	124	5
693		pilOPT	30	0.5	0	0	2	1	1	0.4	0.7	0.7	0.7	2.8449E1	1.0000E2	5.0000E1	4.9800E2	186	3
694		pilOPT	30	0.9	4	0	2	0	1	0.3	0.5	0.7	0.7	2.7836E1	1.0000E2	4.5450E1	2.0100E2	96	3
695		pilOPT	30	0.5	1	0	2	0	1	0.7	0.7	0.7	0.7	2.7819E1	1.0000E2	5.0000E1	6.6300E2	121	3
696		pilOPT	30	0.9	0	0	2	0	1	0.7	0.7	0.7	0.7	2.8306E1	1.0000E2	5.0000E1	3.3000E2	148	3
697		pilOPT	30	0.9	2	0	2	0	1	0.6	0.7	0.7	0.7	2.8417E1	1.0000E2	5.0000E1	2.4900E2	142	3
698		pilOPT	30	0.9	3	0	2	0	1	0.6	0.7	0.7	0.7	2.7435E1	1.0000E2	5.0000E1	2.4900E2	85	4
699		pilOPT	30	0.1	4	0	2	0	1	0.7	0.7	0.7	0.7	2.8211E1	1.0000E2	5.0000E1	1.1820E3	129	3
700		pilOPT	24	0.1	4	0	1	1	0	0.7	0.7	0.7	0.7	2.5015E1	1.0000E2	5.0000E1	1.4190E3	227	3
701		pilOPT	24	0.1	4	0	4	1	0	0.7	0.7	0.2	0.7	2.4867E1	1.0000E2	3.8640E1	8.7300E2	212	6
702		pilOPT	30	0.9	0	0	4	0	1	0.7	0.7	0.7	0.2	2.7910E1	1.0000E2	4.5500E0	9.9000E1	114	4
703		pilOPT	28	0.9	0	0	2	0	1	0.7	0.7	0.5	0.2	2.7582E1	1.0000E2	4.3180E1	2.2200E2	166	5
704		pilOPT	24	0.9	0	0	1	0	1	0.7	0.6	0.7	0.2	2.5344E1	1.0000E2	4.5450E1	2.8800E2	236	4
705		pilOPT	30	0.9	0	0	2	0	1	0.7	0.7	0.6	0.2	2.8314E1	1.0000E2	4.3180E1	2.1000E2	141	4
706		pilOPT	30	0.5	0	0	4	0	1	0.7	0.6	0.7	0.2	2.8116E1	1.0000E2	4.0910E1	3.3600E2	130	4

Figure A.20

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
707		pilOPT	30	0.5	4	0	2	1	3	0.3	0.3	0.2	0.7	2.8137E1	1.0000E2	9.0900E0	1.7100E2	136	7
708		pilOPT	30	0.9	4	0	4	0	1	0.6	0.6	0.7	0.7	2.7565E1	1.0000E2	1.3640E1	8.7000E1	86	3
709		pilOPT	30	0.9	1	0	2	0	1	0.6	0.7	0.7	0.7	2.7699E1	1.0000E2	5.0000E1	2.4900E2	109	3
710		pilOPT	30	0.1	4	0	1	0	1	0.4	0.7	0.7	0.7	2.8202E1	1.0000E2	5.0000E1	9.6600E2	126	3
711		pilOPT	26	0.1	0	0	3	1	1	0.6	0.7	0.7	0.7	2.7126E1	1.0000E2	5.0000E1	1.0980E3	287	3
712		pilOPT	28	0.1	0	0	3	1	1	0.5	0.7	0.7	0.7	2.8060E1	1.0000E2	5.0000E1	9.9900E2	246	3
713		pilOPT	30	0.9	4	0	4	0	2	0.5	0.7	0.7	0.7	2.8249E1	1.0000E2	5.0000E1	6.0000E2	129	3
714		pilOPT	30	0.9	0	0	1	0	1	0.6	0.7	0.7	0.7	2.8582E1	1.0000E2	5.0000E1	4.1400E2	177	3
715		pilOPT	30	0.9	3	0	3	0	1	0.6	0.7	0.7	0.7	2.7387E1	1.0000E2	5.0000E1	2.2200E2	82	5
716		pilOPT	28	0.1	4	0	3	0	1	0.6	0.7	0.7	0.7	2.7439E1	1.0000E2	5.0000E1	1.0980E3	142	3
717		pilOPT	30	0.5	0	0	1	0	1	0.6	0.7	0.7	0.7	2.8767E1	1.0000E2	5.0000E1	6.2100E2	196	3
718		pilOPT	30	0.9	1	0	1	0	1	0.6	0.7	0.7	0.7	2.7848E1	1.0000E2	5.0000E1	4.1400E2	122	3
719		pilOPT	30	0.5	3	0	3	0	1	0.5	0.7	0.7	0.7	2.7443E1	1.0000E2	5.0000E1	4.8900E2	86	4
720		pilOPT	30	0.1	4	0	3	0	1	0.7	0.7	0.7	0.7	2.8177E1	1.0000E2	5.0000E1	1.1460E3	126	3
721		pilOPT	30	0.9	4	0	4	0	1	0.3	0.7	0.7	0.7	2.7582E1	1.0000E2	9.0900E0	9.3000E1	85	3
722		pilOPT	30	0.5	3	0	4	0	1	0.6	0.7	0.6	0.7	2.7399E1	1.0000E2	5.0000E1	4.4400E2	84	5
723		pilOPT	30	0.5	4	0	1	0	1	0.7	0.7	0.7	0.7	2.8127E1	1.0000E2	5.0000E1	6.4500E2	122	3
724		pilOPT	30	0.5	4	0	2	0	1	0.3	0.7	0.7	0.7	2.7954E1	1.0000E2	4.7730E1	4.4700E2	106	3
725		pilOPT	30	0.9	4	0	3	0	1	0.7	0.7	0.7	0.7	2.7688E1	1.0000E2	5.0000E1	2.6100E2	92	3
726		pilOPT	30	0.5	4	0	4	0	1	0.5	0.7	0.7	0.5	2.7692E1	1.0000E2	5.0000E1	3.9300E2	89	3
727		pilOPT	26	0.5	3	0	4	1	1	0.6	0.7	0.6	0.7	2.6034E1	1.0000E2	5.0000E1	4.4400E2	149	5
728		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.7	0.7	2.7565E1	1.0000E2	1.3640E1	8.1000E1	85	3
729		pilOPT	30	0.9	4	0	4	0	1	0.4	0.7	0.7	0.7	2.7571E1	1.0000E2	1.5910E1	8.7000E1	84	3
730		pilOPT	30	0.5	4	1	1	0	1	0.4	0.7	0.7	0.7	2.8152E1	1.0000E2	5.0000E1	5.1300E2	126	13
731		pilOPT	30	0.1	4	0	4	0	1	0.7	0.7	0.7	0.7	2.8076E1	1.0000E2	5.0000E1	1.1340E3	120	3
732		pilOPT	30	0.5	1	0	3	0	1	0.5	0.7	0.7	0.7	2.7714E1	1.0000E2	5.0000E1	4.8900E2	110	3
733		pilOPT	28	0.5	4	1	1	0	1	0.4	0.7	0.7	0.7	2.7411E1	1.0000E2	5.0000E1	5.1300E2	146	13
734		pilOPT	30	0.1	4	0	4	0	1	0.7	0.7	0.7	0.3	2.8022E1	1.0000E2	5.0000E1	8.6400E2	114	4
735		pilOPT	30	0.9	0	0	2	0	1	0.6	0.7	0.7	0.3	2.8306E1	1.0000E2	4.5450E1	1.7700E2	141	4
736		pilOPT	30	0.5	4	0	1	0	1	0.3	0.6	0.7	0.7	2.8075E1	1.0000E2	5.0000E1	4.5000E2	114	3
737		pilOPT	30	0.5	4	0	2	1	1	0.6	0.7	0.7	0.7	2.7943E1	1.0000E2	5.0000E1	5.9400E2	129	3
738		pilOPT	30	0.5	0	0	4	1	3	0.5	0.7	0.7	0.7	2.9009E1	1.0000E2	4.5450E1	2.5800E2	239	4
739		pilOPT	30	0.5	0	0	4	1	2	0.5	0.7	0.7	0.6	2.8978E1	1.0000E2	5.0000E1	4.8600E2	248	3
740		pilOPT	30	0.1	0	0	2	0	1	0.6	0.7	0.2	0.6	2.8843E1	1.0000E2	3.8640E1	7.4700E2	196	4
741		pilOPT	30	0.5	4	0	2	1	1	0.6	0.6	0.7	0.7	2.7941E1	1.0000E2	5.0000E1	5.8500E2	129	3
742		pilOPT	28	0.1	4	0	3	0	1	0.5	0.3	0.7	0.7	2.7408E1	1.0000E2	5.0000E1	8.6700E2	139	4
743		pilOPT	30	0.1	4	0	2	0	1	0.6	0.7	0.7	0.7	2.8200E1	1.0000E2	5.0000E1	1.0800E3	127	3
744		pilOPT	30	0.5	0	0	3	0	1	0.4	0.7	0.7	0.7	2.8312E1	1.0000E2	5.0000E1	4.5900E2	147	3
745		pilOPT	30	0.9	3	0	1	0	1	0.6	0.6	0.6	0.7	2.7516E1	1.0000E2	5.0000E1	3.9000E2	88	5
746		pilOPT	30	0.5	1	0	2	0	1	0.6	0.7	0.7	0.7	2.7818E1	1.0000E2	5.0000E1	5.9400E2	119	3
747		pilOPT	30	0.9	3	0	4	0	1	0.4	0.7	0.7	0.5	2.7393E1	1.0000E2	1.3640E1	7.8000E1	83	7
748		pilOPT	30	0.9	3	0	4	0	1	0.4	0.7	0.7	0.4	2.7393E1	1.0000E2	6.8200E0	9.3000E1	82	6
749		pilOPT	30	0.1	4	0	1	0	0	0.6	0.7	0.7	0.7	2.8238E1	1.0000E2	5.0000E1	1.2990E3	130	3
750		pilOPT	30	0.5	2	0	1	1	0	0.7	0.7	0.7	0.7	2.8936E1	1.0000E2	5.0000E1	1.0950E3	226	3
751		pilOPT	30	0.1	4	0	2	1	1	0.6	0.7	0.7	0.7	2.8152E1	1.0000E2	5.0000E1	1.0800E3	147	3
752		pilOPT	30	0.5	4	0	2	0	1	0.2	0.7	0.7	0.7	2.7956E1	1.0000E2	4.5450E1	3.7800E2	104	3
753		pilOPT	30	0.9	3	0	4	0	1	0.7	0.7	0.7	0.3	2.7400E1	1.0000E2	6.8200E0	1.0200E2	82	8
754		pilOPT	30	0.5	4	0	3	0	1	0.7	0.7	0.7	0.7	2.7855E1	1.0000E2	5.0000E1	6.1200E2	102	3
755		pilOPT	30	0.5	3	0	3	0	1	0.7	0.7	0.7	0.7	2.7437E1	1.0000E2	5.0000E1	6.1200E2	85	4
756		pilOPT	28	0.5	1	0	1	0	0	0.7	0.7	0.7	0.7	2.7393E1	1.0000E2	5.0000E1	1.0950E3	160	3
757		pilOPT	30	0.5	4	0	4	0	2	0.4	0.7	0.6	0.6	2.8197E1	1.0000E2	5.0000E1	3.9300E2	124	3
758		pilOPT	30	0.5	4	0	1	0	1	0.6	0.2	0.7	0.5	2.8079E1	1.0000E2	3.8640E1	4.9200E2	114	5
759		pilOPT	30	0.5	4	0	1	0	1	0.6	0.3	0.7	0.5	2.8061E1	1.0000E2	4.3180E1	5.1300E2	114	4
760		pilOPT	30	0.1	0	0	4	0	1	0.4	0.7	0.2	0.7	2.8621E1	1.0000E2	3.8640E1	5.8800E2	173	4
761		pilOPT	30	0.9	2	0	2	0	1	0.4	0.7	0.7	0.7	2.8401E1	1.0000E2	4.7730E1	2.1300E2	138	3
762		pilOPT	30	0.5	4	0	3	0	2	0.4	0.4	0.7	0.7	2.8195E1	1.0000E2	5.0000E1	4.9800E2	124	4
763		pilOPT	30	0.5	4	0	3	0	1	0.4	0.7	0.7	0.7	2.7844E1	1.0000E2	5.0000E1	4.5900E2	100	3
764		pilOPT	30	0.9	4	0	4	0	2	0.4	0.7	0.6	0.7	2.8219E1	1.0000E2	5.0000E1	4.5000E2	126	3
765		pilOPT	30	0.5	0	0	1	0	1	0.7	0.7	0.7	0.7	2.8782E1	1.0000E2	5.0000E1	6.4500E2	197	3
766		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.3	0.7	2.7607E1	1.0000E2	1.1360E1	7.2000E1	85	4
767		pilOPT	30	0.5	4	0	2	0	2	0.5	0.6	0.6	0.6	2.8197E1	1.0000E2	5.0000E1	4.4400E2	124	3
768		pilOPT	30	0.5	4	0	4	0	1	0.4	0.3	0.7	0.7	2.7733E1	1.0000E2	3.8640E1	3.9900E2	91	5
769		pilOPT	28	0.9	0	0	1	0	1	0.7	0.7	0.7	0.7	2.7851E1	1.0000E2	5.0000E1	4.4100E2	198	3
770		pilOPT	30	0.5	0	0	4	0	1	0.6	0.7	0.3	0.7	2.8136E1	1.0000E2	3.8640E1	4.1700E2	134	4
771		pilOPT	30	0.1	4	0	4	1	1	0.5	0.7	0.7	0.7	2.8026E1	1.0000E2	5.0000E1	9.9000E2	137	3
772		pilOPT	28	0.9	0	0	1	0	0	0.6	0.7	0.7	0.7	2.8007E1	1.0000E2	5.0000E1	8.2800E2	227	3
773		pilOPT	26	0.5	0	0	1	0	0	0.7	0.7	0.7	0.7	2.7159E1	1.0000E2	5.0000E1	1.0950E3	273	3
774		pilOPT	30	0.1	4	0	4	0	1	0.4	0.7	0.7	0.7	2.8049E1	1.0000E2	5.0000E1	8.6400E2	115	3
775		pilOPT	30	0.5	3	0	4	0	1	0.5	0.7	0.7	0.6	2.7401E1	1.0000E2	5.0000E1	4.0500E2	84	5
776		pilOPT	30	0.9	4	0	1	0	0	0.7	0.7	0.7	0.7	2.8104E1	1.0000E2	5.0000E1	8.9700E2	118	3
777		pilOPT	28	0.9	0	0	1	0	0	0.7	0.7	0.7	0.7	2.8025E1	1.0000E2	5.0000E1	8.9700E2	231	3

Figure A.21

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
778		pilOPT	30	0.1	4	1	4	0	1	0.7	0.7	0.7	0.7	2.8159E1	1.0000E2	5.0000E1	1.1340E3	132	14
779		pilOPT	30	0.5	0	0	2	0	1	0.7	0.7	0.7	0.3	2.8490E1	1.0000E2	5.0000E1	4.8600E2	163	4
780		pilOPT	30	0.9	1	0	3	0	1	0.5	0.7	0.7	0.6	2.7606E1	1.0000E2	4.7730E1	1.7400E2	99	4
781		pilOPT	30	0.9	4	0	1	0	1	0.5	0.7	0.7	0.7	2.8002E1	1.0000E2	5.0000E1	3.3300E2	111	3
782		pilOPT	28	0.9	0	0	1	0	1	0.4	0.7	0.7	0.7	2.7803E1	1.0000E2	5.0000E1	3.0600E2	189	3
783		pilOPT	24	0.5	0	0	4	0	1	0.7	0.7	0.7	0.3	2.5098E1	1.0000E2	4.5450E1	3.8700E2	204	4
784		pilOPT	30	0.5	1	0	3	0	1	0.3	0.7	0.7	0.7	2.7717E1	1.0000E2	4.5450E1	4.2300E2	108	3
785		pilOPT	30	0.5	1	0	2	1	1	0.7	0.7	0.7	0.7	2.7799E1	1.0000E2	5.0000E1	6.6300E2	142	3
786		pilOPT	30	0.1	4	0	1	0	1	0.5	0.7	0.7	0.7	2.8213E1	1.0000E2	5.0000E1	1.0890E3	127	3
787		pilOPT	30	0.5	3	0	4	0	1	0.4	0.7	0.7	0.3	2.7453E1	1.0000E2	4.3180E1	2.9400E2	85	7
788		pilOPT	30	0.9	4	0	4	0	1	0.3	0.7	0.7	0.7	2.7582E1	1.0000E2	9.0900E0	9.3000E1	85	3
789		pilOPT	30	0.5	3	0	4	0	1	0.4	0.7	0.7	0.2	2.7494E1	1.0000E2	4.3180E1	2.4000E2	86	8
790		pilOPT	30	0.9	4	0	4	0	3	0.2	0.4	0.7	0.7	2.8198E1	1.0000E2	2.2730E1	1.5600E2	122	6
791		pilOPT	26	0.9	4	0	2	0	1	0.7	0.7	0.7	0.7	2.6256E1	1.0000E2	5.0000E1	3.3000E2	150	3
792		pilOPT	28	0.9	4	0	4	0	1	0.6	0.7	0.7	0.7	2.7053E1	1.0000E2	1.8180E1	9.0000E1	105	3
793		pilOPT	30	0.5	4	0	4	1	1	0.4	0.7	0.7	0.2	2.7721E1	1.0000E2	4.3180E1	2.4000E2	111	5
794		pilOPT	30	0.5	0	0	3	1	0	0.3	0.6	0.2	0.7	2.8291E1	1.0000E2	2.5000E1	3.3300E2	177	6
795		pilOPT	30	0.9	4	0	4	1	1	0.3	0.6	0.2	0.7	2.7674E1	1.0000E2	9.0900E0	8.1000E1	108	6
796		pilOPT	30	0.5	3	0	4	0	1	0.7	0.7	0.7	0.7	2.7383E1	1.0000E2	5.0000E1	4.8600E2	83	4
797		pilOPT	30	0.5	4	0	3	1	1	0.5	0.4	0.7	0.2	2.7824E1	1.0000E2	4.0910E1	2.7600E2	116	5
798		pilOPT	26	0.9	4	0	4	0	1	0.7	0.6	0.7	0.6	2.6105E1	1.0000E2	1.3640E1	8.4000E1	133	3
799		pilOPT	26	0.5	4	0	2	0	1	0.7	0.7	0.7	0.7	2.6340E1	1.0000E2	5.0000E1	6.6300E2	159	3
800		pilOPT	30	0.9	2	0	2	0	1	0.6	0.7	0.7	0.7	2.8417E1	1.0000E2	5.0000E1	2.4900E2	142	3
801		pilOPT	26	0.5	0	0	2	0	1	0.6	0.7	0.3	0.7	2.6790E1	1.0000E2	4.0910E1	5.4300E2	214	4
802		pilOPT	30	0.9	4	0	3	0	1	0.6	0.7	0.7	0.7	2.7691E1	1.0000E2	5.0000E1	2.2200E2	90	3
803		pilOPT	30	0.5	3	0	1	0	1	0.6	0.7	0.7	0.7	2.7540E1	1.0000E2	5.0000E1	6.2100E2	88	4
804		pilOPT	30	0.5	4	0	3	0	1	0.3	0.7	0.6	0.7	2.7846E1	1.0000E2	4.5450E1	3.8700E2	99	3
805		pilOPT	30	0.5	4	0	4	0	1	0.5	0.7	0.3	0.7	2.7730E1	1.0000E2	3.8640E1	3.9600E2	91	4
806		pilOPT	30	0.5	4	0	3	1	3	0.7	0.7	0.6	0.7	2.8220E1	1.0000E2	5.0000E1	2.9100E2	153	4
807		pilOPT	30	0.1	4	0	2	0	3	0.6	0.7	0.6	0.7	2.8273E1	1.0000E2	5.0000E1	2.2500E2	132	4
808		pilOPT	30	0.1	3	0	1	0	3	0.7	0.7	0.7	0.6	2.7616E1	1.0000E2	4.7730E1	2.7900E2	95	7
809		pilOPT	30	0.9	4	0	3	0	2	0.7	0.2	0.2	0.3	2.8132E1	1.0000E2	2.0450E1	3.8700E2	113	6
810		pilOPT	30	0.9	0	1	4	0	0	0.7	0.5	0.7	0.3	2.8210E1	1.0000E2	3.1820E1	2.1900E2	185	30
811		pilOPT	30	0.1	1	0	1	1	1	0.2	0.6	0.7	0.4	2.7974E1	1.0000E2	4.5450E1	5.4300E2	145	4
812		pilOPT	28	0.1	4	0	1	0	3	0.2	0.7	0.7	0.7	2.7461E1	1.0000E2	4.0910E1	1.5900E2	144	5
813		pilOPT	24	0.1	4	0	1	0	3	0.2	0.7	0.6	0.7	2.4869E1	1.0000E2	3.8640E1	1.5900E2	187	5
814		pilOPT	30	0.9	2	1	2	1	1	0.6	0.7	0.7	0.2	2.8419E1	1.0000E2	4.5450E1	1.3200E2	170	22
815		pilOPT	30	0.5	0	0	4	0	1	0.4	0.7	0.3	0.7	2.8135E1	1.0000E2	3.6360E1	3.6900E2	131	4
816		pilOPT	30	0.5	3	0	3	0	1	0.6	0.7	0.7	0.7	2.7440E1	1.0000E2	5.0000E1	5.3400E2	85	4
817		pilOPT	30	0.9	3	0	1	0	1	0.6	0.7	0.7	0.7	2.7502E1	1.0000E2	5.0000E1	4.1400E2	86	4
818		pilOPT	28	0.9	1	0	2	0	1	0.7	0.7	0.7	0.7	2.7141E1	1.0000E2	5.0000E1	3.3000E2	130	3
819		pilOPT	28	0.9	0	0	1	0	1	0.5	0.7	0.7	0.7	2.7822E1	1.0000E2	5.0000E1	3.3300E2	192	3
820		pilOPT	30	0.9	4	0	4	0	1	0.4	0.7	0.7	0.2	2.7631E1	1.0000E2	9.0900E0	9.3000E1	85	5
821		pilOPT	30	0.5	0	0	4	0	0	0.2	0.7	0.7	0.7	2.8226E1	1.0000E2	4.0910E1	2.7000E2	161	4
822		pilOPT	30	0.5	4	0	4	0	1	0.4	0.3	0.6	0.7	2.7736E1	1.0000E2	3.1820E1	3.7500E2	91	5
823		pilOPT	30	0.5	0	0	4	0	1	0.3	0.4	0.7	0.7	2.8117E1	1.0000E2	3.6360E1	3.5700E2	125	4
824		pilOPT	30	0.5	3	0	2	0	1	0.7	0.7	0.7	0.7	2.7488E1	1.0000E2	5.0000E1	6.6300E2	85	4
825		pilOPT	30	0.5	1	0	4	0	1	0.2	0.4	0.7	0.6	2.7661E1	1.0000E2	3.6360E1	2.7000E2	97	5
826		pilOPT	30	0.5	3	0	3	0	1	0.2	0.7	0.7	0.7	2.7498E1	1.0000E2	4.5450E1	3.4500E2	84	5
827		pilOPT	30	0.5	4	1	3	0	1	0.2	0.7	0.7	0.3	2.7995E1	1.0000E2	3.8640E1	2.0400E2	110	21
828		pilOPT	30	0.5	4	1	3	0	3	0.4	0.7	0.7	0.7	2.8327E1	1.0000E2	4.3180E1	2.4300E2	142	21
829		pilOPT	30	0.1	0	1	4	0	3	0.6	0.3	0.7	0.2	2.8955E1	1.0000E2	2.0450E1	1.6800E2	226	26
830		pilOPT	30	0.5	4	0	1	0	1	0.5	0.7	0.7	0.7	2.8104E1	1.0000E2	5.0000E1	5.4900E2	119	3
831		pilOPT	30	0.9	4	0	2	0	1	0.7	0.7	0.7	0.7	2.7829E1	1.0000E2	5.0000E1	3.3000E2	100	3
832		pilOPT	28	0.9	4	0	2	0	1	0.6	0.7	0.7	0.7	2.7227E1	1.0000E2	5.0000E1	2.4900E2	122	3
833		pilOPT	30	0.9	0	0	3	0	1	0.7	0.7	0.7	0.7	2.8086E1	1.0000E2	5.0000E1	2.6100E2	132	3
834		pilOPT	30	0.9	0	0	2	0	1	0.6	0.7	0.7	0.7	2.8310E1	1.0000E2	5.0000E1	2.4900E2	147	3
835		pilOPT	30	0.9	1	0	2	0	1	0.6	0.7	0.7	0.7	2.7699E1	1.0000E2	5.0000E1	2.4900E2	109	3
836		pilOPT	30	0.5	4	0	1	1	1	0.4	0.7	0.7	0.7	2.8056E1	1.0000E2	5.0000E1	5.1300E2	137	3
837		pilOPT	28	0.9	2	0	2	0	1	0.7	0.7	0.7	0.7	2.7639E1	1.0000E2	5.0000E1	3.3000E2	161	3
838		pilOPT	30	0.9	0	0	3	0	1	0.3	0.7	0.7	0.7	2.8100E1	1.0000E2	4.5450E1	2.0100E2	123	3
839		pilOPT	30	0.9	2	0	2	0	1	0.5	0.7	0.7	0.7	2.8412E1	1.0000E2	5.0000E1	2.0700E2	140	3
840		pilOPT	30	0.1	4	0	1	1	1	0.4	0.7	0.7	0.7	2.8153E1	1.0000E2	5.0000E1	9.6600E2	146	3
841		pilOPT	30	0.5	4	0	1	1	1	0.5	0.7	0.7	0.7	2.8064E1	1.0000E2	5.0000E1	5.4900E2	138	3
842		pilOPT	28	0.9	4	0	2	0	1	0.7	0.7	0.7	0.7	2.7228E1	1.0000E2	5.0000E1	3.3000E2	122	3
843		pilOPT	30	0.5	3	0	2	0	1	0.6	0.7	0.7	0.7	2.7488E1	1.0000E2	5.0000E1	5.9400E2	85	4
844		pilOPT	30	0.9	2	0	2	0	1	0.7	0.7	0.7	0.7	2.8419E1	1.0000E2	5.0000E1	3.3000E2	144	3
845		pilOPT	30	0.5	4	0	1	0	0	0.6	0.7	0.7	0.7	2.8152E1	1.0000E2	5.0000E1	1.0230E3	126	3
846		pilOPT	30	0.5	4	0	2	0	1	0.5	0.7	0.7	0.7	2.7967E1	1.0000E2	5.0000E1	5.1600E2	109	3
847		pilOPT	30	0.9	2	0	3	0	1	0.2	0.7	0.7	0.7	2.8193E1	1.0000E2	4.0910E1	1.8000E2	119	3
848		pilOPT	30	0.5	2	0	3	0	1	0.4	0.7	0.7	0.7	2.8423E1	1.0000E2	5.0000E1	4.5900E2	142	3

Figure A.22

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
849		pilOPT	30	0.9	4	0	2	0	1	0.3	0.7	0.7	0.7	2.7830E1	1.0000E2	4.5450E1	2.1600E2	98	3
850		pilOPT	30	0.5	2	0	3	0	1	0.7	0.7	0.7	0.7	2.8462E1	1.0000E2	5.0000E1	6.1200E2	149	3
851		pilOPT	30	0.9	3	0	1	0	1	0.4	0.7	0.7	0.7	2.7509E1	1.0000E2	5.0000E1	3.0600E2	87	4
852		pilOPT	30	0.9	4	0	3	0	1	0.4	0.7	0.7	0.7	2.7698E1	1.0000E2	4.5450E1	2.0700E2	89	3
853		pilOPT	30	0.9	2	0	2	0	1	0.3	0.7	0.7	0.7	2.8384E1	1.0000E2	4.5450E1	2.1600E2	131	3
854		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.7	0.5	2.7577E1	1.0000E2	1.5910E1	6.6000E1	85	3
855		pilOPT	30	0.9	4	1	1	0	1	0.7	0.7	0.7	0.7	2.8067E1	1.0000E2	5.0000E1	4.4100E2	123	14
856		pilOPT	28	0.5	4	0	4	1	0	0.7	0.7	0.7	0.6	2.7266E1	1.0000E2	5.0000E1	4.9200E2	151	4
857		pilOPT	30	0.9	3	0	3	0	1	0.6	0.7	0.7	0.7	2.7387E1	1.0000E2	5.0000E1	2.2200E2	82	5
858		pilOPT	30	0.9	4	0	2	1	1	0.6	0.7	0.7	0.7	2.7817E1	1.0000E2	5.0000E1	2.4900E2	120	3
859		pilOPT	30	0.5	4	0	2	1	1	0.7	0.7	0.7	0.7	2.7949E1	1.0000E2	5.0000E1	6.6300E2	130	3
860		pilOPT	30	0.5	0	0	1	0	1	0.6	0.7	0.7	0.7	2.8767E1	1.0000E2	5.0000E1	6.2100E2	196	3
861		pilOPT	30	0.5	0	0	1	0	1	0.2	0.7	0.7	0.7	2.8670E1	1.0000E2	4.5450E1	3.9300E2	175	3
862		pilOPT	30	0.9	4	1	2	0	1	0.6	0.7	0.7	0.7	2.7894E1	1.0000E2	5.0000E1	2.4900E2	108	14
863		pilOPT	28	0.9	0	0	3	0	1	0.3	0.7	0.7	0.7	2.7435E1	1.0000E2	4.5450E1	2.0100E2	148	3
864		pilOPT	30	0.5	4	0	1	0	1	0.7	0.7	0.7	0.7	2.8127E1	1.0000E2	5.0000E1	6.4500E2	122	3
865		pilOPT	30	0.9	0	0	2	0	1	0.6	0.7	0.7	0.3	2.8306E1	1.0000E2	4.5450E1	1.7700E2	141	4
866		pilOPT	30	0.5	3	0	2	0	0	0.6	0.7	0.7	0.7	2.7523E1	1.0000E2	5.0000E1	7.2300E2	89	5
867		pilOPT	30	0.5	4	0	4	0	3	0.3	0.7	0.7	0.7	2.8241E1	1.0000E2	3.8640E1	2.2200E2	127	4
868		pilOPT	30	0.5	4	1	4	0	1	0.2	0.7	0.7	0.7	2.7827E1	1.0000E2	4.3180E1	3.0300E2	101	16
869		pilOPT	30	0.9	0	0	2	0	1	0.3	0.7	0.7	0.7	2.8290E1	1.0000E2	4.5450E1	2.1600E2	135	3
870		pilOPT	30	0.5	4	0	2	0	0	0.6	0.7	0.7	0.7	2.8055E1	1.0000E2	5.0000E1	7.2300E2	115	3
871		pilOPT	30	0.9	1	0	2	0	1	0.5	0.7	0.7	0.7	2.7703E1	1.0000E2	5.0000E1	2.0700E2	108	3
872		pilOPT	30	0.9	1	0	2	0	1	0.4	0.7	0.7	0.7	2.7707E1	1.0000E2	4.7730E1	2.1300E2	108	3
873		pilOPT	30	0.5	3	1	4	0	1	0.2	0.7	0.7	0.7	2.7597E1	1.0000E2	4.3180E1	3.0300E2	101	26
874		pilOPT	30	0.5	3	1	4	0	1	0.4	0.7	0.7	0.7	2.7513E1	1.0000E2	4.5450E1	4.1100E2	95	21
875		pilOPT	30	0.5	4	0	1	0	1	0.3	0.7	0.7	0.7	2.8083E1	1.0000E2	5.0000E1	4.5900E2	115	3
876		pilOPT	30	0.9	4	0	2	0	1	0.5	0.7	0.7	0.7	2.7830E1	1.0000E2	5.0000E1	2.0700E2	99	3
877		pilOPT	30	0.5	4	0	4	0	1	0.4	0.7	0.7	0.3	2.7699E1	1.0000E2	4.3180E1	2.9400E2	90	4
878		pilOPT	30	0.9	0	0	2	0	1	0.7	0.3	0.7	0.3	2.8321E1	1.0000E2	3.6360E1	2.1300E2	141	4
879		pilOPT	30	0.9	0	0	4	0	1	0.7	0.7	0.7	0.7	2.7845E1	1.0000E2	1.8180E1	8.7000E1	116	3
880		pilOPT	28	0.5	4	0	2	0	1	0.6	0.7	0.7	0.7	2.7315E1	1.0000E2	5.0000E1	5.9400E2	131	3
881		pilOPT	30	0.5	4	0	4	0	1	0.7	0.7	0.7	0.6	2.7698E1	1.0000E2	5.0000E1	4.6200E2	93	3
882		pilOPT	30	0.5	3	0	4	1	1	0.3	0.7	0.7	0.3	2.7478E1	1.0000E2	4.0910E1	2.5500E2	106	7
883		pilOPT	30	0.1	4	0	2	1	3	0.4	0.4	0.5	0.5	2.8106E1	1.0000E2	9.0900E0	2.0400E2	138	6
884		pilOPT	30	0.5	2	0	1	1	0	0.2	0.6	0.7	0.7	2.8724E1	1.0000E2	4.5450E1	5.7600E2	199	3
885		pilOPT	30	0.1	4	0	2	0	3	0.3	0.3	0.5	0.5	2.8142E1	1.0000E2	1.3640E1	1.8600E2	116	6
886		pilOPT	30	0.9	4	0	2	0	1	0.2	0.7	0.3	0.7	2.7866E1	1.0000E2	2.7270E1	1.8000E2	96	4
887		pilOPT	30	0.9	4	0	2	0	1	0.2	0.7	0.2	0.7	2.7893E1	1.0000E2	2.9550E1	1.9800E2	96	5
888		pilOPT	30	0.9	0	1	3	1	1	0.7	0.3	0.7	0.7	2.8162E1	1.0000E2	4.0910E1	2.4300E2	167	20
889		pilOPT	30	0.9	0	1	4	1	1	0.7	0.3	0.7	0.7	2.7953E1	1.0000E2	1.1360E1	8.7000E1	147	21
890		pilOPT	30	0.5	0	0	4	0	1	0.7	0.7	0.7	0.7	2.8099E1	1.0000E2	5.0000E1	4.8600E2	137	3
891		pilOPT	30	0.9	0	0	2	0	1	0.6	0.7	0.7	0.7	2.8310E1	1.0000E2	5.0000E1	2.4900E2	147	3
892		pilOPT	30	0.9	0	0	4	1	1	0.7	0.7	0.7	0.7	2.7817E1	1.0000E2	1.8180E1	8.7000E1	137	3
893		pilOPT	30	0.5	2	0	4	0	1	0.4	0.7	0.7	0.7	2.8192E1	1.0000E2	4.5450E1	4.1100E2	127	3
894		pilOPT	30	0.5	4	0	2	0	1	0.4	0.7	0.7	0.6	2.7954E1	1.0000E2	5.0000E1	4.1400E2	106	3
895		pilOPT	26	0.5	4	0	4	0	1	0.6	0.7	0.2	0.7	2.6180E1	1.0000E2	3.8640E1	4.2000E2	142	5
896		pilOPT	30	0.5	4	0	2	0	1	0.2	0.7	0.7	0.7	2.7956E1	1.0000E2	4.5450E1	3.7800E2	104	3
897		pilOPT	30	0.5	4	0	1	1	1	0.7	0.7	0.7	0.6	2.8067E1	1.0000E2	5.0000E1	6.1500E2	139	3
898		pilOPT	30	0.5	4	0	2	0	1	0.6	0.7	0.7	0.6	2.7967E1	1.0000E2	5.0000E1	5.1600E2	109	3
899		pilOPT	30	0.1	0	0	4	0	0	0.5	0.7	0.7	0.7	2.8768E1	1.0000E2	5.0000E1	9.7800E2	204	3
900		pilOPT	30	0.9	0	0	1	1	1	0.2	0.7	0.7	0.7	2.8472E1	1.0000E2	4.5450E1	2.6700E2	182	3
901		pilOPT	30	0.9	4	0	2	1	0	0.7	0.7	0.7	0.7	2.7936E1	1.0000E2	5.0000E1	6.2700E2	131	3
902		pilOPT	30	0.9	0	0	2	0	1	0.4	0.7	0.7	0.7	2.8300E1	1.0000E2	4.7730E1	2.1300E2	143	3
903		pilOPT	30	0.9	4	0	2	1	1	0.6	0.7	0.7	0.5	2.7817E1	1.0000E2	5.0000E1	1.2300E2	119	3
904		pilOPT	30	0.1	0	0	4	0	1	0.6	0.6	0.7	0.7	2.8699E1	1.0000E2	5.0000E1	9.3900E2	194	3
905		pilOPT	30	0.5	4	0	4	0	1	0.5	0.7	0.7	0.6	2.7697E1	1.0000E2	5.0000E1	4.0500E2	92	3
906		pilOPT	30	0.9	2	0	2	0	1	0.4	0.7	0.7	0.7	2.8401E1	1.0000E2	4.7730E1	2.1300E2	138	3
907		pilOPT	30	0.1	2	0	3	0	1	0.5	0.6	0.7	0.7	2.8929E1	1.0000E2	5.0000E1	8.8800E2	187	3
908		pilOPT	30	0.5	4	0	1	1	0	0.6	0.7	0.7	0.7	2.8121E1	1.0000E2	5.0000E1	1.0230E3	146	3
909		pilOPT	30	0.5	0	0	1	0	1	0.5	0.7	0.7	0.7	2.8747E1	1.0000E2	5.0000E1	5.4900E2	192	3
910		pilOPT	30	0.5	4	1	3	0	1	0.5	0.7	0.7	0.7	2.7903E1	1.0000E2	5.0000E1	4.8900E2	109	14
911		pilOPT	28	0.5	4	0	1	0	0	0.7	0.7	0.7	0.7	2.7452E1	1.0000E2	5.0000E1	1.0950E3	147	3
912		pilOPT	30	0.9	0	0	2	0	1	0.7	0.7	0.7	0.7	2.8306E1	1.0000E2	5.0000E1	3.3000E2	148	3
913		pilOPT	30	0.5	4	0	1	0	0	0.4	0.7	0.7	0.7	2.8127E1	1.0000E2	5.0000E1	8.2500E2	118	3
914		pilOPT	30	0.5	2	0	3	0	1	0.4	0.7	0.7	0.3	2.8387E1	1.0000E2	4.5450E1	3.1800E2	135	4
915		pilOPT	30	0.5	3	0	2	0	1	0.4	0.7	0.7	0.6	2.7500E1	1.0000E2	5.0000E1	4.1400E2	86	4
916		pilOPT	26	0.9	4	0	1	0	1	0.7	0.7	0.7	0.7	2.6360E1	1.0000E2	5.0000E1	4.4100E2	161	3
917		pilOPT	30	0.5	1	0	4	0	1	0.7	0.7	0.7	0.7	2.7583E1	1.0000E2	5.0000E1	4.8600E2	102	3
918		pilOPT	30	0.9	0	0	4	0	1	0.3	0.7	0.7	0.7	2.7881E1	1.0000E2	9.0900E0	9.3000E1	110	3
919		pilOPT	30	0.9	1	0	2	0	1	0.3	0.7	0.7	0.7	2.7712E1	1.0000E2	4.5450E1	2.1600E2	107	3

Figure A.23

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
920		pilOPT	30	0.9	3	0	1	0	1	0.4	0.7	0.7	0.7	2.7509E1	1.0000E2	5.0000E1	3.0600E2	87	4
921		pilOPT	28	0.5	4	0	3	0	1	0.3	0.7	0.5	0.7	2.7230E1	1.0000E2	4.5450E1	3.7800E2	119	3
922		pilOPT	30	0.5	0	0	4	0	1	0.5	0.7	0.7	0.7	2.8095E1	1.0000E2	5.0000E1	4.3200E2	132	3
923		pilOPT	30	0.1	3	0	2	0	1	0.5	0.7	0.7	0.7	2.7569E1	1.0000E2	5.0000E1	1.0290E3	90	4
924		pilOPT	30	0.9	0	0	3	0	1	0.7	0.7	0.7	0.7	2.8086E1	1.0000E2	5.0000E1	2.6100E2	132	3
925		pilOPT	30	0.9	3	0	2	0	1	0.6	0.3	0.7	0.7	2.7493E1	1.0000E2	4.0910E1	2.2800E2	87	7
926		pilOPT	30	0.9	4	0	4	0	1	0.7	0.3	0.7	0.7	2.7595E1	1.0000E2	1.1360E1	8.7000E1	85	5
927		pilOPT	30	0.9	0	0	4	0	1	0.2	0.7	0.7	0.7	2.7901E1	1.0000E2	1.1360E1	8.4000E1	110	3
928		pilOPT	30	0.9	4	0	4	0	1	0.5	0.4	0.7	0.7	2.7591E1	1.0000E2	1.5910E1	7.5000E1	85	4
929		pilOPT	30	0.5	2	0	4	0	1	0.3	0.7	0.7	0.7	2.8183E1	1.0000E2	4.5450E1	3.6600E2	121	3
930		pilOPT	30	0.9	4	0	2	0	1	0.4	0.7	0.7	0.5	2.7824E1	1.0000E2	5.0000E1	9.6000E1	97	3
931		pilOPT	30	0.9	4	0	1	0	1	0.4	0.6	0.7	0.5	2.7975E1	1.0000E2	5.0000E1	1.9500E2	107	3
932		pilOPT	30	0.5	4	0	4	0	0	0.7	0.7	0.7	0.7	2.7880E1	1.0000E2	5.0000E1	5.4300E2	106	4
933		pilOPT	30	0.5	4	0	2	0	1	0.4	0.7	0.7	0.3	2.7924E1	1.0000E2	4.7730E1	3.3000E2	103	4
934		pilOPT	30	0.1	0	0	3	0	1	0.5	0.7	0.7	0.7	2.8839E1	1.0000E2	5.0000E1	9.9900E2	203	3
935		pilOPT	30	0.5	4	0	2	0	1	0.7	0.3	0.7	0.7	2.7981E1	1.0000E2	4.3180E1	6.3600E2	110	4
936		pilOPT	30	0.1	0	0	4	0	1	0.7	0.7	0.7	0.7	2.8729E1	1.0000E2	5.0000E1	1.1340E3	201	3
937		pilOPT	30	0.5	3	0	3	0	1	0.3	0.7	0.7	0.7	2.7465E1	1.0000E2	4.5450E1	4.2300E2	85	4
938		pilOPT	30	0.9	4	0	1	0	1	0.4	0.7	0.7	0.7	2.7994E1	1.0000E2	5.0000E1	3.0600E2	110	3
939		pilOPT	30	0.9	2	0	2	0	1	0.7	0.7	0.7	0.7	2.8419E1	1.0000E2	5.0000E1	3.3000E2	144	3
940		pilOPT	30	0.1	0	0	1	0	1	0.6	0.7	0.7	0.7	2.8993E1	1.0000E2	5.0000E1	1.1490E3	226	3
941		pilOPT	30	0.5	4	0	4	1	1	0.7	0.7	0.7	0.7	2.7701E1	1.0000E2	5.0000E1	4.8600E2	115	3
942		pilOPT	30	0.5	4	0	4	0	1	0.4	0.3	0.7	0.7	2.7733E1	1.0000E2	3.8640E1	3.9900E2	91	5
943		pilOPT	30	0.9	0	0	1	0	1	0.6	0.3	0.7	0.6	2.8577E1	1.0000E2	4.0910E1	3.6600E2	171	4
944		pilOPT	30	0.9	4	0	2	0	1	0.3	0.7	0.7	0.7	2.7830E1	1.0000E2	4.5450E1	2.1600E2	98	3
945		pilOPT	30	0.9	1	0	4	0	2	0.5	0.7	0.7	0.6	2.8075E1	1.0000E2	5.0000E1	4.8600E2	139	3
946		pilOPT	30	0.1	4	0	4	0	1	0.2	0.7	0.7	0.7	2.8035E1	1.0000E2	4.5450E1	7.4400E2	112	3
947		pilOPT	30	0.5	3	0	4	0	1	0.2	0.7	0.7	0.7	2.7447E1	1.0000E2	4.3180E1	3.0300E2	82	5
948		pilOPT	30	0.5	3	0	3	0	1	0.4	0.6	0.7	0.7	2.7462E1	1.0000E2	5.0000E1	4.5600E2	84	5
949		pilOPT	30	0.5	3	0	2	0	1	0.5	0.7	0.7	0.6	2.7492E1	1.0000E2	5.0000E1	4.4700E2	87	4
950		pilOPT	30	0.9	0	0	1	0	1	0.7	0.7	0.7	0.7	2.8591E1	1.0000E2	5.0000E1	4.4100E2	180	3
951		pilOPT	30	0.5	0	0	4	0	1	0.6	0.6	0.7	0.7	2.8110E1	1.0000E2	5.0000E1	4.5300E2	135	3
952		pilOPT	30	0.1	4	0	3	0	1	0.7	0.7	0.7	0.7	2.8177E1	1.0000E2	5.0000E1	1.1460E3	126	3
953		pilOPT	28	0.9	4	0	3	0	1	0.7	0.7	0.7	0.7	2.7140E1	1.0000E2	5.0000E1	2.6100E2	114	3
954		pilOPT	30	0.5	2	0	1	0	1	0.5	0.7	0.7	0.7	2.8855E1	1.0000E2	5.0000E1	5.4900E2	180	3
955		pilOPT	30	0.5	4	0	4	0	1	0.5	0.7	0.7	0.3	2.7698E1	1.0000E2	4.5450E1	3.2700E2	90	4
956		pilOPT	30	0.9	4	0	4	0	1	0.4	0.7	0.7	0.7	2.7571E1	1.0000E2	1.5910E1	8.7000E1	84	3
957		pilOPT	30	0.5	0	0	1	1	1	0.4	0.7	0.7	0.7	2.8684E1	1.0000E2	5.0000E1	5.1300E2	208	3
958		pilOPT	28	0.9	4	0	2	0	1	0.7	0.7	0.7	0.7	2.7228E1	1.0000E2	5.0000E1	3.3000E2	122	3
959		pilOPT	30	0.1	4	0	4	0	1	0.6	0.7	0.7	0.6	2.8050E1	1.0000E2	5.0000E1	9.7800E2	117	3
960		pilOPT	30	0.9	4	0	2	1	1	0.2	0.7	0.7	0.7	2.7824E1	1.0000E2	4.3180E1	2.0700E2	116	3
961		pilOPT	30	0.9	4	0	2	0	1	0.2	0.7	0.7	0.7	2.7838E1	1.0000E2	4.3180E1	2.0700E2	96	3
962		pilOPT	30	0.9	4	0	2	1	1	0.3	0.7	0.7	0.7	2.7816E1	1.0000E2	4.5450E1	2.1600E2	118	3
963		pilOPT	30	0.5	2	0	2	1	1	0.6	0.7	0.7	0.7	2.8563E1	1.0000E2	5.0000E1	5.9400E2	184	3
964		pilOPT	30	0.1	0	0	4	0	1	0.5	0.6	0.7	0.7	2.8678E1	1.0000E2	5.0000E1	8.7900E2	189	3
965		pilOPT	30	0.5	1	0	3	0	1	0.7	0.7	0.7	0.7	2.7710E1	1.0000E2	5.0000E1	6.1200E2	112	3
966		pilOPT	30	0.5	4	0	1	1	1	0.2	0.7	0.7	0.7	2.8035E1	1.0000E2	4.5450E1	3.9300E2	133	3
967		pilOPT	30	0.5	2	0	3	0	1	0.7	0.3	0.7	0.7	2.8448E1	1.0000E2	4.3180E1	5.8800E2	147	4
968		pilOPT	30	0.9	0	1	2	0	1	0.7	0.3	0.7	0.7	2.8397E1	1.0000E2	4.0910E1	3.0600E2	164	19
969		pilOPT	30	0.5	4	0	2	1	1	0.6	0.7	0.7	0.7	2.7943E1	1.0000E2	5.0000E1	5.9400E2	129	3
970		pilOPT	30	0.1	1	0	3	0	1	0.7	0.7	0.7	0.7	2.8004E1	1.0000E2	5.0000E1	1.1460E3	137	3
971		pilOPT	30	0.5	1	0	3	0	1	0.7	0.5	0.7	0.7	2.7725E1	1.0000E2	5.0000E1	5.9100E2	112	4
972		pilOPT	30	0.9	4	0	3	1	1	0.6	0.7	0.7	0.7	2.7695E1	1.0000E2	5.0000E1	2.2200E2	111	3
973		pilOPT	30	0.5	4	0	4	0	1	0.3	0.7	0.3	0.3	2.7735E1	1.0000E2	2.2730E1	2.2500E2	90	5
974		pilOPT	30	0.9	0	0	2	1	1	0.6	0.7	0.7	0.7	2.8260E1	1.0000E2	5.0000E1	2.4900E2	168	3
975		pilOPT	30	0.9	1	0	4	0	1	0.7	0.7	0.7	0.7	2.7461E1	1.0000E2	1.8180E1	8.7000E1	91	4
976		pilOPT	30	0.9	1	0	2	0	1	0.7	0.7	0.7	0.7	2.7695E1	1.0000E2	5.0000E1	3.3000E2	110	3
977		pilOPT	30	0.9	3	0	2	0	1	0.7	0.7	0.7	0.7	2.7427E1	1.0000E2	5.0000E1	3.3000E2	84	4
978		pilOPT	30	0.5	4	0	2	0	0	0.7	0.7	0.2	0.7	2.8061E1	1.0000E2	3.8640E1	6.6300E2	113	6
979		pilOPT	28	0.9	0	0	2	0	0	0.7	0.7	0.7	0.7	2.7827E1	1.0000E2	5.0000E1	6.2700E2	213	3
980		pilOPT	30	0.9	1	0	2	0	1	0.4	0.7	0.7	0.7	2.7707E1	1.0000E2	4.7730E1	2.1300E2	108	3
981		pilOPT	30	0.1	0	0	2	0	1	0.7	0.3	0.7	0.7	2.8900E1	1.0000E2	4.7730E1	1.0380E3	210	4
982		pilOPT	30	0.5	0	0	2	0	1	0.7	0.3	0.7	0.7	2.8531E1	1.0000E2	4.3180E1	6.3600E2	169	4
983		pilOPT	26	0.9	0	0	2	0	1	0.6	0.3	0.7	0.7	2.6643E1	1.0000E2	4.0910E1	2.2800E2	196	4
984		pilOPT	30	0.1	4	0	3	0	1	0.5	0.7	0.7	0.7	2.8151E1	1.0000E2	5.0000E1	9.9900E2	123	3
985		pilOPT	30	0.5	4	0	3	1	1	0.4	0.7	0.7	0.7	2.7824E1	1.0000E2	5.0000E1	4.5900E2	120	3
986		pilOPT	30	0.9	4	0	3	0	1	0.5	0.7	0.6	0.7	2.7700E1	1.0000E2	4.7730E1	1.9500E2	90	3
987		pilOPT	28	0.5	4	0	1	0	1	0.3	0.7	0.7	0.3	2.7333E1	1.0000E2	4.7730E1	2.8500E2	129	4
988		pilOPT	30	0.5	4	0	3	0	3	0.6	0.6	0.6	0.6	2.8247E1	1.0000E2	4.5450E1	2.3400E2	129	5
989		pilOPT	30	0.5	0	0	1	1	1	0.5	0.7	0.7	0.7	2.8714E1	1.0000E2	5.0000E1	5.4900E2	213	3
990		pilOPT	30	0.5	4	0	3	0	3	0.6	0.7	0.7	0.6	2.8261E1	1.0000E2	5.0000E1	2.3700E2	131	4

Figure A.24

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
990		pilOPT	30	0.5	4	0	3	0	3	0.6	0.7	0.7	0.6	2.8261E1	1.0000E2	5.0000E1	2.3700E2	131	4
991		pilOPT	30	0.5	0	0	2	0	1	0.7	0.7	0.7	0.7	2.8537E1	1.0000E2	5.0000E1	6.6300E2	173	3
992		pilOPT	30	0.9	3	0	2	0	1	0.7	0.7	0.7	0.7	2.7427E1	1.0000E2	5.0000E1	3.3000E2	84	4
993		pilOPT	30	0.5	0	0	2	0	1	0.4	0.7	0.7	0.7	2.8496E1	1.0000E2	5.0000E1	4.9800E2	164	3
994		pilOPT	30	0.9	4	0	2	0	1	0.5	0.7	0.7	0.7	2.7830E1	1.0000E2	5.0000E1	2.0700E2	99	3
995		pilOPT	30	0.9	4	0	2	0	1	0.7	0.7	0.3	0.7	2.7856E1	1.0000E2	3.8640E1	2.9100E2	101	4
996		pilOPT	30	0.5	4	0	2	1	1	0.3	0.7	0.7	0.7	2.7925E1	1.0000E2	4.7730E1	4.4700E2	126	3
997		pilOPT	30	0.1	4	0	2	0	1	0.7	0.7	0.7	0.7	2.8211E1	1.0000E2	5.0000E1	1.1820E3	129	3
998		pilOPT	30	0.9	3	0	2	0	1	0.3	0.7	0.6	0.7	2.7468E1	1.0000E2	4.5450E1	1.9800E2	84	5
999		pilOPT	26	0.9	2	0	4	0	1	0.6	0.3	0.7	0.7	2.6348E1	1.0000E2	1.1360E1	8.4000E1	160	4
1000		pilOPT	30	0.5	4	0	4	1	1	0.5	0.7	0.7	0.7	2.7701E1	1.0000E2	5.0000E1	4.3200E2	114	3
1001		pilOPT	28	0.9	4	0	4	0	1	0.5	0.7	0.7	0.7	2.7057E1	1.0000E2	1.3640E1	8.1000E1	105	3
1002		pilOPT	30	0.1	0	0	1	1	1	0.7	0.7	0.7	0.7	2.9000E1	1.0000E2	5.0000E1	1.2330E3	254	3
1003		pilOPT	30	0.9	4	0	4	1	1	0.5	0.7	0.7	0.7	2.7573E1	1.0000E2	1.3640E1	8.1000E1	107	3
1004		pilOPT	30	0.5	4	1	4	1	1	0.2	0.7	0.6	0.7	2.7812E1	1.0000E2	4.0910E1	2.8200E2	121	17
1005		pilOPT	30	0.1	3	0	2	0	1	0.7	0.7	0.7	0.7	2.7574E1	1.0000E2	5.0000E1	1.1820E3	92	4
1006		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.7	0.3	2.7600E1	1.0000E2	6.8200E0	9.0000E1	85	4
1007		pilOPT	24	0.9	1	0	1	1	1	0.3	0.7	0.7	0.7	2.4936E1	1.0000E2	4.7730E1	2.9400E2	218	3
1008		pilOPT	30	0.9	4	0	2	0	1	0.6	0.7	0.3	0.7	2.7857E1	1.0000E2	3.8640E1	2.0700E2	100	4
1009		pilOPT	26	0.9	1	0	1	1	1	0.3	0.7	0.7	0.7	2.6317E1	1.0000E2	4.7730E1	2.9400E2	190	3
1010		pilOPT	30	0.1	4	0	1	0	1	0.7	0.7	0.7	0.7	2.8236E1	1.0000E2	5.0000E1	1.2330E3	131	3
1011		pilOPT	30	0.5	2	0	2	0	1	0.6	0.7	0.7	0.7	2.8645E1	1.0000E2	5.0000E1	5.9400E2	162	3
1012		pilOPT	30	0.9	4	0	4	0	1	0.5	0.7	0.7	0.3	2.7600E1	1.0000E2	6.8200E0	9.0000E1	85	4
1013		pilOPT	28	0.5	4	0	4	0	1	0.5	0.7	0.7	0.7	2.7147E1	1.0000E2	5.0000E1	4.3200E2	114	3
1014		pilOPT	30	0.1	4	0	4	0	1	0.2	0.7	0.7	0.7	2.8035E1	1.0000E2	4.5450E1	7.4400E2	112	3
1015		pilOPT	30	0.9	4	0	1	0	1	0.2	0.7	0.7	0.7	2.7987E1	1.0000E2	4.5450E1	2.6700E2	107	3
1016		pilOPT	30	0.9	0	0	2	0	1	0.7	0.7	0.5	0.7	2.8323E1	1.0000E2	5.0000E1	3.0600E2	149	3
1017		pilOPT	30	0.5	4	0	2	1	1	0.5	0.7	0.7	0.7	2.7937E1	1.0000E2	5.0000E1	5.1600E2	128	3
1018		pilOPT	30	0.5	1	0	1	1	1	0.3	0.7	0.7	0.7	2.7904E1	1.0000E2	5.0000E1	4.5900E2	145	3
1019		pilOPT	30	0.9	2	0	2	0	0	0.7	0.7	0.7	0.7	2.8646E1	1.0000E2	5.0000E1	6.2700E2	183	3
1020		pilOPT	30	0.9	4	0	4	0	2	0.4	0.7	0.7	0.7	2.8233E1	1.0000E2	5.0000E1	5.1600E2	128	3
1021		pilOPT	30	0.5	4	0	1	1	1	0.4	0.7	0.7	0.7	2.8056E1	1.0000E2	5.0000E1	5.1300E2	137	3
1022		pilOPT	30	0.9	0	0	2	1	1	0.4	0.7	0.7	0.7	2.8250E1	1.0000E2	4.7730E1	2.1300E2	165	3
1023		pilOPT	30	0.1	4	0	4	0	1	0.3	0.7	0.7	0.7	2.8042E1	1.0000E2	5.0000E1	8.0400E2	114	3
1024		pilOPT	30	0.9	4	0	2	0	1	0.3	0.7	0.3	0.7	2.7855E1	1.0000E2	3.4090E1	1.9800E2	96	4
1025		pilOPT	30	0.5	3	0	2	0	1	0.5	0.7	0.7	0.7	2.7491E1	1.0000E2	5.0000E1	5.1600E2	87	4
1026		pilOPT	30	0.9	3	0	2	0	1	0.2	0.7	0.7	0.7	2.7488E1	1.0000E2	4.3180E1	2.0700E2	84	5
1027		pilOPT	30	0.9	4	0	3	0	1	0.7	0.2	0.2	0.6	2.7806E1	1.0000E2	1.8180E1	1.9500E2	93	6
1028		pilOPT	30	0.9	4	0	3	0	1	0.7	0.3	0.3	0.6	2.7755E1	1.0000E2	2.7270E1	2.0700E2	92	5
1029		pilOPT	30	0.9	3	0	3	0	1	0.7	0.7	0.7	0.7	2.7382E1	1.0000E2	5.0000E1	2.6100E2	82	5
1030		pilOPT	30	0.9	4	0	2	0	1	0.4	0.7	0.4	0.7	2.7841E1	1.0000E2	5.0000E1	2.1000E2	98	4
1031		pilOPT	30	0.9	3	0	4	0	1	0.3	0.4	0.7	0.7	2.7422E1	1.0000E2	1.1360E1	9.0000E1	83	7
1032		pilOPT	30	0.1	4	0	2	0	1	0.6	0.7	0.7	0.7	2.8200E1	1.0000E2	5.0000E1	1.0800E3	127	3
1033		pilOPT	30	0.9	4	1	4	0	1	0.5	0.6	0.7	0.3	2.7766E1	1.0000E2	6.8200E0	8.4000E1	101	22
1034		pilOPT	30	0.9	4	0	3	0	1	0.5	0.7	0.7	0.7	2.7693E1	1.0000E2	5.0000E1	2.1900E2	90	3
1035		pilOPT	30	0.9	3	0	4	0	1	0.5	0.2	0.7	0.7	2.7456E1	1.0000E2	6.8200E0	7.5000E1	84	9
1036		pilOPT	30	0.9	4	0	2	0	1	0.2	0.7	0.7	0.7	2.7838E1	1.0000E2	4.3180E1	2.0700E2	96	3
1037		pilOPT	30	0.9	1	0	4	0	1	0.6	0.7	0.7	0.7	2.7471E1	1.0000E2	1.8180E1	9.0000E1	91	4
1038		pilOPT	30	0.9	4	0	3	0	1	0.3	0.7	0.7	0.7	2.7705E1	1.0000E2	4.5450E1	2.0100E2	90	3
1039		pilOPT	30	0.9	0	0	1	1	1	0.6	0.7	0.7	0.7	2.8543E1	1.0000E2	5.0000E1	4.1400E2	198	3
1040		pilOPT	30	0.9	1	0	1	0	0	0.6	0.7	0.7	0.7	2.7950E1	1.0000E2	5.0000E1	8.2800E2	128	3
1041		pilOPT	30	0.9	2	0	3	0	1	0.7	0.7	0.7	0.7	2.8197E1	1.0000E2	5.0000E1	2.6100E2	128	3
1042		pilOPT	30	0.5	0	0	3	0	1	0.4	0.7	0.7	0.7	2.8312E1	1.0000E2	5.0000E1	4.5900E2	147	3
1043		pilOPT	30	0.5	4	0	2	1	1	0.5	0.7	0.7	0.7	2.7937E1	1.0000E2	5.0000E1	5.1600E2	128	3
1044		pilOPT	30	0.9	3	0	4	0	1	0.7	0.7	0.7	0.7	2.7334E1	1.0000E2	1.8180E1	8.7000E1	82	5
1045		pilOPT	30	0.9	4	0	2	0	1	0.6	0.7	0.5	0.6	2.7835E1	1.0000E2	5.0000E1	1.5900E2	99	3
1046		pilOPT	30	0.1	0	0	3	1	1	0.5	0.7	0.7	0.7	2.8807E1	1.0000E2	5.0000E1	9.9900E2	225	3
1047		pilOPT	30	0.9	2	0	4	0	1	0.7	0.7	0.7	0.7	2.7943E1	1.0000E2	1.8180E1	8.7000E1	112	3
1048		pilOPT	30	0.9	0	0	1	0	1	0.2	0.7	0.7	0.7	2.8517E1	1.0000E2	4.5450E1	2.6700E2	160	3
1049		pilOPT	30	0.5	4	0	1	0	1	0.4	0.7	0.6	0.6	2.8066E1	1.0000E2	5.0000E1	4.2300E2	114	3
1050		pilOPT	30	0.9	4	0	2	1	1	0.3	0.7	0.7	0.7	2.7816E1	1.0000E2	4.5450E1	2.1600E2	118	3
1051		pilOPT	30	0.1	1	0	4	1	1	0.7	0.7	0.7	0.7	2.7894E1	1.0000E2	5.0000E1	1.1340E3	152	3
1052		pilOPT	30	0.9	2	0	1	0	1	0.6	0.7	0.7	0.7	2.8699E1	1.0000E2	5.0000E1	4.1400E2	166	3
1053		pilOPT	30	0.9	4	0	4	0	1	0.6	0.7	0.7	0.6	2.7568E1	1.0000E2	1.8180E1	9.0000E1	87	3
1054		pilOPT	30	0.5	4	0	1	1	1	0.3	0.7	0.7	0.7	2.8043E1	1.0000E2	5.0000E1	4.5900E2	135	3
1055		pilOPT	30	0.9	3	0	2	0	1	0.6	0.2	0.6	0.3	2.7571E1	1.0000E2	2.7270E1	1.4400E2	86	9
1056		pilOPT	30	0.1	3	0	3	0	1	0.7	0.7	0.7	0.7	2.7558E1	1.0000E2	5.0000E1	1.1460E3	91	4
1057		pilOPT	30	0.9	4	0	3	0	1	0.5	0.7	0.7	0.7	2.7693E1	1.0000E2	5.0000E1	2.1900E2	90	3
1058		pilOPT	30	0.1	4	0	2	0	1	0.3	0.7	0.7	0.7	2.8160E1	1.0000E2	5.0000E1	8.4000E2	121	3
1059		pilOPT	30	0.9	0	0	4	0	1	0.2	0.4	0.7	0.4	2.7974E1	1.0000E2	2.2700E0	8.7000E1	110	4
1060		pilOPT	30	0.9	1	0	2	0	1	0.7	0.3	0.7	0.7	2.7738E1	1.0000E2	4.0910E1	3.0600E2	110	5

Figure A.25

ID	RID	Category	coolingsetpoint_input	depth	glazingtype	lightingdensity	numshading	occupancydensity	shadingtype	wwr_e	wwr_n	wwr_s	wwr_w	op_optemp	percent_comfort_time	sda	udli_2000	min_cooling	min_lighting
1059		pilOPT	30	0.9	0	0	4	0	1	0.2	0.4	0.7	0.4	2.7974E1	1.0000E2	2.2700E0	8.7000E1	110	4
1060		pilOPT	30	0.9	1	0	2	0	1	0.7	0.3	0.7	0.7	2.7738E1	1.0000E2	4.0910E1	3.0600E2	110	5
1061		pilOPT	30	0.1	4	1	4	0	1	0.3	0.7	0.7	0.7	2.8120E1	1.0000E2	5.0000E1	8.0400E2	125	15
1062		pilOPT	24	0.9	4	1	1	0	1	0.6	0.7	0.7	0.7	2.4902E1	1.0000E2	5.0000E1	4.1400E2	188	14
1063		pilOPT	26	0.9	4	1	1	0	1	0.6	0.7	0.7	0.7	2.6392E1	1.0000E2	5.0000E1	4.1400E2	170	14
1064		pilOPT	30	0.9	0	0	2	1	1	0.7	0.7	0.7	0.7	2.8259E1	1.0000E2	5.0000E1	3.3000E2	170	3
1065		pilOPT	30	0.5	4	1	4	0	1	0.7	0.2	0.7	0.7	2.7933E1	1.0000E2	3.8640E1	4.8900E2	118	26
1066		pilOPT	30	0.1	4	0	3	0	1	0.4	0.7	0.7	0.7	2.8138E1	1.0000E2	5.0000E1	9.3300E2	121	3
1067		pilOPT	30	0.5	0	0	4	0	0	0.6	0.7	0.7	0.7	2.8372E1	1.0000E2	5.0000E1	4.5900E2	181	3
1068		pilOPT	30	0.5	0	0	3	1	1	0.6	0.7	0.7	0.7	2.8290E1	1.0000E2	5.0000E1	5.3400E2	174	3
1069		pilOPT	24	0.9	4	0	1	0	1	0.7	0.7	0.7	0.7	2.4840E1	1.0000E2	5.0000E1	4.4100E2	179	3
1070		pilOPT	30	0.5	4	0	3	0	1	0.3	0.7	0.7	0.7	2.7844E1	1.0000E2	4.5450E1	4.2300E2	99	3

Figure A.26

A.4. Examples of design solutions

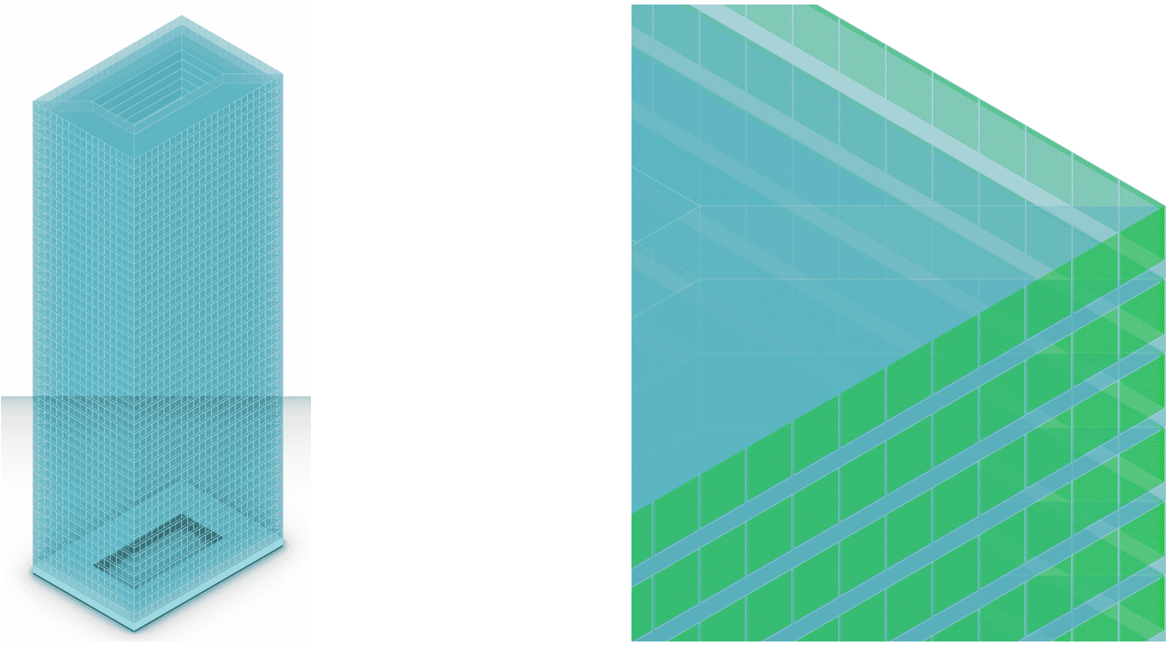

Figure A.27: Visualization of a design solution with high wwr and with internal blinds.

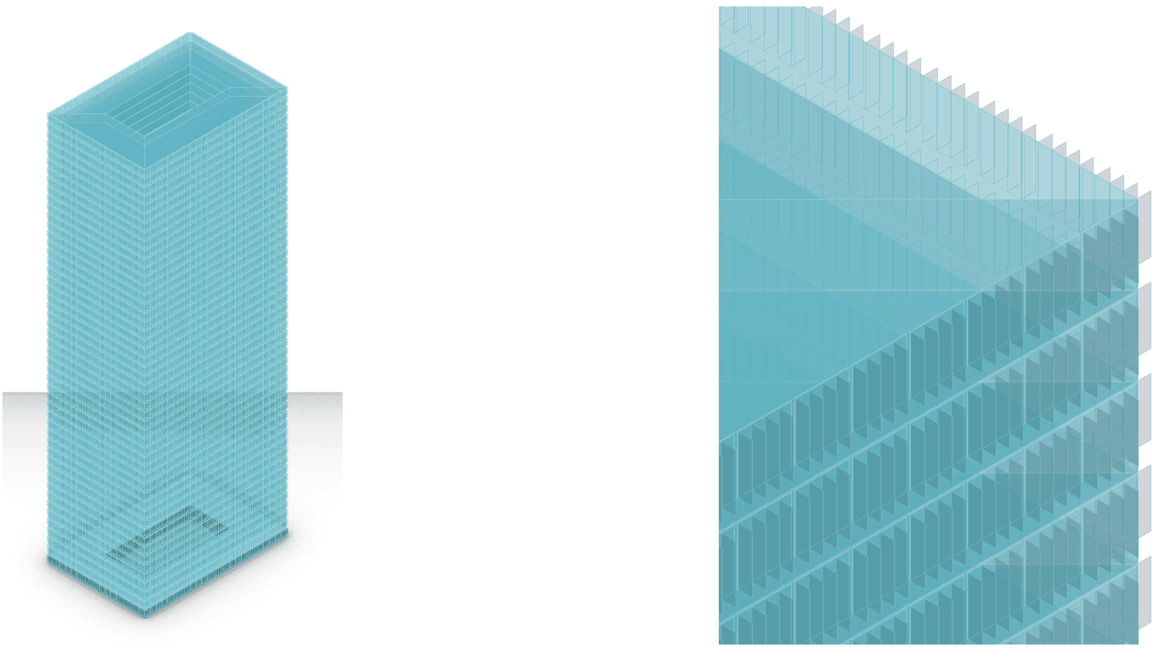

Figure A.28: Visualization of a design solution with high wwr and four vertical louvres of 0.9m depth.

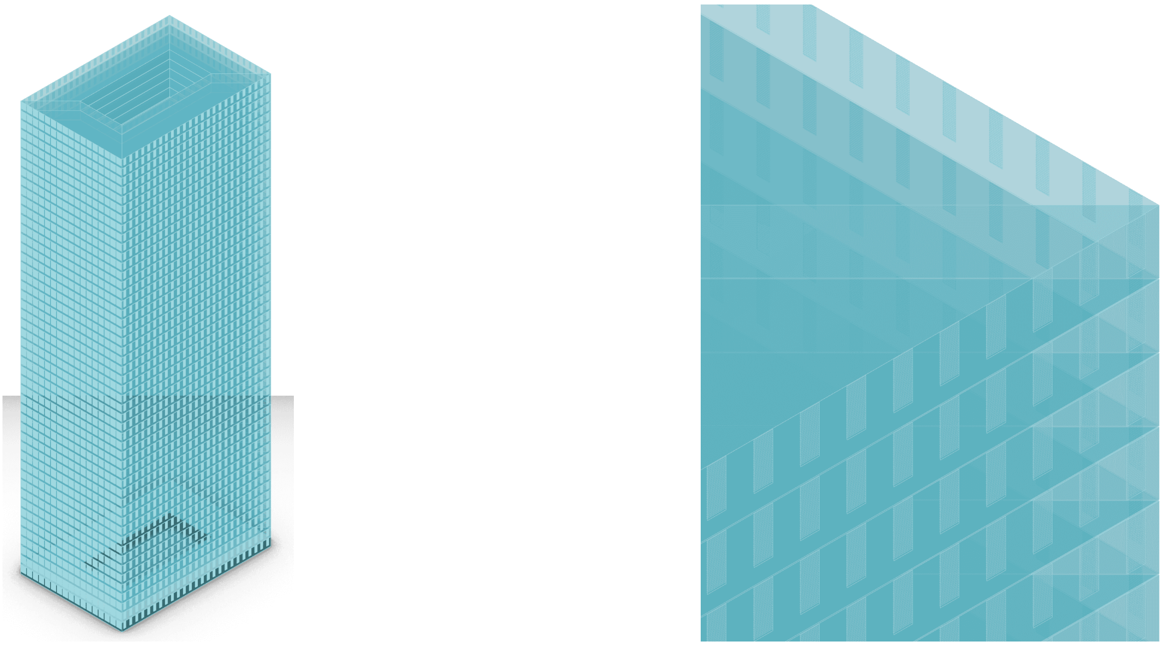

Figure A.29: Visualization of a design solutions with low wwr and internal blinds.

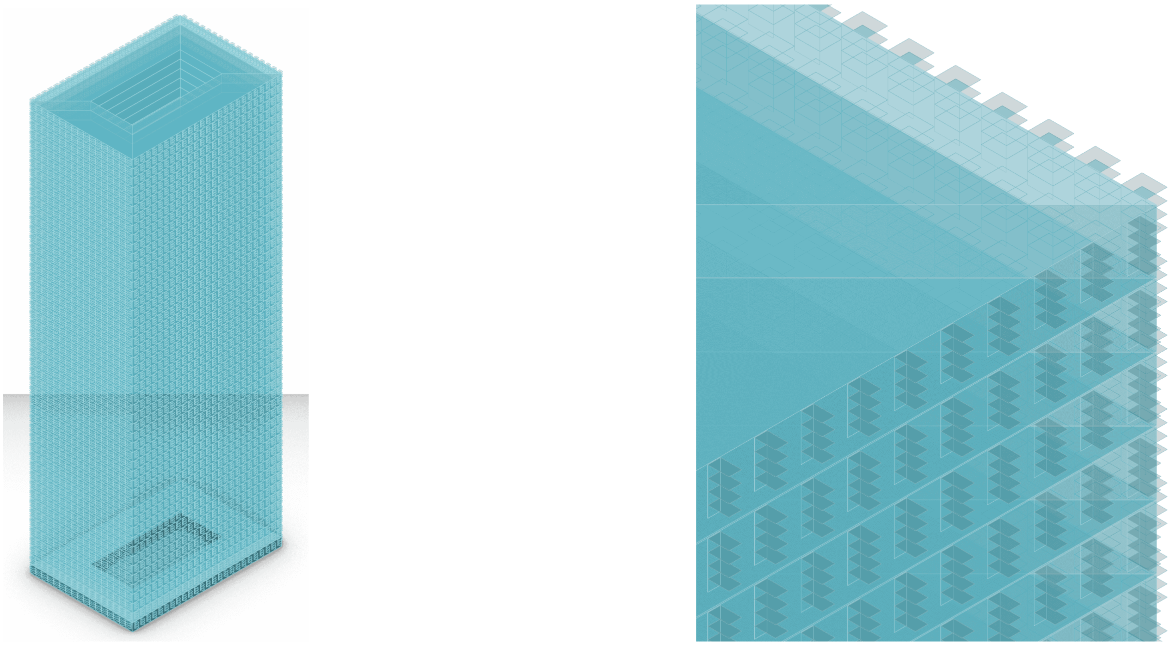

Figure A.30: Visualization of a design solution with low wwr and four horizontal louvres of 0.9 m depth.

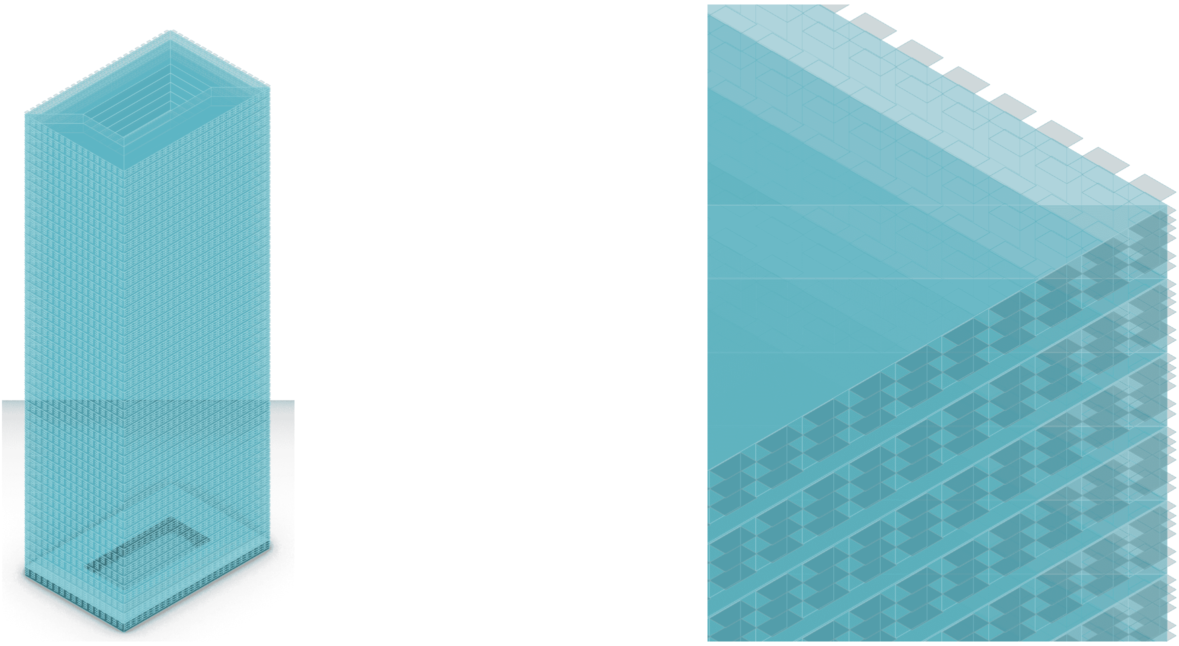

Figure A.31: Visualization of a design solution with high wwr and three horizontal louvres of 0.9 m depth.

Figure A.32: Visualization of a design solution with low wwr and two vertical louvres of 0.3 m depth.

Figure A.33: Visualization of a design solution with low wwr and one horizontal overhang of 0.5 m depth.

Bibliography

[1]

[2]

[3]

[4] Energyplus version 9.2.0, 2019. URL https://energyplus.net/.

[5] Modefrontier, 2019. URL https://www.esteco.com/modefrontier.

[6] Tini Grace Abraham, Sandhyalaxmi G Navada, Savitha G Kini, and Nidhi Gupta. Energy conservation measures for an office building in warm and humid climate. *Indian Journal of Science and Technology*, 9(44):105318, 2016.

[7] International Energy Agency. Ebc annual report 2017: Energy in buildings and communities programme. 2017.

[8] Tahmina Ahsan. Passive design features for energy-efficient residential buildings in tropical climates: The context of dhaka, bangladesh, 2009.

[9] Salwa M Al-Masrani, Karam M Al-Obaidi, Nor Azizah Zalin, and MI Aida Isma. Design optimisation of solar shading systems for tropical office buildings: Challenges and future trends. *Solar Energy*, 170:849–872, 2018.

[10] Shady Attia, Elisabeth Gratia, André De Herde, and Jan LM Hensen. Simulation-based decision support tool for early stages of zero-energy building design. *Energy and buildings*, 49:2–15, 2012.

[11] Shady Attia, Mohamed Hamdy, William O'Brien, and Salvatore Carlucci. Assessing gaps and needs for integrating building performance optimization tools in net zero energy buildings design. *Energy and Buildings*, 60:110–124, 2013.

[12] BCA. Singapore's zero energy building (zeb) on-track to meet net zero power consumption. 2010.

[13] Jamal van Kastel Michela Turrin Berk Ekici Boris Bähre, Sevil Sariyildiz. Ar0026 mega 2018, computational design collection of notes and study material. 2018.

[14] Salvatore Carlucci, Lujian Bai, Richard de Dear, and Liu Yang. Review of adaptive thermal comfort models in built environmental regulatory documents. *Building and Environment*, 137:73–89, 2018.

[15] The Skyscrape Center. The global tall building database of the ctbuh, 2018. URL http://www.skyscrapercenter.com/compare-data/submit?type%5B%5D=building&status%5B%5D=COM&status%5B%5D=UC&function%5B%5D=office&base_region=7&base_country=140&base_city=1461&base_height_range=0&base_company=All&base_min_year=0&base_max_year=9999&comp_regio.

[16] Kian Jon Chua and Siaw Kiang Chou. Evaluating the performance of shading devices and glazing types to promote energy efficiency of residential buildings. In *Building Simulation*, volume 3, pages 181–194. Springer, 2010.

[17] Qi Cui. *Office building energy saving potential in Singapore*. PhD thesis, NUS national University of Singapore, 2006.

[18] Richard J De Dear and Gail S Brager. Thermal comfort in naturally ventilated buildings: revisions to ashrae standard 55. *Energy and buildings*, 34(6):549–561, 2002.

[19] Comfort futures. Ken yeang, 2018. URL http://www.comfortfutures.com/ken-yeang.

[20] François Garde, A Lenoir, A Scognamiglio, D Aelenei, D Waldren, HN Rostvik, J Ayoub, L Aelenei, M Donn, M Tardif, et al. Design of net zero energy buildings: feedback from international projects. *Energy Procedia*, 61:995–998, 2014.

[21] Ottenwelter E. Bornarel A. Tardif P. M. Garde, F. Integrated building design in tropical climates: lessons learned from the enerpos net zero energy building. *ASHRAE Transactions*, 118(1):81–90, 2012.

[22] Y. Hamzah. Project: Menara mesiniaga features bioclimatics (malaysia). retrieved from solaripedia:, 2018. URL `http://www.solaripedia.com/13/302/3421/menara_mesiniaga_shading_diagram.html`.

[23] Yu Huang and Jian-lei Niu. Optimal building envelope design based on simulated performance: History, current status and new potentials. *Energy and Buildings*, 117:387–398, 2016.

[24] Lokman Hakim Ismail, Magda Sibley, and Izudinshah Abdul Wahab. Bioclimatic technology in high rise office building design: a comparison study for indoor environmental condition. *Journal of Science and Technology*, 3(2), 2011.

[25] A Katili, Rabah Boukhanouf, and Robin Wilson. Space cooling in buildings in hot and humid climates–a review of the effect of humidity on the applicability of existing cooling techniques. In *14th International Conference on Sustainable Energy Technologies â€“SET*, 2015.

[26] Ayca Kirimtat, Basak Kundakci Koyunbaba, Ioannis Chatzikonstantinou, and Sevil Sariyildiz. Review of simulation modeling for shading devices in buildings. *Renewable and Sustainable Energy Reviews*, 53:23–49, 2016.

[27] Dewi Larasati and Sahid Mochtar. Application of bioclimatic parameter as sustainability approach on multi-story building design in tropical area. *Procedia Environmental Sciences*, 17:822–830, 2013.

[28] Vasileios Machairas, Aris Tsangrassoulis, and Kleo Axarli. Algorithms for optimization of building design: A review. *Renewable and sustainable energy reviews*, 31:101–112, 2014.

[29] Haghighat F Magnier, L. Multiobjective optimization of building design using trnsys simulations, genetic algorithm, and artificial neural network. *Building and Environment*, 45:739–746, 2010.

[30] Anna Joanna Marszal and Per Heiselberg. Zero energy building (zeb) definitions-a literature review. *Proceedings joint actions climate change*, pages 8–10, 2009.

[31] P. Micheal. Tropical moist climate-climate type. retrieved november 26, 2018, from the encyclopedia of earth:, 2011. URL `https://editors.eol.org/eoearth/wiki/Tropical_Moist_Climates_-_A_Climate_Type`.

[32] Seyedehzahra Mirrahimi, Mohd Farid Mohamed, Lim Chin Haw, Nik Lukman Nik Ibrahim, Wardah Fatimah Mohammad Yusoff, and Ardalan Aflaki. The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate. *Renewable and Sustainable Energy Reviews*, 53:1508–1519, 2016.

[33] Mostapha Sadeghipour Roudsari. Ladybug 0.0.67 and honeybee 0.0.64, 2019. `https://www.food4rhino.com/app/ladybug-tools`, Last accessed on 2019-10-20.

[34] Wan Iman Wan Nazi, Yao Dong Wang, and Tony Roskilly. Methodologies to reduce cooling load using heat balance analysis: a case study in an office building in a tropical country. *Energy Procedia*, 75:1269–1274, 2015.

[35] Toke Rammer Nielsen and Svend Svendsen. Optimization of buildings with respect to energy and indoor environment. 2003.

[36] Carlos Ernesto Ochoa and Isaac Guedi Capeluto. Strategic decision-making for intelligent buildings: Comparative impact of passive design strategies and active features in a hot climate. *Building and Environment*, 43(11):1829–1839, 2008.

[37] Climate of Singapore. Singapore's third national communication and first biennial update report, 2014.

[38] Climate of Singapore. Meteorological service singapore, 2018. URL http://www.weather.gov.sg/climate-climate-of-singapore/.

[39] B Ogwezi, G Jeronimidis, G Cook, J Sakula, and S Gupta. Adaptive buildings' facades for thermal comfort in hot-humid climates. In *TSBE Engineering Doctorate Conference 2012*, 2012.

[40] Ana I Palmero-Marrero and Armando C Oliveira. Effect of louver shading devices on building energy requirements. *Applied Energy*, 87(6):2040–2049, 2010.

[41] R. Powell. *Rethinking the skyscraper: the complete architecture of Ken Yeang*. Thames and Hudson, 1999.

[42] One Raffles Quay. One raffles quay, north tower, 2018. URL http://www.orq.com.sg/northtower-specs.html.

[43] Upendra Rajapaksha and Richard Hyde. Barriers to and opportunities for advanced passive cooling in sub-tropical climates. *Architectural Science Review*, 55(1):49–60, 2012.

[44] Babak Raji. Sustainable high-rises: Design strategies for energy-efficient and comfortable tall office buildings in various climates. 2018.

[45] Mike Riley, Alison Cotgrave, and Michael Farragher. *Building Design, Construction and Performance in Tropical Climates*. Routledge, 2017.

[46] V. Roberts. The demand for cooling in singapore's buildings. retrieved from energy ramblings:, 2018. URL http://www.energyramblings.com/2015/09/05/the-demand-for-cooling-in-singapores-buildings/.

[47] Mat Santamouris, K Pavlou, A Synnefa, K Niachou, and D Kolokotsa. Recent progress on passive cooling techniques: Advanced technological developments to improve survivability levels in low-income households. *Energy and Buildings*, 39(7):859–866, 2007.

[48] About BCA Green Mark Scheme. Singapore cools off, and all must pitch. retrieved from the new york times, 2019. URL https://www.bca.gov.sg/greenmark/green_mark_buildings.html.

[49] Green Singapore. Green singapore. retrieved from comfort futures:, 2019. URL http://www.comfortfutures.com/green-asia.

[50] Sanja Stevanovic. Optimization of passive solar design strategies: A review. *Renewable and Sustainable Energy Reviews*, 25:177–196, 2013.

[51] MK Tanuharja. Integrated facade system in high rise office building in tropical climate condition, 2015.

[52] Doris Hooi Chyee Toe and Tetsu Kubota. Development of an adaptive thermal comfort equation for naturally ventilated buildings in hot–humid climates using ashrae rp-884 database. *Frontiers of Architectural Research*, 2(3):278–291, 2013.

[53] Eleftheria Touloupaki and Theodoros Theodosiou. Performance simulation integrated in parametric 3d modeling as a method for early stage design optimization—a review. *Energies*, 10(5):637, 2017.

[54] Arnold W. Singapore cools off, and all must pitch. retrieved from the new york times, 2002. URL https://www.nytimes.com/2002/06/02/business/the-business-world-singapore-cools-off-and-all-must-pitch-in.html?pagewanted=all.

[55] Wikipedia. List of tallest buildings in singapore, 2019. URL https://en.wikipedia.org/wiki/List_of_tallest_buildings_in_Singapore.

[56] Robert Wimmer. Adapting zero carbon house for tropical climate–passive cooling design in the philipines. *SB13 Sustainable Buildings, Infrastructure and Communities in Emerging Economies, Manila*, pages 1–8, 2013.

[57] NH Wong and S Li. A study of the effectiveness of passive climate control in naturally ventilated residential buildings in singapore. *Building and Environment*, 42(3):1395–1405, 2007.

[58] NH Wong, H Feriadi, PY Lim, KW Tham, C Sekhar, and KW Cheong. Thermal comfort evaluation of naturally ventilated public housing in singapore. *Building and Environment*, 37(12):1267–1277, 2002.

[59] T. Wortmann. *Efficient, Visual, and Interactive Architectural Design Optimization with Model-based Methods*. PhD thesis, Singapore University of Technology and Design, 2018.

[60] Y. Yoneda. Tour singapore's greenest building: Bca academy's zero energy headquarters. retrieved from inhabitat:, 2019. URL https://inhabitat.com/tour-singapores-greenest-building-bca-academys-zero-energy-headquarters/?variation=b.