PROPOSING A NEW MULTISTORY OFFICE BUILDING TYPE IN MODERATE CLIMATE AS A GENERIC PASSIVE STRATEGY

A dissertation presented

by

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to

Breuer Marcel Doctoral School of Architecture,

The University of Pecs, Faculty of Engineering and Information Technology

for the degree of

Doctor of Philosophy in the subject of

Architecture engineering

Pecs, Hungary

2020

APPROVAL SHEET

This dissertation proposal entitled PROPOSING A NEW MULTISTORY OFFICE BUILDING TYPE IN MODERATE CLIMATE AS A GENERIC PASSIVE STRATEGY submitted by MOHAMMAD REZA GANJALI BONJAR for the degree DOCTOR OF PHILOSOPHY has been examined and approved for PROPOSAL HEARING.

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PROPOSING A NEW MULTISTORY OFFICE BUILDING TYPE IN MODERATE CLIMATE AS A GENERIC PASSIVE STRATEGY

(Szentágothai János Kutatóközpont)

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Abstract

Fully glazed facades have forced up the thermal loads in modern, contemporary office buildings, resulting in a considerable amount of cooling and heating demand. Moreover, occupancy time is increasing in office spaces, while the improvement of well-being and level of productivity is fundamentally based on the indoor comfort environment. This study aims to test a new, climate-responsive building envelope and related space organization concept. According to the proposed `introverted space organization with closed facade` (ISOCF) concept, the windows are abandoned completely from the façade and different internal courtyards are simultaneously integrated to ensure passive lighting and ventilation. As an effect, the internal space organization requires contiguous open spaces, instead of standard cellular office partitions. To evaluate the impact of the ISOCF strategy, thermal, and visual comfort, as well as the energy performance of various building versions, were analyzed. In a dynamic thermal building simulation framework, a reference office building is modeled with three window-wall ratios (WWR) scenarios and three completely new ISOCF design variations in moderate climate conditions. The differences between energy and comfort performance in all models were analyzed to evaluate the positive and negative impacts and interrelations. The results indicated that the ISOCF models provide a significant improvement in heating and total energy demand, whereas heating dominates 80% of the total energy need. Thermal (PMV) and visual comfort were improved as well, while the lighting and cooling energy consumption suffered marginally due to WWR enlargement. The study serves as a fundamental basis for the development of a comprehensive future ISOCF multistory office building typology and design guidelines.

Keywords: closed facade; passive strategy; thermal and visual comfort; energy performance; thermal simulation; multistory office building

Pécsi Tudományegyetem
Műszaki és Informatikai Kar
Breuer Marcell
Doktori Iskola

ACKNOWLEDGMENTS

First, I would like to express my sincere gratitude to the University of Pecs, especially the Faculty of Engineering and Information Technology, for being supportive during my study. I would like to extend special thanks to Professor. Dr. Istvan Kistelegdi and Dr. Baranyai Balint for their unforgiven support and supervision over the last couple of years and express my regards towards them.

I extended much appreciation for the doctoral school's staff in the faculty for their advice and support during the study period. Many people helped me during my study, which I would like to thank them for being helpful.

Hereby, I want to thank my wife for always being supportive, her patience and support, motivate me to tackle all the unexpected issues which I faced during my academic years. I also would like to thank my family, who stayed strong and always being supportive during the whole years which I was far from them. I would like to thank my mother for her love, which helped me during the toughest days of my career and study far from family. I would like to thank my brother and sister for their incredible inspirations. Lastly, my biggest appreciation and regard is to my father, who not only was the main reason to achieve this degree, but he is always the most important motive and support in my entire life.

Mohammad Reza Ganjali Bonjar

ACRONYMS

IPCC	Intergovernmental Panel on Climate Change
EU	European Union
SHGC	Solar Heat Gain Coefficient
WWR	Window Wall Ratio
DSF	Double Skin Facade
IT	Informatics technology
NV	Natural ventilation
HVAC	Heating, ventilation, and air conditioning
IAQ	Indoor air quality
BIPV	Building Integrated PV on facade
PV	Photovoltaic
TQM	Total quality management
BPR	Business process reengineering
OPOD	Open Plan Offices Design
ICC	Introverted climate concept
IDA ICE	IDA Indoor and Climate Energy simulation software
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfied
DF	Daylight factor
VAV	Variable Air Volume
RH	Relative humidity
PC	Personal computer
ICT	Information and communication technology

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1. INTRODUCTION

1.1. Background of research

The 21st century is characterized by climatic and demographic alterations. More specifically, the latest detailed announcement on climate change (Houghton, et al., 1990) announcement by the Intergovernmental Panel on Climate Change (IPCC) exposed the historical peak in atmospheric concentrations of carbon dioxide, methane, and nitrous oxide (Pachauri, et al., 2014).

The predicted climatic changes will have significant implications for building planning in the future. The population explosion in comparatively young states will demand extensive construction projects, in which the standard European concepts will be insufficient to meet. The architecture of the future will need to be based on detailed climatic analysis, taking into account the impact of solar radiation, temperature, humidity, and wind on buildings. Only close attention to the climate and the local architectural tradition can produce fully adequate buildings and optimal energy concepts (Petra, et al., 2012). In the same topic, in Europe, the highest energy saving and energy efficiency potential are possible in the building sector, in other words, is responsible for the largest share of the total EU final energy consumption (42%) and 35% of CO_2 emissions are caused by building sector, to tackle this issue European Union (EU) and particularly EU directive on the energy performance of buildings implemented national regulations in member states construction regulations (Cellura, et al., 2013).

According to the state of the art in research, office and commercial buildings is one of the highest energy consumers in comparison to the other building types, which represents an annual energy use between 100 and 1000 kWh/m^2 per annum. This will also depend on the depending on the type of office equipment and its geographical location. (Santamouris & Dascalaki, 2002).

Although for offices in the European Region, it is about 306 kWh/m^2 per annum. Additionally, the mean electric index is 150 kWh/m^2 per annum and the mean fuel index 158 kWh/m^2 per annum (Lagoudi, et al., 1996) Koschenz et al. discussed how fully glazed facades have forced up the internal and external thermal loads in modern office contemporary buildings. This resulted in a considerable amount of cooling demand for such structures (Koschenz & Beat, 2004).

Researches have also shown that due to the increased amount of people working in the informatics technology (IT) tertiary sector in the last decade, cooling loads have become more in demand, especially with buildings that have the most amount of solar gain in the facade (Jenkins, et al., 2008) (Zoltán, 2014).

However, the study shows nonresidential building and agriculture are among the fastest-growing energy demand sectors and is projected to be 26% higher in 2030 than it was in 2005, compared to only 12% higher for residential buildings. (Capros, et al. 2007)

On another hand, it is evident by increasing the time people are spending at the office spaces and requirement of standard comfort needed to help to improve the well-being and increased levels of productivity of the workers, and we need to meet the shortcomings to optimize office buildings and analysis the new possible innovation methods for future office buildings.

1.2. Literature Review of Facade Optimization

1.2.1. Window Properties

Studies have shown that facade optimization can provide energy efficiency while maintaining a suitable internal comfort level. In this context, the study demonstrates how building facade window U-values affect indoor thermal comfort. Windows should be optimized (double or triple glazing) because these can cause high heating and cooling energy consumption (Thalfeldt, et al., 2013).

In another research, Takeshi et al. also argue that to reduce annual heat demand, windows U and V-values must be considered in solar reflectance of a building (Ihara, et al., 2015).

As mentioned, optimizing building design for thermal comfort can be attained by proper treatment of building envelope design. Besides, both the U-value and Solar Heat Gain Coefficient (SHGC) of the glazing should be taken into consideration (Abed, et al., 2019).

1.2.2. Window Wall Ratio (WWR)

In another investigation, the various building facade geometry parameters can affect building energy consumption in an office building, thus reducing energy savings. Proper use of building and fenestration geometry parameters combined with other fenestration elements will prominently minimize building energy use and therefore improve building performance (Irina, et al., 2013).

Additionally, for all the orientations, the locations will determine the optimal WWR value that is required for heating and cooling. Focusing on just one of the total energy balance is not adequate and may lead to erroneous assumptions (Francesco, 2016).

Various investigations on the impact of the window to wall ratio have shown that with the increase of WWR, the heating and lighting energy consumption reduced, whereas the cooling energy consumption is amplified. This is because the exposed window areas allowed more daylight that was transmitted inside the building, which resulted in increased heating and lighting of the interior space (Amirta & Subhasis, 2018) (Samah, et al., 2017).

A study by Goia and Francesco argued that warm-dominated climates are an excellent choice for those where the WWR value is more critical. To note, the WWR value that exceeds the optimal range leads to the highest increase in energy use. Thus, it is critical to have the precise WWR in the north-, east- and west-facing facades in a warm climate because this can cause a higher increase in the total energy use. Nevertheless, in colder climates, the East and west-facing facades are those where a non-optimal transparent percentage causes the lowest increase in energy use. Of course, the investigation showed that more transparent building envelopes are suggested moving for colder climates (Francesco, 2016). Therefore, increasing window size likewise increases energy consumption, especially in cold conditions. However, adding fixed shading, especially with a high glazing g-value, can compensate for energy loss, although window shape or positioning on the wall had a minimal direct effect (Tapio, et al., 2019).

1.2.3. Natural Lighting

As mentioned earlier the potential of energy savings by integrating the daylighting is high (Bodart & André, 2002).

Different studies have indicated that through an improved design use of natural light, energy consumption can be kept at a minimum (Gago, et al., 2015).

The size of the window plays an essential role in the case of thermal comfort and energy performance of the buildings as in the same context study demonstrates that large window areas can ensure a considerable saving of lighting energy via daylighting. At the same time, a large window area also lets in a large amount of unwanted solar radiation. Thus, cooling prevailing climates employing several popular energy-efficient designs on the window can reduce a large amount of solar heat gain.

The facade orientation and the climate condition of the building is an important variable to consider. Orientation and geography location can have a substantial influence on the thermal and daylighting performance of window designs. In cooling dominant climates, all the window designs perform better on the east and west orientations while the performance is reduced on the north side. Of course in locations where the latitudes are low, the difference among orientations is quite evident because as the latitude rises, the difference of these temperatures becomes insignificant (Huang, et al., 2014) (Nielsen, et al., 2011).

In a similar study involving the daylight target without overheating in south-oriented rooms, the choice of *g*-value from the perspective of space heating demand corresponds well with the *g*-value to prevent overheating. The study also pointed out, in north-oriented rooms, high *g*-values are recommended to reduce space heating demand (Vanhoutteghem, et al., 2015).

Overall, the indoor daylight performance is influenced by several factors like the geographic location, climate, light availability, geometry, window properties, window-to-wall ratio, and orientations (Ghisi & John, 2005) (Ran, et al., 2009) (Jae-Wook, et al., 2013) (Krüger & Adriano, 2008) (Geun, et al., 2012) (Geun, et al., 2012).

1.2.4. Faced Louver and shading

A similar study also showed that, depending on the distance from the facade, the Venetian blind position could affect the contribution of daylight in an office by between 10 and 60 percent. The reduction of energy use and glare has the potential to significantly improve thermal comfort (Bessoudo, et al., 2010).

Another study illustrates the effect of louver shading devices on building energy requirements may depend on several factors. For example, the location, louver inclination angle, and window area have special significance to improve thermal comfort conditions. In south-facing facades, the louver system can be optimized to provide suitable shading in summer while allowing solar incidence during the winter period. Parameters like the number of louvers, the spacing between louvers, position above the window, and louver area, affect thermal comfort (Palmero-, et al., 2010).

A study by Yao indicates that flexible solar shade not only improves indoor thermal comfort in summer but also reduces extremely uncomfortable weather (Yao, 2014). Another study by Manzan showed how the impact of shading devices on buildings' energy must be taken into consideration, including the electrical energy absorbed by the lighting system since this load affects both heating and cooling loads (Manzan, 2014).

Further analyses have also shown that shading devices on the south-oriented facades contribute to the reduction of the total energy demand in buildings with glazed envelope (Krstić-, et al., 2019). In the case of movable shading and during winter, there is a possibility to use as much as daylight, which able to decrease the amount of heating while we do not have this feature in the case of fixed shading type. The disadvantage of fixed shading tools appears mostly in cold climates where heating is the main issue, and it has a negative impact in the case of the lighting and heating electrical energy consumption.

Finally, it was also discovered that the louver’s reflectivity is the crucial influence that affects the blind’s general performance. The higher the reflectivity, the better the blind performs (Huang, et al., 2014).

1.2.5. Double Skin Facade (DSF)

An alternative possible design solution could be the addition of a double-skin facade. If designed correctly, it could not only support the passive heating strategy in the cold period of the year while enhancing natural ventilation (NV) in the building (Haase & Amato, 2009).

It must be noted that Double Skin Facade (DSF) is a purely stack effect and is effective enough to extract solar heat gain inside the facade cavity to retain lower internal surface temperature. However, the increase of air change by mechanical fan assists the extraction process; nonetheless, the magnitude of energy-saving is negligible due to its installation and maintenance cost. The external surface temperature of the double glazed facade is very high because of the characteristic of heat absorption glass (Wong, et al., 2005).

In this framework, using an algorithm based on the energy content of the return air and the recuperation of the air returning from the airflow and supply window showed to be the most promising strategies to lower the heating demand. In general, having control over airflow, is an effective way to decrease the cooling demand for all facade, on the other hand not the most effective strategy for heating demand (Saelens, et al., 2008).

The studies demonstrate that DSF can have variable results due to climate conditions. The connection to this study examines the effect of climate facade in a moderate climate. However, in the case of closed cavities, the buffer effect is moderate with the overcast sky the south orientations the cavity has a risk of overheating even on the coldest days, which can be compensated with controllable openings. Besides, the heat loads are so high that shading is necessary even on cold, but sunny days (Adrienn & András, 2015).

Another study demonstrates that DSF can lead to overheating problems due to internal heating gains. The results indicate that the main concern is the reduction of the cooling load. Consequently, reducing air temperature inside the air gap is a critical aspect that can be attained (Alberto, et al., 2017).

Nevertheless, the study has highlighted the complexity of applying DSF technology to buildings because the outcomes necessitate not only precise design details but also the applicable operation of the systems like controlling the opening and closure of windows. (Barbosa & Kenneth, 2016).

Another study recommends that control strategies for the cavities of double skin envelope systems must take into account outdoor air temperature to increase energy savings. Natural ventilation obtainable from the cavity to the indoor space is at suitable air temperatures when the sky ratio is partly cloudy (Yu, et al., 2011).

In connection to commercial and public buildings, many of the office buildings have no atrium or chimney to benefit from any stack ventilation. However, then again, natural ventilation can be systematized using only the front windows both by single-sided ventilation or by cross-ventilation (Elisabeth, et al., 2004).

In a similar study, the possibility of using a ventilation shaft capable of enhancing NV could be a collective solution together with ventilated windows to decrease the entry of solar heat gain into the building, thereby reducing peak cooling load (Haase & Amato, 2009).

Thus, the amalgamation of natural ventilation in office buildings would cause the lowering of construction cost as a result of downsizing heating, ventilation, and air conditioning (HVAC) systems (Zheming, et al., 2016).

Although the DSF is an effective way to improve the energy consumption performance and thermal comfort of the buildings, there is a significant impact of multiple factors such as climate, building properties, occupancy, and operation profiles on the performance of natural ventilation. These strategic natural ventilation designs should contemplate not only the climatic conditions but also various issues such as the building's thermal characteristics, the ventilation type, and profile and internal gains (Runming, et al., 2009).

It must be noted that Double skin facades are already a common feature of the architectural competitions in Europe, but then again there are still relatively few buildings in which they have been recognized (Zöllner, et al., 2002) (Zalewski, et al., 2002) (Elisabeth & André, 2004).

Finally, in the context of DSF, it is sometimes challenging to apply the strategy of natural daytime ventilation because the extraction through the double skin has been revealed to be delicate and is a function of the wind direction of the building. The lower double skin opening also has an impact on the direction of airflow and natural cross ventilation is almost difficult when the double skin was on the windward side (Elisabeth & André, 2007) (Elisabeth, et al., 2004).

1.2.6. *Natural Ventilation*

Natural Ventilation has been acknowledged as one of the most promising passive strategies to reduce building energy consumption by HVAC systems. It was evident that NV can add to the decrease in building energy (Wang & Ali, 2009).

Furthermore, strategic NV designs should reflect not only the climatic conditions but also multiple factors such as the building's thermal characteristics, the ventilation type, and profile internal gains (Runming, et al., 2009).

Consequently, ambient air quality and size must be taken into consideration when evaluating the reality of NV's total energy savings potential. A study by Tong demonstrates how the utilization of natural ventilation creates tremendous energy-saving potential, thus reducing the emissions associated with coal-fired power generation, which results in lowering initial construction costs as a result of downsizing HVAC systems (Zheming, et al., 2016).

In the case of office buildings, lots of these structures have no atriums to benefit from any stack ventilation. On the other hand, natural ventilation can be structured with only frontage windows either by single-sided ventilation or by cross ventilation. When the wind is not favorable single-sided ventilation is can be useful. Windows have to be designed to ensure sufficient air ventilation rate when the outdoor wind is unfavorable (Elisabeth, et al., 2004).

Natural ventilation not only helps to improve the energy performance of the buildings but, at the same time, is one of the most effective solutions to decrease the level of CO_2 concentration and help to improve the indoor air quality (IAQ). In a similar study, ventilation plays a significant role in improving indoor air quality by decreasing the CO_2 concentration levels. The research also illustrates that natural ventilation cannot counterbalance a poorly controlled heating system. This leads to unsatisfactorily high indoor air temperatures, which can lead to unsatisfactory thermal comfort conditions (Papadopoulos & Avgelis, 2003).

1.2.7. Building Integrated PV on the facade (BIPV)

In this context, the replacement of the windows with innovation where both visibility and energy conversion efficiency is taken into consideration can be a solution for a better energy-efficient envelope, as the study made a parametric investigated on the application of the see-through solar cell transmittance on wall window ration (WWR) of office buildings. The study by Miyazaki et al. shows that the combination of the solar cell transmittance of 40% and WWR of 50% achieved the minimum primary energy for all window orientation. The result is an energy savings of 54% was achieved compared to the average model (Miyazaki, et al., 2005).

Numerous studies have also proven that the building integrated photovoltaic (BIPV) is valid in terms of the overall energy performance of the buildings, particularly at commercial buildings. In the same study, the fabricated solar cells onto the window of a typical mid-sized office building in various climate conditions, and as a result, they demonstrate BIPV has advantages to reduce the consumption of annual HVAC system energy in most climate conditions (Young, et al., 2014).

To improve the output of buildings, passive strategies like energy-efficient facades can be used. Improving facade elements' energy performance is crucial since they are the interface between the indoor and outdoor environments. The global program on reducing fossil fuel consumption has resulted in the push for accepting renewable technologies such as solar photovoltaic to generate clean energy. Building-integrated photovoltaic (BIPV) windows are regarded as one of the emerging glazing technologies for building facade elements (Chow, et al., 2010) (AbuBakr, et al., 2008) (Pho & Nalanie, 2014).

In the same context, the active building envelope is requisite to satisfy multiple (and sometimes opposed) requirements such as comply with solar shading in summer to avoid overheating, provide solar gains and thermal insulation in winter to reduce heat loads, supply daylight utilization to decrease lighting loads, allow the outside view to the occupants and give maximum electrical output (Olivieri, et al., 2014).

However, there are still some issues that the architectures should take into account mostly in connection to the office buildings and the situation of double skin facades if they aim to use the BIPV system for their building envelope. In connection to this, a study demonstrates that BIPV, photovoltaic (PV) panels are incorporated within building components, such as envelopes, roofs, or shading devices. Double-skin facades, mostly combined with integrated PV panels, have become an essential element in the construction of buildings in the last 15 years (Rafaela & Soteris, 2016).

In the same context, the study demonstrated that an air gap placed behind PV modules is essential to precede the breakdown of them. The gap can restrict the temperature rise of PV modules, which can be important mostly in the summer. Another finding of this study presents the importance of the position of the outlet from the air gap, which should be located in a region of wind-induced negative pressure to the enhancement of the natural ventilation within a building with a ventilated PV facade (Geun, et al., 2007).

The study shows the combination of the solar cell transmittance of 40% and WWR of 50% achieved the smallest amount of primary energy consumption in the case of uniform transmittance for all window orientation. The energy-saving of 54% was reached compared to the standard model (Miyazaki, et al., 2005).

1.3. Literature Review of Vernacular Architecture

Passive environmental controls like improvements in design, use of proper building substance, and inclusion of passive solar features of vernacular architecture can be used in the construction of modern buildings to ameliorate indoor thermal comfort conditions (Chandel, et al., 2016).

Using courtyards and atrium in vernacular architecture is inspiring to solve the cooling problem, and various studies are proven which this strategy was and is useful to overcome the cooling problem.

There are several types of architectural zones which modifies the outdoor and indoor climatic conditions without mechanical control systems. These zones are called transitional spaces that can be closed, such as an atrium or semi-closed like balcony and porch or open such as courtyard and patio (Mohammad, et al., 2012).

In the middle of Iran, where generally cooling down the air is critical, the method to defeat the problem, which was utilized for centuries, was a closed cubic form with a courtyard in the center of the building had been selected. Planting trees generate shadow and moisture softens the air of the building. Moreover, a pool house or fountain aids the cooling of the enclosed air through the evaporation of water. Consequently, the building has a free plan around the courtyard, and the windows and doors are facing it, thus the general form of the building is introverted (Hadi, 2014) (Figure 1).

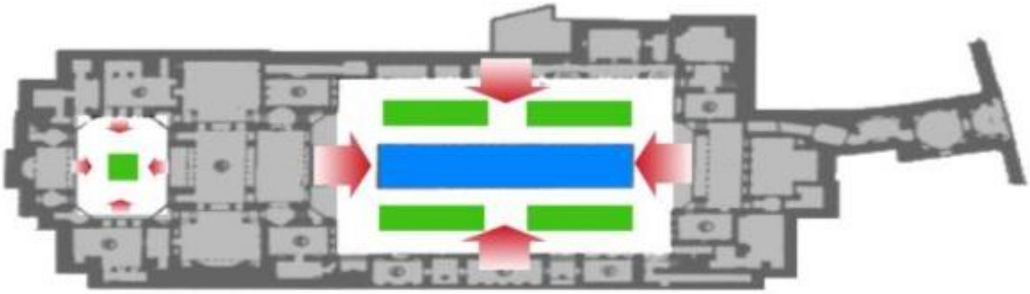


Figure 1 - Central courtyard and introversion architecture in a warm and dry climate (Pirnia, 2005)

The intensity of heat and dampness in the building can be decreased with the help of the yard, which functions as a passive system in the center of the building, it can easily make better use of the wind flow. It takes advantage of the spaces with opening windows toward the yard and also toward the alleys, which can create transverse ventilation in the building (Parinaz, et al., 2018) (Figure 2).

Figure 2 - The role of courtyards in making wind drafts and shadows-section from the central courtyard-Najafi house (Parinaz, et al., 2018)

The study discovered that the incorporated usage of a courtyard and atrium could save energy in all climates if a courtyard strategy is adopted during the hot seasons, and an atrium architectural mode is used in winter. Using the passive characteristics of courtyards, atria, and, most prominently, their integrated usage influences energy consumption (Tofigh & Begum, 2016) (Swasti & Abir, 2014).

The courtyard is a practical design strategy for a building from the perspective of climatic and cost-benefit analyses. These strategies can be applied to single-story or multi-story buildings. Nevertheless, the courtyard requires a controlled opening to remain its temperature low enough to cool down the indoors through ventilation (Nasser & Khalid, 2001).

1.3.1. Courtyards

Different definitions exist for the courtyard. As defined by the Oxford Dictionary, the courtyard is “an unroofed area that is completely or partially enclosed by walls or buildings, typically one forming part of a castle or large house”. In the past, it was used as a conventional element, particularly in designing houses. In recent times, it is considered as one of the passive design methods to moderate climatic conditions (Heidari, 2000).

One of the chief reasons for using the courtyard for more than 5000 years is its ecological effects. In different climates, it can be utilized as a source of day-lighting for adjacent rooms in in-depth plans. Another advantage of the courtyard in cold seasons is defending the parent building from rough conditions of weather such as winds (Upadhyay, 2008). During winter, it can raise direct solar heat gain in the rooms, which have a glazing zone on the courtyard. Its achievement during hot seasons is different. If deciduous trees are planted in the yard, it can be a solar protector. Besides, natural ventilation during summer occurs through the courtyard. During the daytime, the air in the yard is getting warmer and rises that pulls out the internal warm air through the openings. Therefore, it makes an air movement inside the adjoining building. During nights the procedure is reverse in which the cold ambient air sinks into the courtyard and enters into the interior spaces through the low-level openings. This creates airflows in the rooms, and the cooled air becomes warm, and then it lifts and leaves the rooms through the high-level openings (Kamyar, et al., 2010) (Heidari, 2000) (Figure 3).

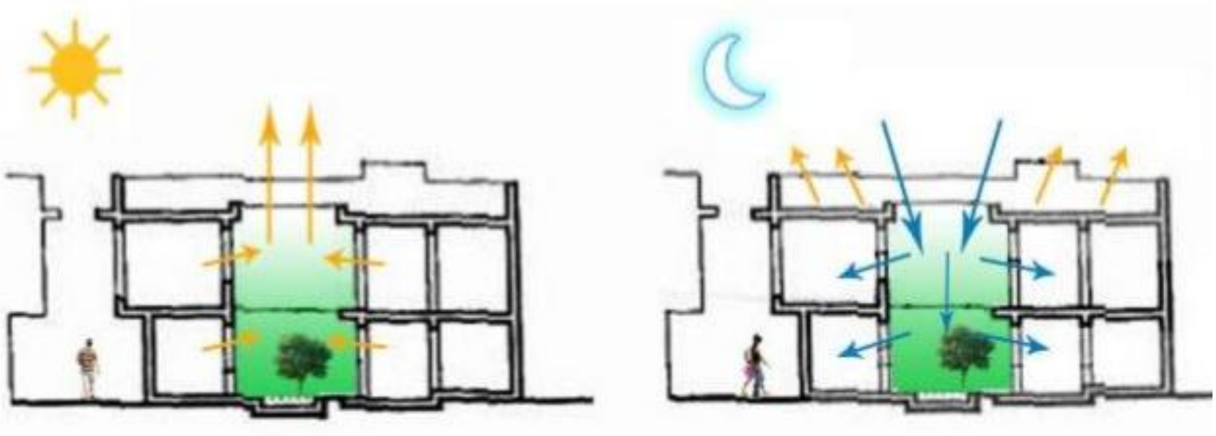


Figure 3 - The courtyard's effect on ventilation during days and nights (Ahmed, 2013)

1.3.2. Atrium

The definition of the Oxford dictionary for atrium is "a central hall in a modern building, typically rising through several stories and having a glazed roof". It can also be said that covering a courtyard with a glass roof makes an atrium (Swinal, 2011) (Mohammad, et al., 2012).

These days, the atrium is a popular construction style that is used at a high frequency in different regions, mainly in high latitudes, since it is an extraordinary building element which can be used for multi-purposes as a semi-outdoor space in buildings (Mabb, 2001) (Hung, 2003).

It is widely applicable, and it can be used as entry, lobby, and circulation spaces in buildings. Educational and museum buildings are good examples for that, in which atriums are shared as a gathering place. Additional application of atrium is for the extension, conservation, and refurbishing purposes. It allows architects and conservationists to reconstruct historical buildings by making a connection between new and existing buildings, and it also ensures natural lighting and protects the historical characteristics of the buildings. Besides, occasionally atrium is used as a beautiful and iconic space in particular in offices, hotels, and recreational buildings to convey power and prosperity. Also, it can be a city connector to empower transition between public and private areas (Swinal, 2011) (Goulding, et al., 1993) (Hung, 2003).

From an environmental point of view, the atrium as a glazed enclosed space can generally supply day-lighting and thermal comfort, which diminishes energy consumption of the parent building. In huge buildings, it can be an essential resource for natural lighting, which replaces artificial lighting. That is why the requisite lighting and cooling energy (to eliminate the produced heat from the lights) decreases. Furthermore, compared to the windows on exterior walls, a significant area of glazing can be used open to the atrium, for it defends the windows from heat loss and severe weather conditions (Goulding, et al., 1993) (Nick & Koen, 2005) (John, et al., 1992).

The achievement of the atrium changes in different climates and seasons. In cold seasons, the indoor air temperature is frequently higher than the outdoor temperature due to the solar heat gain still in unheated atriums. This raise in temperature depends on the proportion of the glazing area to the parent building wall area and thermal transmittance of the walls. Moreover, the glazing inclination and orientation influence solar heat increase, and then, indoor air temperature. The significant benefits of this temperature rise are reducing heat loss throughout the parent building walls and providing pre-heated ventilation. As a result, the heating energy demand of the parent building decreases. In summers, to prevent overheating is the major problem that should be solved. Habitually, the indoor air temperature in hot seasons is superior to ambient temperature. The first step to prevent the indoor air temperature from rising is shading. Different shading tools exist in atriums. They can be fixed, which reduces solar radiation during the whole years, or can be moveable to get rid of solar radiation only in overheating periods. They also reduce glare inside the atrium and the rooms. The second step is ensuring natural ventilation. It can be performed by creating a sufficient area of openings in suitable places principally in upper and lower levels of the atrium to present cross and displacement ventilation. Besides, using thermal mass material on inside surfaces can absorb heating energy during the day and release it at night when air temperature decreases. As well, planting and fountains can temperate the indoor environment for all year (Figure 4).

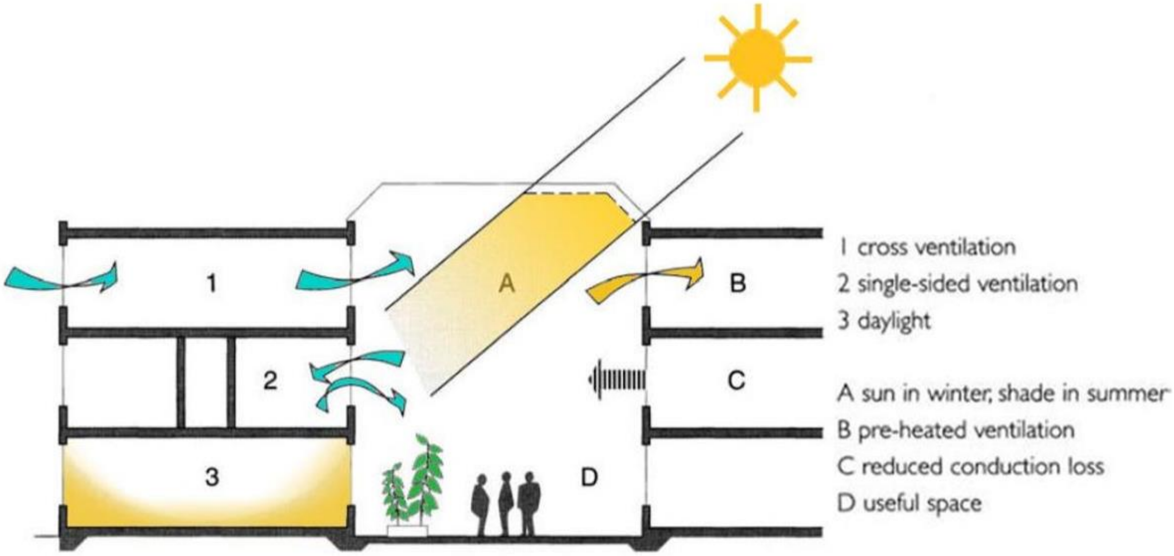


Figure 4 - Environmental benefits of an atrium (Nick & Koen, 2005)

1.4. Literature Review of Future office building workspaces

The changes in requirements for office buildings that have arisen in the last two decades are the result of innovative conceptions relating to the organization of office work associated with the more extensive use of electronic media and data processing. As a consequence of this, new functional solutions modified to new organizational requirements have come up (Wacław & Elzbieta, 2007).

The hierarchical structure of management, which was obligatory till the end of the 1980s, had its origin in the theory of rational bureaucratic work drawn up by Max Weber at the turn of the 20th century (Grudzewski & Hejduk, 2001).

The main assumptions confirming this theory are a transparent, multi-level hierarchy and a formal procedure of decisions. Based on this theory, offices were characterized by the organization of workplaces, facilitating the process of documents in order and clearness of hierarchical position, expressing the status and significance of individual positions. The significant characteristic of these solutions was a large number of office rooms required for low- and medium-level management staff to offer adequate control and supervision of clerical workers. During the last three decades of the 20th century, the rational Taylor's model inchoate to provide a way to new trends in the area of company management – total quality management (TQM) and business process reengineering (BPM) – which forwarded the idea of diminishing the number of management levels. These concepts, mutually with new IT technologies, caused a fundamental change in the organization of office work. Hierarchical organizational structures began to create rise to new structures based on team working (Wacław & Elzbieta, 2007).

On the other hand, mobile phones, PCs, and wireless networks provided flexible work, and the quick appearance of project work in knowledge-based organizations gave new and more dynamic ways of working. More powerful computers, the knowledge-intensive and multidisciplinary environment of office work, gave many design solutions for open-plan offices. After the foreword of alternative offices, several typologies of workplace design were elaborated (Franklin, 1999) (Franklin & William, 2001) (Christina & Dannielson, 2009) (Paul, et al., 1999).

From the viewpoint of business value creation, the question is how open and flexible workspace solutions improve value creation in organizations. An assessment of Telenor's new office building in the Oslo area, based on a study combined with interviews and document studies, verifies that a more significant part of the 2,500 employees who participated in the survey, perceived that their new open and flexible workplace combined with a new information and communication technology (ICT) platform and a more flexible, project and team-based work style, superior knowledge distribution, learning, co-operation and modernization (Arge & Kikkan, 2004).

Nowadays most preferential model of work environment is the activity-based office, where fewer individual workspaces are obtainable, but there is more space devoted to interactive uses. Space is optimized for all types of teamwork, starting from substantial formal meetings to chance interactions, as two people pass in the corridor. New work environments offer not just spaces for meeting and interacting with each other but also tranquility and intimacy for focused work and research. A basic design is shown in (Zoltán, 2014) (Figure 5).

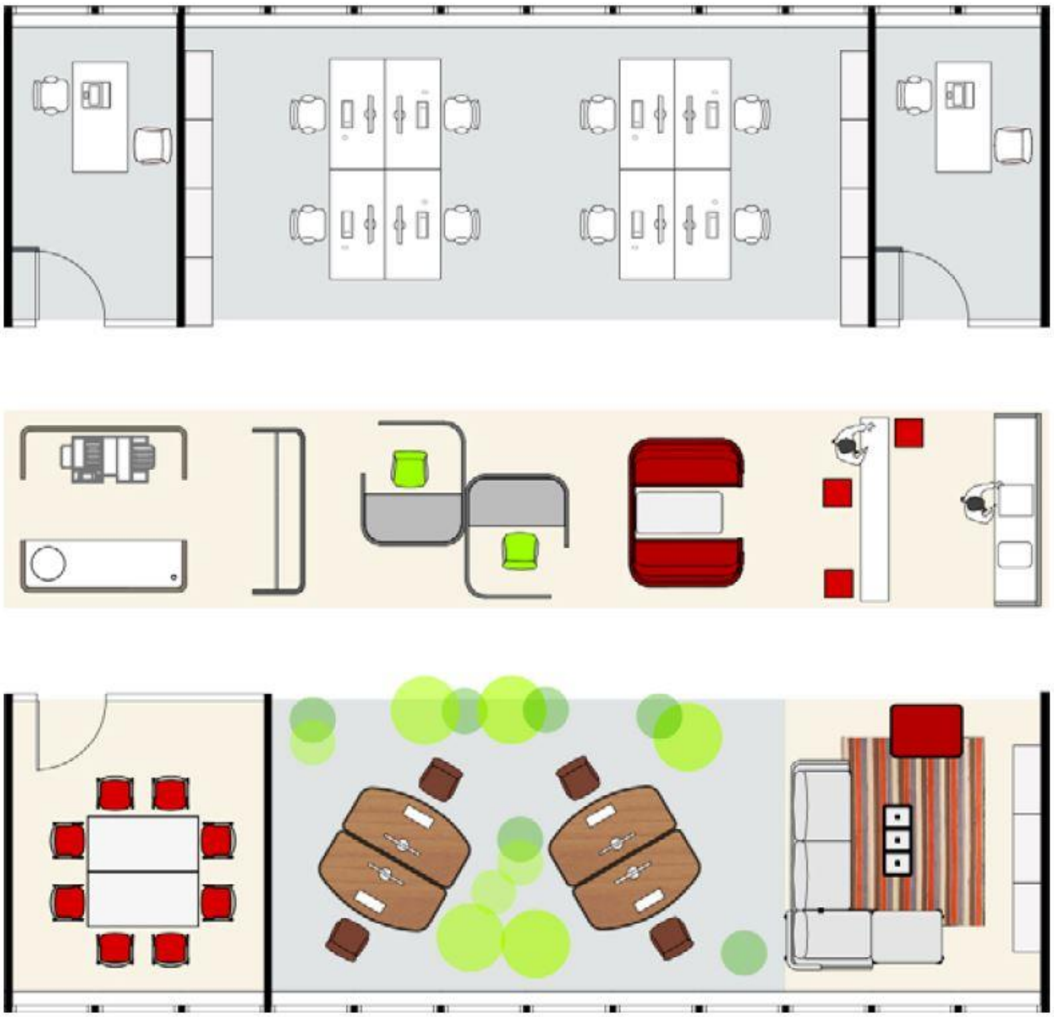


Figure 5 - Activity Based Office (Zoltán, 2014)

Modern, future-oriented office design must integrate sustainability besides mobility and flexibility. Although the focal point is on work efficiency, there is equal attention to space effectiveness. The consequences of these trends eventuate in a workplace where a shared work environment is a standard. As an example Figure 6 and Figure 7 show an office building built in 1971, bulldozed in 2004. However, the structure and yet the spaces would have allowed a modern office conception and design (Zoltán, 2014) (André, et al., 2011).

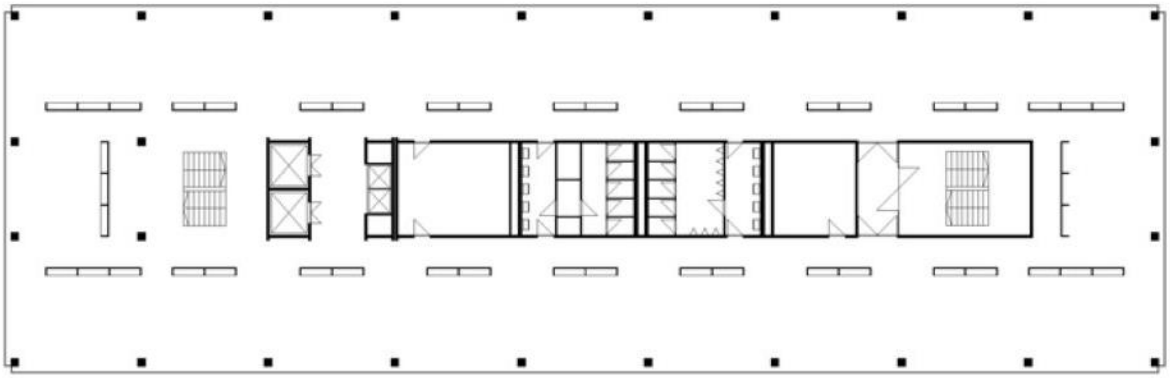


Figure 6 - Basic floor plan (year of construction 1971- demolished 2004) (Zoltán, 2014)

Figure 7 - How an activity-based concept could have worked (Zoltán, 2014)

In the same context, the research pointed out that Open Plan Offices Design (OPOD) has its own positive and negative effects. Using the fishbone cause-and-effect method, the study came up with the OPOD structures and sub-features affecting the staff's health and well-being (Figure 8) organizes. The OPOD features and sub-features are classified into ‘Positive Features’ and ‘Negative Features’ (Arezou, et al., 2014).

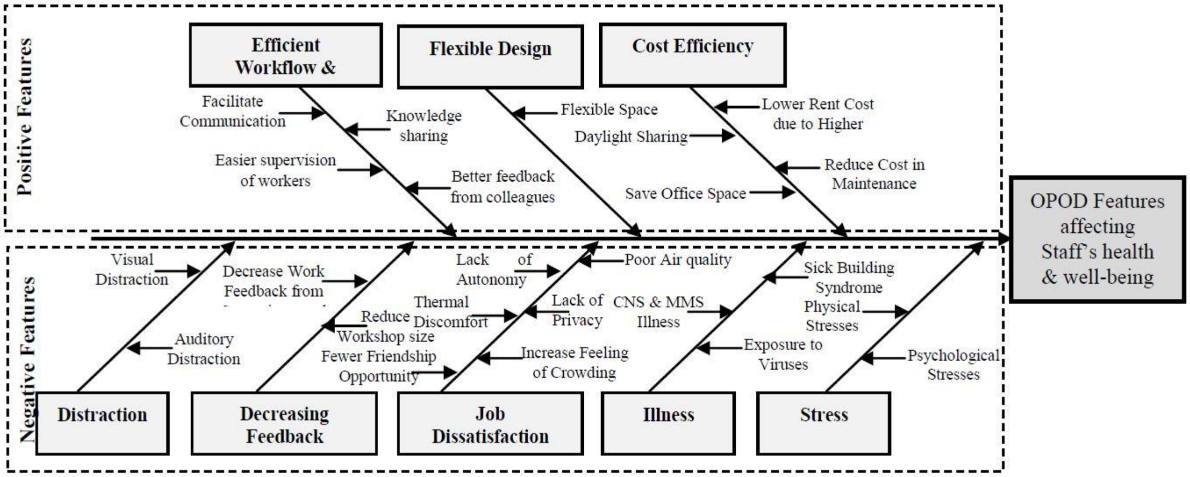


Figure 8 - Fishbone cause and effect diagram on OPOD features affecting the health and well-being status of staff in office buildings - Positive and Negative effective OPOD Features (Arezou, et al., 2014)

<u>*Conclusion of the literature review*</u>

Office buildings are responsible for significant energy demand for the buildings sector by considering the time and period of usage. In general, as the studies demonstrated, a climate-responsive building envelope design should assist the design strategies and try to exploit climatic conditions (Haase & Amato, 2009).

Based on a comprehensive literature and scientific paper research, a wide range of different climate-responsive façade optimization strategies is investigated, such as, window and opening properties, window wall ratio (WWR), natural lighting (daylighting), shadings, double skin façade (DSF), natural ventilation and building integrated PV on façade (BIPV). **At the same time, it is apparent that all studies deal with only one specific part-system of the building, without considering the most fundamental design element, the space organization based climate-responsive concept, including innovative corresponding envelope strategy.** So far, the climate responsible façade and space organization had not been studied and analyzed with the help of energy simulation There is only a few research has found on trying comprehensive architectural solutions, (i.e. complex space organization strategies and their energy and comfort performance) to reduce the office buildings' energy consumption, increasing the optimum usage of space, while maintaining the necessary level of comfort.

Besides, vernacular architecture with courtyards, where the building is totally closed from outside and open internally through the courtyards, shows a promising approach for future office building optimization as well, working centuries before with high- efficiency rate (low tech systems).

Furthermore, analysis of the most up to date office space design concepts and strategies leads to the conclusion that the open space concept plays a key role in future flexibility and development of office space optimization.

Therefore, it is apparent that we need to meet the above-mentioned shortcomings are based firstly on the lack of education of architects in the topic of building physics, and secondly, engineering research focusses only on part-systems, since they do not become familiar with the building as a complex space system.

1.5. Research goals

To search for solutions for the ‘literature analysis’ shortcomings, a new “Introverted Climate Concept with Closed Facade” (ISOCF) for office buildings under a moderate climate is proposed. Based on a comprehensive combination of vernacular low tech architectural strategies, climate-responsive façade, and space arrangement, as well as the new trend of open and more flexible working space, a completely new office building design strategy is developed in the following dissertation. The research aims to analyze the potential of climate zoning based space organization and to build envelope concepts regarding their energy performance, as well as thermal and visual comfort.

For the investigations and implemented office and laboratory building was chosen as a reference, possessing generic net floor space, geometry, structures, and services systems. In this way, inductive insights and finings can be concluded for most of the office building substance in moderate climate circumstances.

The objective of the following research is to tackle the issue of office building energy performance with the help of the ISOCF. The study aims to investigate the heuristic architecture approach, by analyzing the potential of energy-saving and comfort improvement in various versions of solution concepts with a different number of courtyards, possessing the same size and settings. The developed test concepts will be compared with the original reference cases to demonstrate the change in the level of energy performance, thermal and visual comfort, and space efficiency. Space efficiency is representing the increasing number of occupants and equipment with a lower demand for energy consumption to accommodate a more significant number of users in the building. To achieve this goal, the cube 'A' of the Szentágothai János Kutatóközpont institute building was chosen as an initial reference. (Baranyai & Bachman, 2010) (Figure 9).

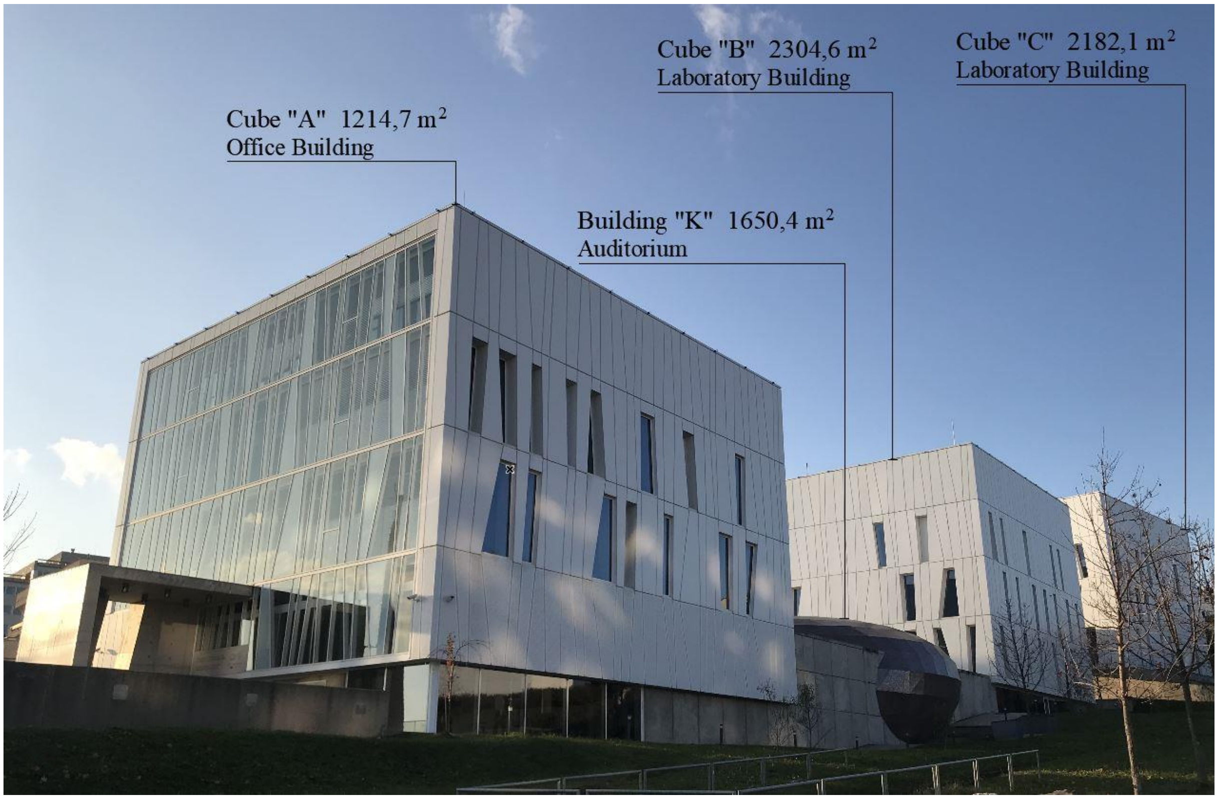


Figure 9 - Photo of the Szentágothai Research Centre reference office and laboratory building, University of Pécs, Hungary (Mohammad, et al., 2018)

1.6. Research questions

- How can an office building facade and space organization be developed and optimized to be the most efficient way facade and space organization concept to avoid overheating increase energy efficiency at most?

- Is it possible to create a building concept that ultimately shows it is back to the external, always attaching summer overheating and winter under heating extreme climate conditions and, at the same time, ensuring appropriate natural light and natural ventilation through integrated atrium?

- How many and what kind of design concept variations can be developed accruing to the above-mentioned concept?

- Is it worst, same, or better visual and thermal comfort of new concept atrium solution in comparison to the classic office? Comparison between the new concept of atrium visual and thermal comfort delivery and the energy performance between new concept variants and the reference today's conventional modern office building, as a theoretical interpretation of future improvement solution.

- How great energy efficiency and what kind of comfort conditions can be ensured with the following concept and variations?

- How much energy efficiency and comfort can be achieved by facade and space organization on an existing generic modern contemporary office?

- Is it possible to apply this solution generically to further office buildings?

- Is it possible to develop the greater and more useful area in offices by following open space and up to date concepts, if yes, how great if the occupation efficiency related to net floor space?
  What are the benefits of advantages and this of integration atria in such offices?

1.7. Research limitations

- The framework of the research limited itself to the concept of a closed facade with an integrated atrium.

- The research limited its framework to the size of the office part of the building, in other words, it is limited itself not for the whole building, but for the cube, ‘A’, as the other cubes of the building have almost the same size.

- The research limits itself to the passive architectural questions and their energy and comfort effects and particularly energy demand questions without considering further questions of HVAC systems that can change the results. Considering 80% of building energy can be saved by passive systems, and the remaining 20% should be by mechanics, we limited ourselves to passive strategies.

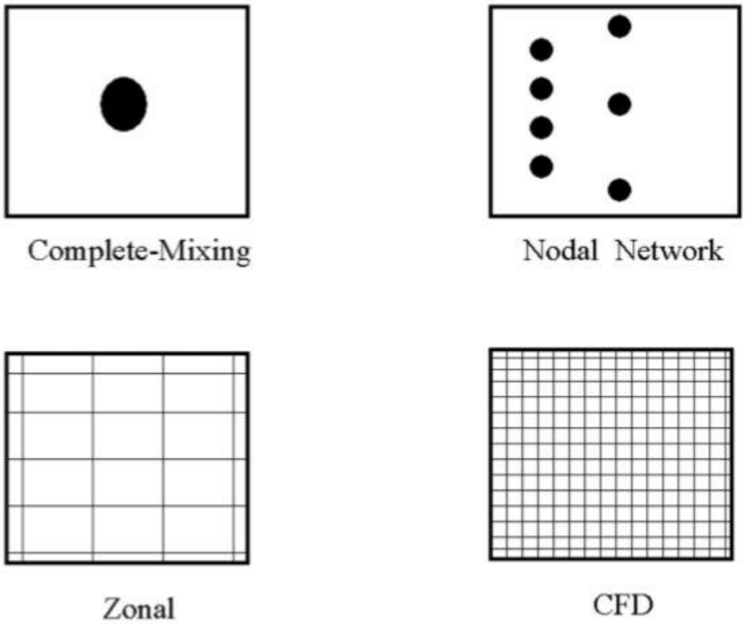
2. RESEARCH METHODOLOGY

2.1 Thermal dynamic simulation method

The thermal dynamic simulation method is the primary tool to analyze the main part of the research. Particularly the “zonal simulation method’’ using IDA ICE simulation software has been used.

2.1.1. Zonal Simulation method

Zonal models refer to air models that use a three-dimensional grid to separate the complete room into a system of control volumes or cells. It is essential to avoid confusing zone with zonal, where the previous refers to conventional building zoning, and the last refers to one type of room thermal models. As the zonal models are presenting a three-dimensional airflow model appropriate for building load and energy simulation, they are deliberated in more accurately. It is well evidenced that using zonal pressure models for load and energy calculation programs is probable to use (Brent & Qingyan, 2011) (Baranyai & Kistelegdi, 2014) (Fariborz, et al., 2001).



Complete-Mixing

Nodal Network

Zonal

CFD

Figure 10 - Classification of the simulation models (Brent & Qingyan, 2011)

2.1.2. Indoor Climate and Energy IDA ICE

IDA indoor and climate and energy (ICE) is a new tool to assess and simulate thermal comfort, indoor air quality, and energy consumption in buildings. The mathematical models are defined in terms of equations in a formal language, NMF. NMF is an independent program language for modeling the dynamical system by using differential-algebraic, which consists of the translator, solver, and modeler (Mika, 1999) (Per, et al., 2003).

IDA ICE may use the moat buildings types for the calculation of:

- The full zone heat balance, including specific contributions from sun, occupants, equipment, lights, ventilation, heating and cooling devices, surface transmissions, air leakage, cold bridges, and furniture;
- The solar influx through windows with a full 3D account of the local shading devices together with surrounding buildings and other objects;
- Air and surface temperatures;

- The operation temperature at multiple arbitrary occupant locations, e.g., in the proximity of hot or cold surfaces. Full non-linear Stephan-Boltzmann radiation with the view factors is used to calculate the radiation exchange between surfaces;
- The directed operating temperature for the estimation of asymmetric comfort conditions;
- Comfort indices, PPD and PMV, at multiple arbitrary occupant's locations.
- Daylight level at an arbitrary room location;
- The air, CO_2, and moisture levels, both which possible to be used to control VAV (Variable Air Volume) system airflow;
- Air temperature stratification in displacement ventilation systems;
- Wind and buoyancy-driven airflows through leaks and openings via a fully integrated airflow network model. This enables the study of, e.g., temporary open windows or doors between rooms.
- The airflow, temperature, moisture, CO_2, and pressure at arbitrary locations of the handling and distribution systems;
- Power levels for primary and secondary system components;
- Total energy costs are based on time-dependent prices (Seven & Gerhard, 2001) (Becky, 2006) (Mika, 1999).

2.1.3. Climate model in IDA ICE

The climate model is an algorithmic model. Naturally, its single input link obtains data from a source, which can be a climate file or a synthetic climate generator (SYNTCLIM). Through several output links, it provides data to one or more receivers. These, in turn, can be facades, connected to windows, leaks, or exterior walls, or they can be components in the primary or secondary central system (Axel, et al., 1999).

The climate model calculates and delivers the following data:

Table 1 - Climate model calculates

DESCRIPTION	NAME	UNIT
AIR TEMPERATURE	T_{air}	°C
SKY TEMPERATURE	T_{sky}	°C
GROUND TEMPERATURE	T_{ground}	°C
AIR HUMIDITY RATIO	HumAir	kg H20/ kg dry air
AIR PRESSURE	Pair	Pa
CO_2 _FRACTION	Xair	µg /kg dry air
DIRECT NORMAL SOLAR RADIATION	IDiffNorm	W/m^2
DIFFUSE HORIZONTAL SOLAR RADIATION	IDffHor	W/m^2
WIN DIRECTION	WindDir	°
WIND VELOCITY	WindVel	m/s
ELEVATION ANGLE OF THE SUN	ElevSun	°
AZIMUTH ANGLE OF THE SUN	AzimutSun	°

2.1.4. Zone Models

2.1.4.1. Convective heat transfer coefficient

The convective heat transfer coefficient is calculated with an external Fortran subroutine U_FILM. The coefficient is a function of the temperature difference between the air and the surface and the slope of the surface (Brown, 1990). Fig. 11 The X-axis is the temperature difference between the air surface. In the floor case, the temperature difference is between the surface and air. The model contains NMF extensions to produce analytical Jacobians (Axel, et al., 1999).

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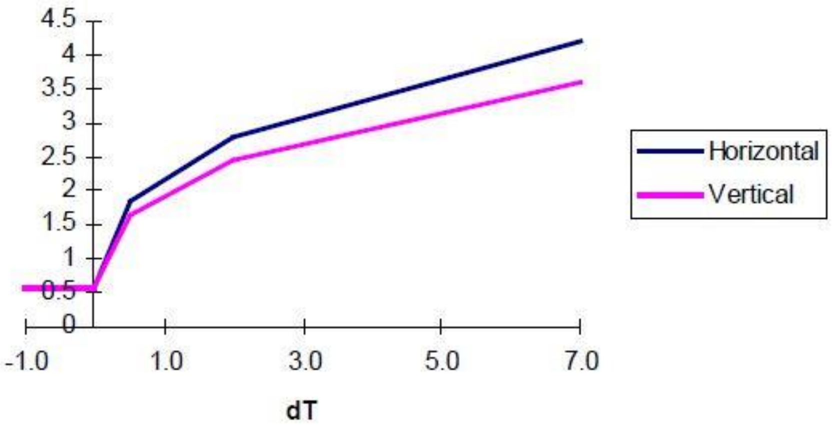


Figure 11 - The convective heat transfer coefficient (BRIS)

2.1.4.2. Heat load from occupants

The models below used for heat load from occupants were developed by Fanger [ISO 7730 1984]. The convective heat load from occupants is

$$Q_{cv,occ} = f_{cl} h_{cl} 1.8(T_{cl} - T_{Air}) + 1.8 \cdot 0.014\, M\ (34 - T_{Air})$$

where fcl is the ratio of surface area while clothed to the surface area while naked hcl is convective heat transfer coefficient between air and clothes, W / m2 K Tcl is the surface temperature of clothing, °C Tair is air temperature, °C M is metabolic rate, Met

The convective heat transfer coefficient, hcl, between clothes and air is

$$h_{cl} = \begin{matrix} 2.38\,(t_{cl} - t_a)^{0.25} & \mathit{for}\ 2.38(t_{cl} - t_a)^{0.25} > 12.1\sqrt{v_{ar}} \\ 12.1\sqrt{v_{ar}} & \mathit{for}\ 2.38(t_{cl} - t_a)^{0.25} < 12.1\sqrt{v_{ar}} \end{matrix}$$

And the fcl factor

$$f_{cl} = \begin{matrix} 1.00 + 1.29\, I_{cl} & \mathit{for}\ I_{cl} < 0.078 \\ 1.05 + 0.645\, I_{cl} & \mathit{for}\ I_{cl} > 0.078 \end{matrix}$$

The radiative heat load from occupants is

$$Q_{rad,occ} = 1.8\ 3.96\ 10^{-8} f_{cl} (T_{cl}{}^{4} - T_{mrt}{}^{4})$$

where Tmrt is the mean radiant temperature in the point of the occupant, °C (Axel, et al., 1999).

2.1.4.3. Moisture loads

The moisture loads (kg/s) from occupancy is [ISO 7730 1984]

$$\begin{aligned} & 1.8(3.0510^{-3}(5733 - 6.99(M58 - W) - P_{vap}) + \\ HumOcc \quad & = 0.42((M58 - W) - 58.15) + \\ & 1.710^{-5} M58(5867 - P_{vap})) / 2501000 \end{aligned}$$

where W is external work, W / m2 Pvap is vapor pressure, Pa (Axel, et al., 1999).

2.1.4.4. CO2 loads

The Co2 load from occupancy is [IEA 1993]

$$X_{co2}=M/3.6*1.8$$

2.1.4.5. Local units

The zones can have local convective units for heating and cooling. Power is calculated by the equation

QloxUnit=CtrLocUnit*QLocMax

where CtrLocUnit is the control signal of the unit, - QLocMax is the maximum power of the unit, W.

The control signal is provided via a link. Typically, the local unit is controlled by a PI-controller, which takes input from zone air temperature.

In the case of a cooling unit (QLocMax is less than 0) a fabricated airflow through the unit is planned to estimate possible condensation in the unit. Condensation will arise if the coil surface temperature is below the dew point temperature of the air. The coil surface temperature is agreed upon as a limitation.

The electricity needed to produce the actual cooling power is calculated with the equation

$$QEl = \frac{QLocUnit}{COP}$$

where QLocUnit is the power of the unit, W COP is the coefficient of performance (Axel, et al., 1999).

2.1.5. Envelope Models

2.1.5.1.CEWIND: Window model

The model analyses radiation and transmission over a window. The effect of internal shading devices is comprised; external devices in the plane of the window, i.e. outside blinds, are handled as internal. Besides, fixed external devices, such as fins or overhangs, are not handled in CEWIND but the WINSHADE model. The process of internal shading can be measured by a schedule or by irradiation level. The transmission through the window frame is calculated. For detailed modeling of a zone, it is desirable that the solar radiation entering through a window can be divided into two parts, directly transmitted radiation and radiation first fascinated in the window mixture. The first part is spread as shortwave radiation and the second part heats the window and reaches the zone as longwave radiation and convection. To aid this determination, the shading properties of the window are described by two sets of factors, one regarding total heat load, and one regarding shortwave heat load SC shading coefficient for total heat load SSC shortwave shading coefficient for directly transmitted radiation. The secondarily transmitted part is calculated from the difference between these two factors. The variable shading is accounted for by selecting between two different shading numbers in each set, one valid with shading (SC1, SSC1), one without shading (SC0, SSC0). The decrease due to the shading device is handled as liberated of the decrease due to the particular glazing combination. (Axel, et al., 1999).

Thus

$$SC_1 = m_{SC} \; SC_0$$
$$SSC_1 = m_{SSC} \; SSC_0$$

where mSC is multiplier for total heat load due to shading device mSCC is multiplier for direct transmission due to shading device. The selected shading coefficients are applied to the total solar heat gain for a reference window with unprotected single glazing. This is calculated from incident direct and diffuse radiation, reducing the direct radiation by a factor which depends on the angle of incidence, while the diffuse radiation is reduced by a constant factor, resulting from averaging over the hemisphere seen by the window

$$R_{Thru\,\mathrm{Re}\,f} = \left(F_{ThruDir}\ I_{DirInc} + 0.77\ I_{DiffInc}\right) A_{Glass}$$

where FThruDir is a reduction factor for direct radiation, -

ID_{irInc} is direct incident radiation, W/m2

ID_{iffInc} is diffuse incident radiation, W/m2

A_{Glass} is window area, m2.

The angle dependence of FThruDir is handled by using different trigonometric curve fits for different angle intervals.

The shortwave radiation passing through the window is calculated from the equation

$$R_{Thru} = \ SSC\ R_{ThruRef}$$

The shading coefficients describe the load reaching the zone indirectly via absorption in the window by the expression

$$R_{Indir} = \left(SC - SSC\right) R_{ThruRef}$$

However, for the heat balance of the window, we are interested in the total radiation absorbed in the window, including the part that leaks back out to the ambient. This is given by

$$Q_{Absorb} = \frac{1}{1 - h * 0.11}\ \left(SC - SSC\right)\left(R_{Thru\,\mathrm{Re}\,f} + R_{Back}\right)$$

where RBack is the shortwave radiation reaching the window from inside

h is the u-factor for the window including interior and exterior resistances. It is selected from

h_1 u-factor for shaded window

h_0 u-factor for unshaded window.

In analogy with the handling of shading coefficients, we put

$$h_1 = m_h \ h_0$$

where mh is the multiplier for u-factor due to shading device.

Heat balances are written also for the furthest glass pane, as well as for the external surface of the frame. These balances are considered convective heat transfer, longwave radiation from ground and sky, transmission from the internal surface (glass pane or frame), and, for the frame, absorption of shortwave radiation.

Due to the clear management of convection and longwave radiation, both inside and outside, the U-factors for glass and frame are extended from internal and external surface confrontations.

The following control features have been implemented:

-Time control Shading is ON during prescribed periods. Arbitrary schedules can be specified.

-Solar control Shading is ON, if
time control is ON and
solar radiation/m2 exceeds the parameter solar_limit and
incident angle is less than the parameter cont_angle. (Axel, et al., 1999).

2.1.5.2.RCWALL: RC network wall model

The RCWALL model approaches the performance of a wall by an RC network model with three capacitances. The regular way to model the thermal performance of a wall is to discretize it into several nodes by using some limited alteration method. The number of nodes is a cooperation between the accuracy of the results and the implementation time. If the number of the nodes is enlarged to achieve improved precision, a longer finishing time is required. The same precision can be reached with fewer nodes with an RC-network, if the thermal resistances, the heat capacitances, and the construction of the RC-network are correctly chosen. The parameters of the RC network are planned by an optimization subroutine, which is called once in the PARAMETER_PROCESSING. The process relates the model performance to diagnostic answers found for simple harmonic boundary conditions and calculates the sum of the squares of the deviations.

The frequencies chosen for the summation are 1, 3, 6, 12, 24, 48, and 96 hour time periods. The values of the capacitances and the confrontations are planned by the subroutine RCOPT.NMF. In some cases, typically for light internal walls, the routine will select a two capacitance model. Thus, the number of nodes, nNode, is a calculated model parameter (role CMP). In the two-node case, R1 and R2 are equal, and either one represents the total resistance between Ca and Cb.

The benefits of the RCWALL model are the reduced calculation time due to fewer nodes and the fact that the accuracy is known. A weakness is the lack of physically meaningful temperatures inside the wall. Note also that this model should not be used in fast thermal process simulations, for example in learning automatic control systems, since the selected optimization aims at lower rates. (Axel, et al., 1999).

2.1.5.3. Ideal cooler and heater

An ideal cooler is a room unit that cools the zone when no comprehensive information about an actual room unit, such as a fan coil or active chilled beam, is available or this amount of detail is unmotivated. It has no given physical location on any room surface and is not connected to the plant of the building. Physically, think of it as a separate air conditioner with fixed performance parameters.

An ideal heater is a room unit that heats the zone when no detailed information about an actual room unit, such as a radiator or convector, is available or this amount of detail is unmotivated. It has no given physical location on any room surface and is not connected to the plant of the building. Physically, think of it as a standalone fuel or electric heater with fixed performance parameters and no flue gas emissions.

An ideal cooler and heater are inserted by default when a new zone is created (unless it has been removed from the zone template). The default capacity of the ideal cooler is given per m2 floor area in the zone template and should normally be selected to be large enough to safely be able to cool the zone under all conditions. A PI controller will then be used to keep the room air (or operative) temperature at the cooling setpoint (as specified in the Setpoint collection.). Otherwise, the ideal cooler can be controlled by a proportional controller, or in the Expert edition, a custom control macro. (IDA ICE 4.8)

2.1.6. Input data and boundary conditions for the simulation

Input climate data

The zone model calculates the indoor climate. Two different zone models exist in the library: the detailed one is proposed for design simulations, and the simplified one is intended for energy simulation (Seven & Gerhard, 2001) (Becky, 2006) (Mika, 1999).

The location should be defined in IDA ICE simulation software with the ensuing data: latitude, longitude, height over the sea level, time zone, wind profile, and the calculated building can be shaded by adjoining buildings (Seven & Gerhard, 2001) (Becky, 2006) (Mika, 1999).

The climate model is an algorithmic model that calculates and extradites the following data: air temperature, sky cloudiness, ground temperature, air humidity ratio, air pressure, CO_2-fraction, direct normal and diffuse horizontal solar radiation, wind direction, wind direction and velocity, elevation angle and azimuth angle of the sun.

IDA ICE uses two types of climate statistics for the outdoor climate: artificial design day or climate file with calculated statistics. The basic of the artificial design day is the daily extreme wet and dry bulb temperatures, the wind direction and speed, and the reduction factor for the direct and diffuse sunlight. The weather file includes the information about the air (dry bulb) temperature, the relative humidity (RH), the wind direction and speed, the direct normal radiation and diffuse (sky) radiation on a horizontal surface, all as a function of time (regularly in practice as hourly data). IDA ICE contains a separate translator for converting some of the stated weather data to file formats (Seven & Gerhard, 2001) (Becky, 2006) (Mika, 1999).

2.1.7. Thermal Comfort

According to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), it is “the condition of the mind in which satisfaction is expressed with the thermal environment” (Noël, et al., 2010).

Table 2 shows six primary factors that must be taken into account when defining conditions for thermal comfort.

Table 2 - Six primary factors must be addressed when defining conditions for thermal comfort (ANSI/ASHRAE, 2004)

1.	Metabolic rate
2.	Clothing insulation
3.	Air temperature
4.	Radiant temperature
5.	Airspeed
6.	Humidity

Base on the zonal simulation method examination, the general thermal comfort counting the Fanger’s comfort index, operative temperature, and humidity are analyzed (Fariborz, et al., 2001).

Fanger’s model made a combination of the theories of heat balance with the physiology of thermoregulation to specify a range of comfort temperatures that occupants of the buildings will feel comfortable. The combination of surface and air temperature is operative temperature. The most convenient operative temperature is between 23-26 °C in the cooling period and a minimum of 20-24 °C in the heating period for the standard residential building (Charles, 2003) (Fariborz, et al., 2001).

The thermal comfort adaptable to the building is classified in line with DIN EN 15251. In the table, DIN EN 15251’s four categories are showed. The following study rank to II category in Table 3.

Table 3 - *Comfort categories according to DIN EN 15251 (Anon, 2007)*

Categories	**Description**
I	High level of expectations: recommended rooms with every sensitive people with special requirements, disable people, sick people, small children, and elderly people
II	Normal expectations: recommended for new and renovated buildings
III	Acceptable level of expectations: can be used in existing buildings
IV	Values not included in any other categories: This category is used for part of the year

Source: DIN EN 15251

To be able to make more comfortable working spaces, there should be a mode to measure the comfort level. According to Prof. Ole Fanger, Predicted Mean Vote (PMV) and Predicted the Percentage of occupants Dissatisfied (PPD) are proposed for measuring the thermal comfort, which has turned into the comfort index in the International Standard Organization (ISO-7730) (Hiroki, et al., 2011).

PMV model includes four physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity), and two personal variables (clothing insulation and activity level) into a definition that can be used to predict the average thermal satisfaction of a large group of people. Fanger's PD Draught with local draught, from three physical variables (air temperature, mean air velocity, and turbulence intensity) (Charles, 2003).

In this study, the case study office building, as categorized under the II group in DIN EN 15251, matches the B category of DIN EN ISO 7730. As illustrated below table 4, PMV for the normal building is between the -0.5 to 0.5, and the predicted percentage of dissatisfied (PPD) should be less than 10% (Anon, 2006) (Anon, 2007) (Table 3 and Figure 11).

Table 4 - Classification according to DIN EN ISO 7730 and DIN EN 15251

DIN EN ISO 7730			DIN EN 15251	
Categories	PPD	PMV	Categories	
A	<6%	-0.2<PMV<0.2	I	High
B	<10%	-0.5<PMV<0.5	II	Normal
C	<15%	-0.7<PMV<0.7	III	Moderate
	>15%	-0.7>PMV>0.7	IV	Outside

The below empirical curve in figure 12 and table 5 show the relationship between PPD and PMV. To meet the best condition, at least 5 percent of the population needs to be dissatisfied (Charles, 2003) (Leen, et al., 2009).

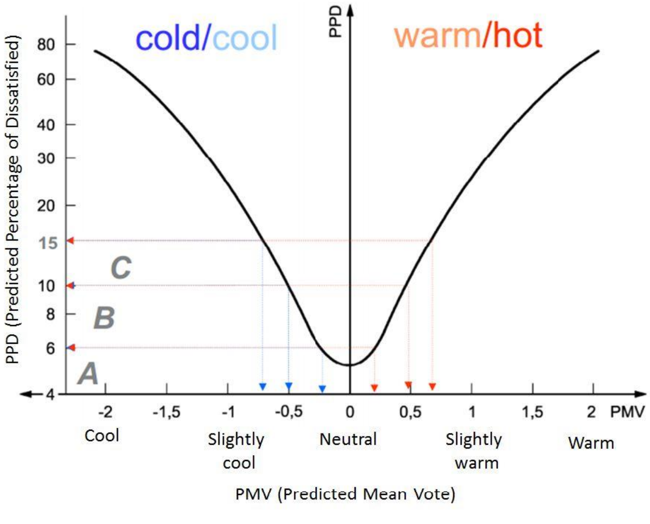


Figure 12 - Predicted mean vote (note that at least 5% of any population would be dissatisfied even under the 'best' condition) (Charles, 2003) (Leen, et al., 2009)

Table 5 - The ASHRAE thermal sensation scale, which was developed for use in quantifying people's thermal sensation, is defined as follows (ANSI/ASHRAE, 2004)

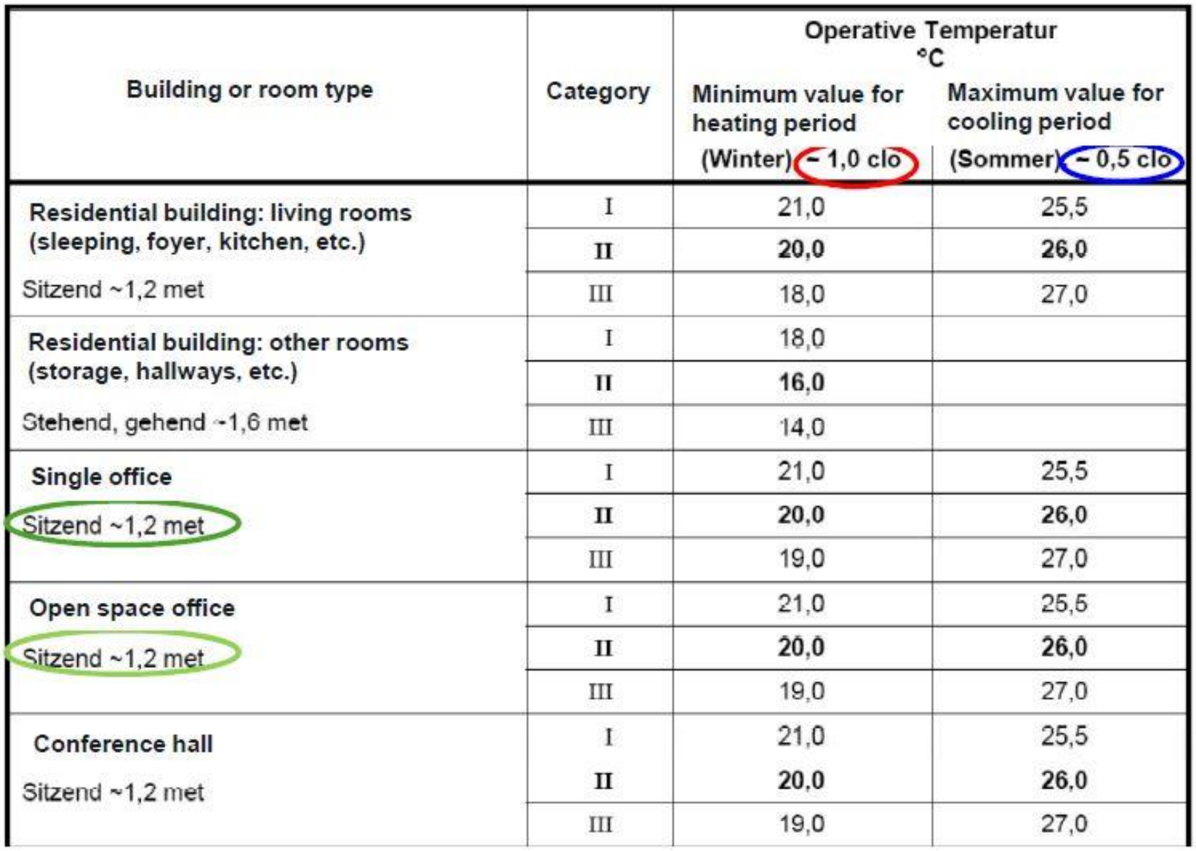
+ 3	**hot**
+ 2	**warm**
+ 1	**slightly warm**
0	**neutral**
- 1	**slightly cool**
- 2	**cool**
- 3	**cold**

The PMV model uses heat balance values to relate the six critical factors for thermal comfort listed in section 2.1.6. and table 2, to the average response of people on the above scale. The PPD index is coherent to the PMV, as defined in Tables 6 and 7. It is based on the surmise that people are voting +2, +3, –2, or –3 on the thermal sensation scale are dissatisfied, and the simplification that PPD is symmetric around a neutral PMV (ANSI/ASHRAE, 2004).

Table 6 - defines the recommended PPD and PMV range for typical applications and Acceptable thermal environment for general comfort (ANSI/ASHRAE, 2004)

PPD	**PMV Range**
< 10	-0.5 < PMV < +0.5

Table 7 - Defines examples for the advised design specifications of indoor tortures for the design of buildings and HVAC systems (Gunter, 2013)



Building or room type	Category	Operative Temperatur °C Minimum value for heating period (Winter) ~1,0 clo	 Maximum value for cooling period (Sommer) ~0,5 clo
Residential building: living rooms (sleeping, foyer, kitchen, etc.) Sitzend ~1,2 met	I	21,0	25,5
	II	**20,0**	**26,0**
	III	18,0	27,0
Residential building: other rooms (storage, hallways, etc.) Stehend, gehend ~1,6 met	I	18,0	
	II	**16,0**	
	III	14,0	
Single office Sitzend ~1,2 met	I	21,0	25,5
	II	**20,0**	**26,0**
	III	19,0	27,0
Open space office Sitzend ~1,2 met	I	21,0	25,5
	II	**20,0**	**26,0**
	III	19,0	27,0
Conference hall Sitzend ~1,2 met	I	21,0	25,5
	II	**20,0**	**26,0**
	III	19,0	27,0

2.1.8. Visual comfort

Window glazing plays a vital task in energy performance and has an important effect on the overall building energy consumption. Heat flow through a glazed window contributes to the heat increase due to incident solar radiation, which finally enhances the cooling load (Ming-Tsun, et al., 2013).

In trade buildings, decisions correlated to fenestration directly influence the main categories of energy consumption. Lighting represents the single most considerable electricity end-use (35%), with a significant part of use during daylight hours. Space cooling represents another extensive electricity end-use (25%), one-third of which is due to electrical lighting and also one-third to solar heat profits through windows (U.S. Department, 2010) (Joe & Ellen, 1999) (Kyle, 2013).

As a simple means to describe the amount of daylight at a specific point in a room, the term daylight factor can be used. A daylight factor (DF) is the ratio of the internal light level to the external light level and is defined as follows, see Figure 2. The daylight factor is normally given in percent:

$$DF = \frac{\mathrm{E}_{\mathrm{indoor}}}{\mathrm{E}_{\mathrm{outdoor}}} \cdot 100\ \%$$

$\mathrm{E}_{\mathrm{indoor}}$ is the illuminance due to daylight at a point on a given plane indoors (lux).
$\mathrm{E}_{\mathrm{outdoor}}$ is the simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of the overcast sky (lux) (Danish Building, 2013).

The study aims to ensure the necessary level of indoor visual comfort while keeping the energy performance of the working space. Due to Hungarian national standards for working spaces, minimum Lux is 300, and the study set points for visual comfort have been set to 300lux (SZCSM-EüM, 3/2002. (II. 8.)).

Real daylight illuminances across the workplace exhibit large variations both spatially and temporally. For example, daylight illuminances typically diminish rapidly with increasing distance from windows. Equally, daylight illuminances at a point can vary greatly from one moment to the next due to changing sun position and/or sky conditions. Daylight autonomy is a quantity of how often (e.g. percentage of the working year) a minimum work plane illuminance threshold of 500-300 lx can be sustained by daylight alone (Nabil & John, 2006).

2.2. Experiment design

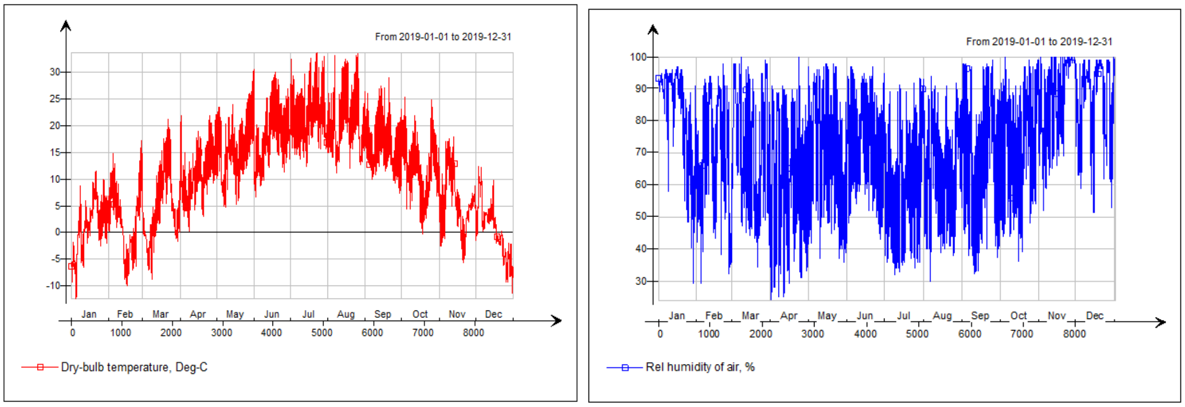
A comparative analysis will be held for new design proposals under the moderate climate zone conditions. To be able to have comparable parameters for the following analysis, the simulation tool will be applied. The energy and indoor comfort performance of each model under similar boundary conditions will be examined in this matter.

This study proposes an introverted space organization within a closed façade enclosure, the ISOCF strategy, consisting of a closed façade and an open-office interior, directly connected to the courtyards. The study examines the impact of the ISOCF concept on energy performance, as well as the thermal and visual comfort of office buildings under a moderate climate. The Szentágothai Research Centre office and laboratory building located in Pécs, Hungary, is proposed as a reference model (RM), representing a generic and typical office building type (Bachamann & Zoltán, 2010). This reference building model is a five-story height with a total area of 2455 m^2, including a lobby, offices, seminary rooms, university classrooms, toilets, and the tea-kitchens.

2.2.1. Climate conditions

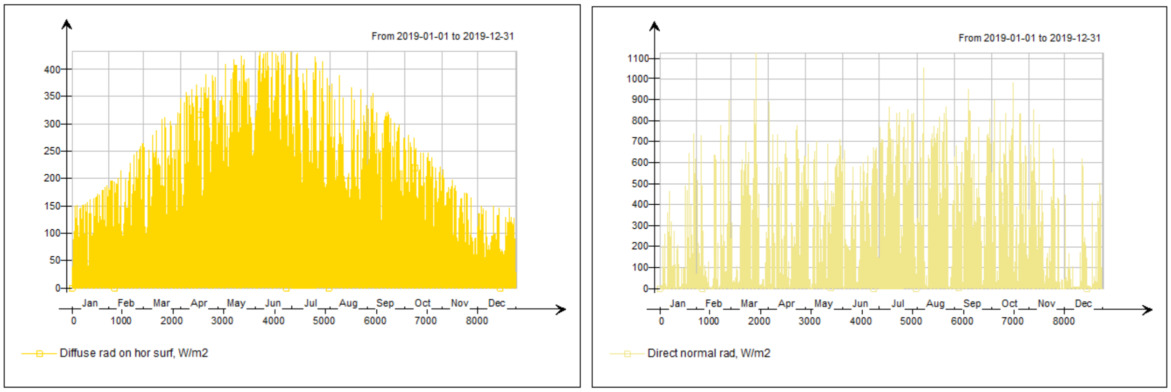
Comprehensive graphic of climate data factors of the ‘Pecs-Pogany’ climate station form IDA ICE 4.8, which are dry-bulb air temperature, the relative humidity of the air, wind speed, and sun radiation illustrated in figure 13, figure 14, and figure 15.

The study was based on Cfb climate, according to 1 km resolution Köppen–Geiger classification, the RM is located in temperate oceanic Cfb climate zone, which is classified for Ljubljana, Budapest, Munich, and Stockholm. In this climate, the coldest month is an average of beyond 0 °C or −3 °C, all months with average temperatures below 22 °C, and at least four months be an average of beyond 10 °C (Beck, et al., 2018).



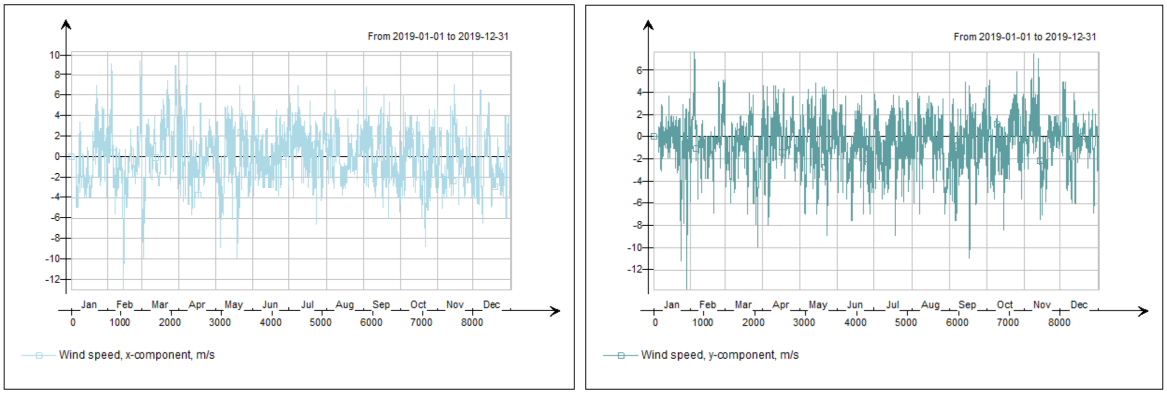
a) *b)*

Figure 13 - Climate data of Pecs-Pogany climate station from the ‘IDA ICE 4.7.1’ climate databank, a) Dry bulb air temperature [°C], (8760 hours), b) Relative humidity of air [%], (8760 hours)



a) *b)*

Figure 14 - Climate data of Pecs-Pogany climate station from the 'IDA ICE 4.7.1' climate databank, a) Direct normal radiation, [W/m^2], (8760 hours), b) Diffuse radiation on a horizontal surface, [W/m^2], (8760 hours)



a) *b)*

Figure 15 - Climate data of Pecs-Pogany climate station from the 'IDA ICE 4.7.1' climate databank, a) Wind speed, x-component, [m/s], (8760 hours), b) Wind speed, y-component, [m/s], (8760 hours)

2.2.2. *Experiment spaces*

This study proposes an introverted space organization within a closed façade enclosure, the ISOCF strategy, consisting of a closed façade and an open-office interior, directly connected to the courtyards. The study examines the impact of the ISOCF concept on energy performance, as well as the thermal and visual comfort of office buildings under a moderate climate. The Szentágothai Research Centre office and laboratory building located in Pécs, Hungary, is proposed as a reference model (RM), representing a generic and typical office building type (Baranyai & Bachman, 2010). This reference building model is a five-story height with a total area of 2455 m^2, including a lobby, offices, seminary rooms, university classrooms, toilets, and the tea-kitchens.

Calculations of thermal and visual comfort as well as energy performance in various test cases were carried out than compared to the different RM versions. Three WWR case scenarios are proposed, whereas RM 1 is following the existing building`s WWR (48%); RM 2 possesses 30% WWR and RM 3 is a version with 90% WWR (Figure 16).

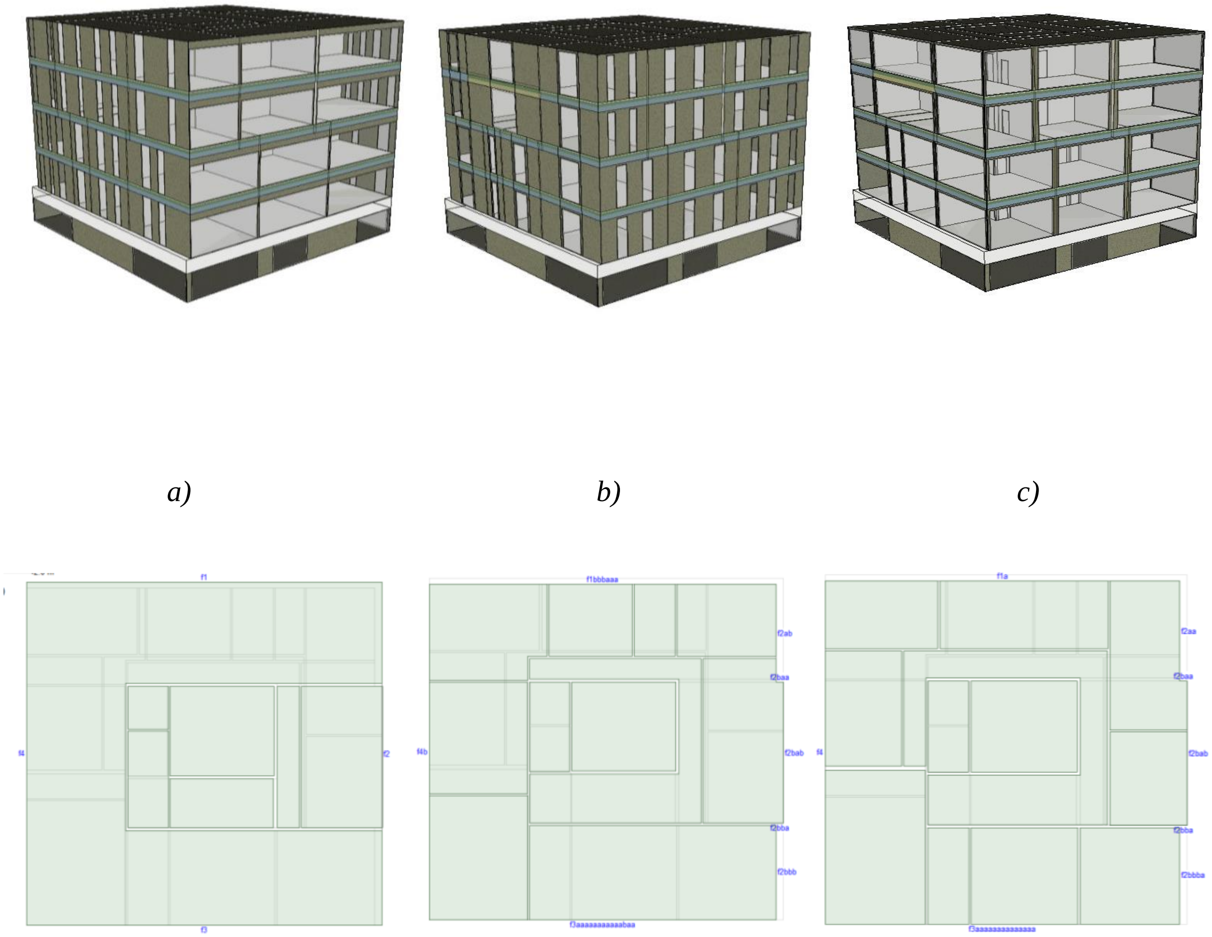


Figure 16 - Generic office building as a reference with three WWR scenario: a)RM 1 with 48% (existing reference building),b) RM 2 with 30%,c) RM 3 with 90%

The following three different ISOCF scenarios are proposed as shown in Figure 17. External facades have been closed 100% towards the outside environment, while they are open internally throughout the courtyards. Necessarily, the working space has been designed as an open working space to achieve flexibility while following the future workspace approach and maximizing the penetration of solar radiation into workspaces.

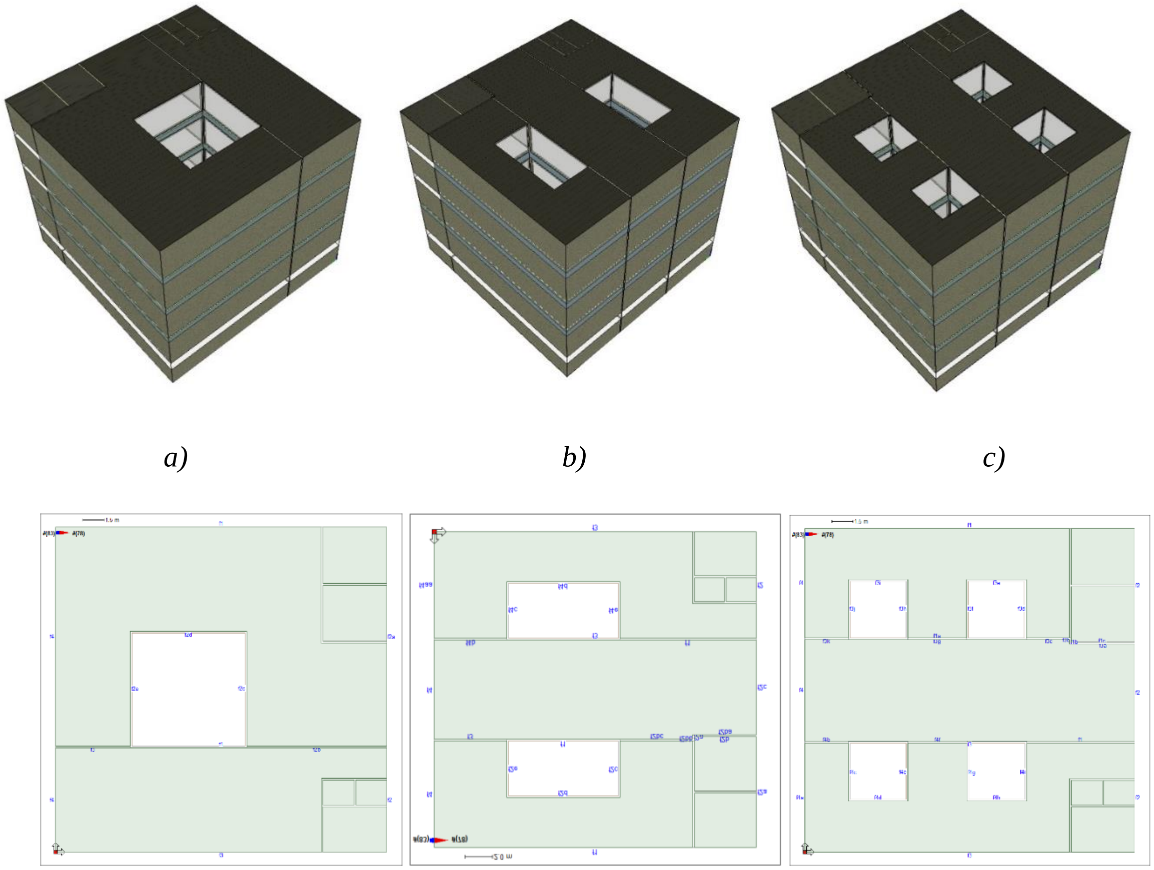

a) b) c)

Figure 17 - Introverted Space Organization with Close Facade (ISOCF)— Simulation model of a)ISOCF 1, b)2 and c)3, main story layout (left), 3D view (right)

2.2.3. Boundary conditions

The boundary conditions for all ISOCF models are the same as it is the case in the RM-s. Occupants, equipment’s and lights are considered as 1 pcs. / 10 m^2. The size of each model is 25*25*20.95 (height) as the same in the real reference research and office building model. In the first scenario (ISOCF 1 model), a single central courtyard with a size of 8m x 8m (64 m^2 floor space) is integrated into the building (Figure 17). To investigate the impact of the number and positioning of the courtyards, the study gradually increases the number of courtyards by spreading and doubling them into the floor planes. In this way, the effect of the various courtyards on daylighting, thermal comfort end energy efficiency can be assessed. According to this idea, in the second scenario (ISOCF 2 model), two parallel courtyards have been implemented with the size of 4m x 8m (2 x 32 m^2 floor space). Finally, in the third scenario (ISOCF 3), four courtyards with a size of 4m x 4m (4 x 16m^2 floor space) have been applied. The boundary conditions of the simulations are listed in Table 7 as well as the structures and materials of the envelope with thermal properties: heat transfer coefficient (U-value), solar heat gain coefficient (SHGC), light transmittance coefficient (T_{vis}), and solar transmittance (T_{sol}).

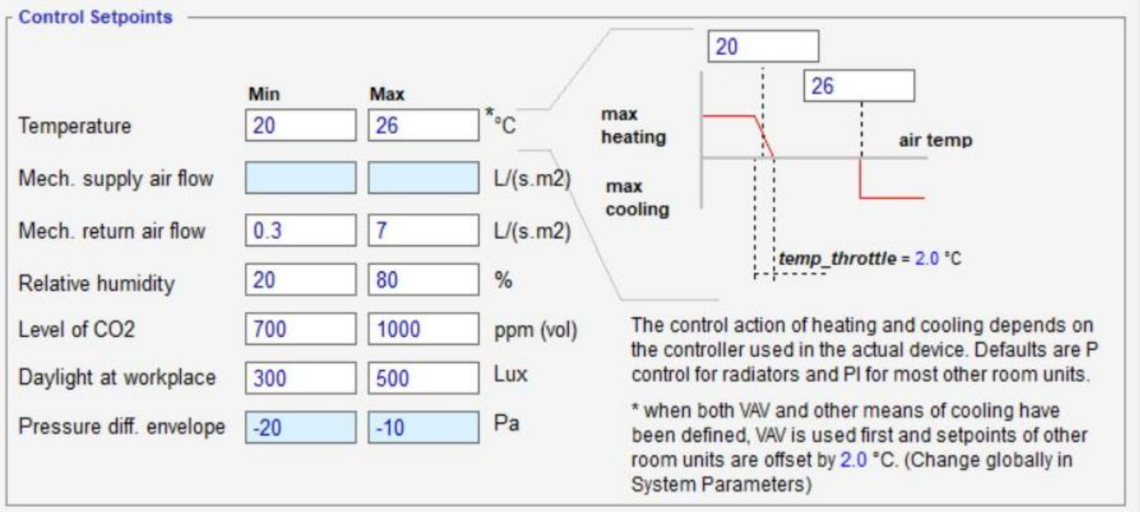
Table 7 Boundary conditions for the simulation (IDA ICE 4.8)

Boundary conditions	Model characteristic
Location	Pecs, Hungary, Latitude 46.0 N, Longitude 18.23 E
Simulation Weather File	IDA ICE 4.8 Weather Data
Daylight	CIE mixed and clear Sky model, Radiance motor
Building Type	Office Building
Net Floor Space	2455 m^2
Glazing Type	glazing 6+16+3.3 mm, U-value=1.4 W/(m^2K). SHBC 0.31, T_{sol} 0.20, T_{vi} 0.52.
Number of floors	5
External walls	20 cm reinforced concrete, 16 cm mineral wool insulation, 63,5 cm air gap + Alu coating. U-value= 0.22 W/(m^2K)
Internal Walls	Gypsum 25mm + Insulation 75mm + Gypsum 25 mm.
Internal Floor	Linoleum 5mm + Cement 60mm+ Rockwool 40mm + Concrete 24mm + Air gap 840mm + Gypsum 12mm.
Roof	suspended gypsum ceiling, 40 cm air gap, 30 cm reinforced concrete, 15 cm XPS insulation, 14 cm concrete + 15 cm gravel; U-value 0.0497 W/(m^2K)
External Floor	15 cm reinforced concrete, 5 cm XPS insulation, 14 cm concrete flooring, U-value 0.41 W/(m^2K)
Basement Wall Towards Ground	Plaster (cement) 10mm + Concrete 200 mm + Gipsum board 160mm + Air gap 50mm + Concrete 60mm; U-value 0.22 W/(m^2K)
Internal Gains	Occupant: Activity level 1.0 MET Constant clothing 0.85 ±0.25 CLO (clothing is automatically adapted between limits to obtain comfort) Occupancy time: Office Occupants: fully present (1) [8:00-17:00], half present (0.5) [6:00-8:00,17:00-21:00], 0.0, otherwise, Toilets and Tea kitchen's: fully presented (1) [5min each hour] every working day [8:00-18:00], 0.0, otherwise, Equipment usage time: Office Equipment: full intensity 1 [7:00-8:00, 17:00-22:00], half intensity 0.5 [15:00-17:00], fully present (1) [8:00-17:00], 0.0, otherwise, Emitted heat per person 106 W Toilets and Tea kitchen's: fully presented (1) [5min each hour] every working

	day [8:00-18:00], 0.0, otherwise, Emitted heat per person 1000 W, Luminous efficiency 10 lm/W Artificial lighting use: Office Occupants: fully present (1) [8:00-17:00], half present (0.5) [6:00-8:00,17:00-21:00], 0.0, otherwise, Toilets and Tea kitchen's: fully presented (1) [5min each hour] every working day [8:00-18:00], 0.0, otherwise,

2.2.4. *Set points*

Fig. 18 illustrates the office set points, whereas the min and max temperature has been set to 20-26 degrees. Relative humidity also has been set to maintain the level between 20-80% and in case of CO2 level, 700-1000 ppm choose for the office zones. In the case of daylight at the workplace, 300-500 lux has been used to ensure the necessary level of visual comfort, due to standards.



Control Setpoints

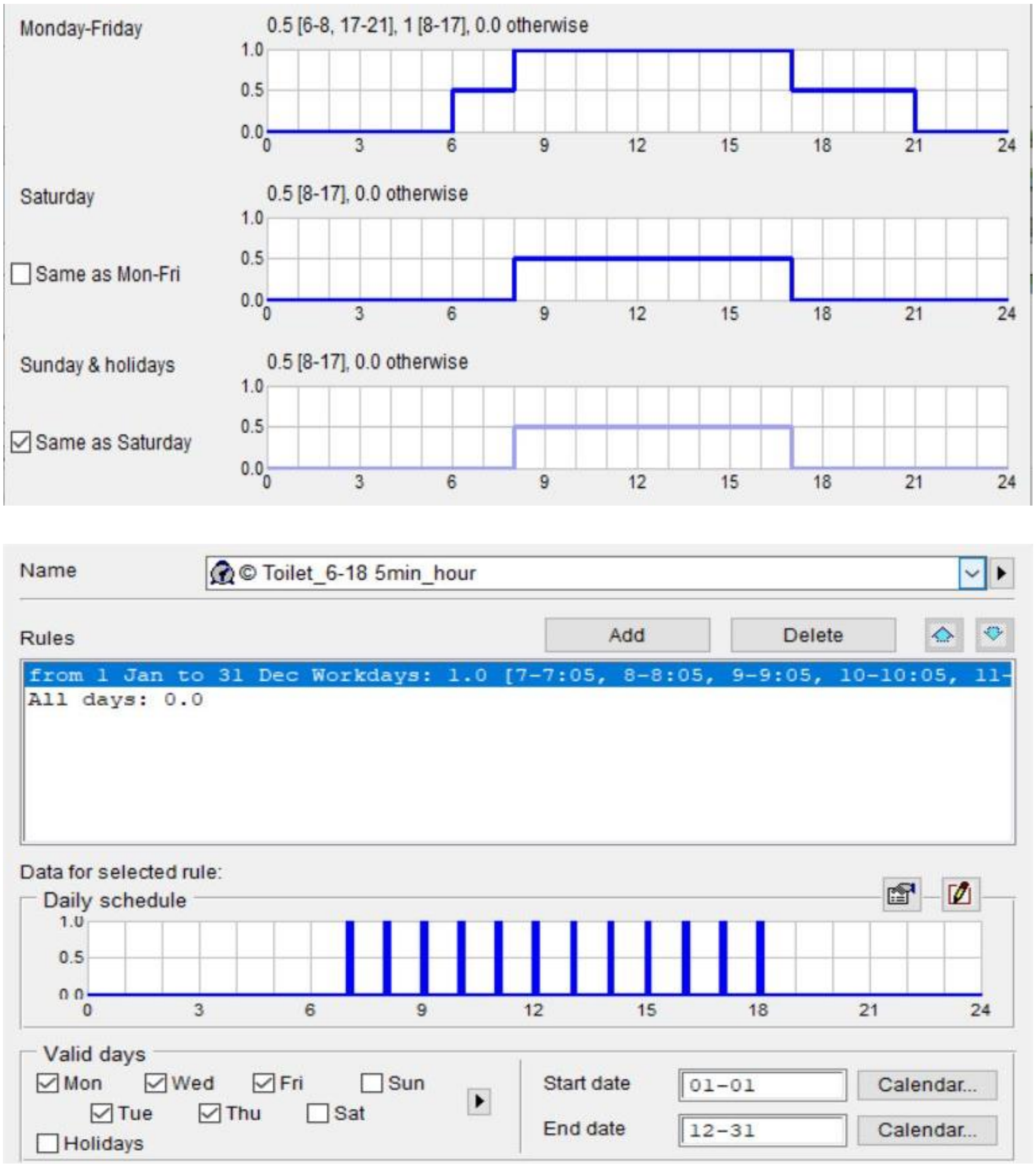
	Min	Max	
Temperature	20	26	*°C
Mech. supply air flow			L/(s.m2)
Mech. return air flow	0.3	7	L/(s.m2)
Relative humidity	20	80	%
Level of CO2	700	1000	ppm (vol)
Daylight at workplace	300	500	Lux
Pressure diff. envelope	-20	-10	Pa

The control action of heating and cooling depends on the controller used in the actual device. Defaults are P control for radiators and PI for most other room units.

* when both VAV and other means of cooling have been defined, VAV is used first and setpoints of other room units are offset by 2.0 °C. (Change globally in System Parameters)

Figure 18 - Workplace zone setpoint collection

Three types of internal gains have been indicated in the thermal zones, which are defined as occupants, equipment, and lights. To have the closest building performance compared to a real building, a time and usage intensity-dependent schedule has been implemented to each zone based on each zone function and size (Fig. 19).



Monday-Friday: 0.5 [6-8, 17-21], 1 [8-17], 0.0 otherwise

Saturday: 0.5 [8-17], 0.0 otherwise

☐ Same as Mon-Fri

Sunday & holidays: 0.5 [8-17], 0.0 otherwise

☑ Same as Saturday

Name: © Toilet_6-18 5min_hour

Rules

```
from 1 Jan to 31 Dec Workdays: 1.0 [7-7:05, 8-8:05, 9-9:05, 10-10:05, 11-
All days: 0.0
```

Data for selected rule:

Valid days: ☑ Mon ☑ Tue ☑ Wed ☑ Thu ☑ Fri ☐ Sat ☐ Sun ☐ Holidays

Start date: 01-01

End date: 12-31

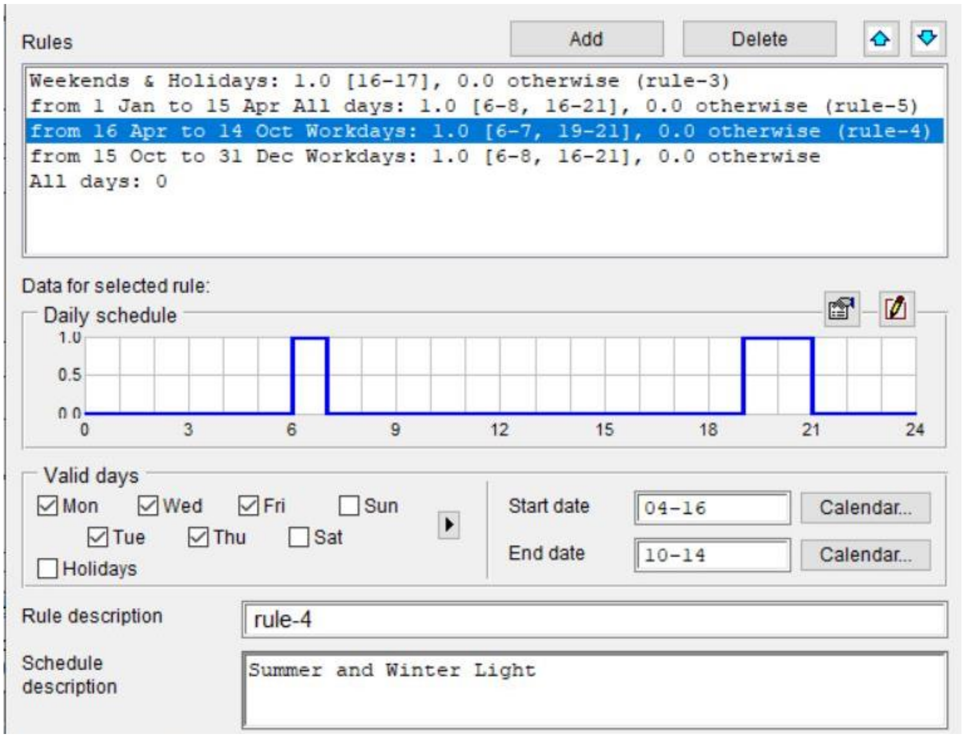
Figure 19 - Occupants schedules

In the case of equipment, the study only considered the main functional needs, whereas PC, microwave, and coffee machines have been implemented on each floor to represent the minimum necessary equipment. Emitted heat per unit (W) has been set to the closest numbers to reality with help of real production descriptions. Fig. 20 also illustrates the equipment's schedule.

The flight schedule has been set season-dependent whereas in winter, starting from 1st January until the 15th of April it is working from 6:00-9:00 in the morning and from 16:00-

21:00. For summer 16th of April until October 16th the lighting schedule has been also set to 6:00-7:00 in the morning and 19:00-21:00, considering longer summer and spring days. It is also defined that for all weekends and holidays that there is only one hour of light consumption considering the real building condition (Fig 20).

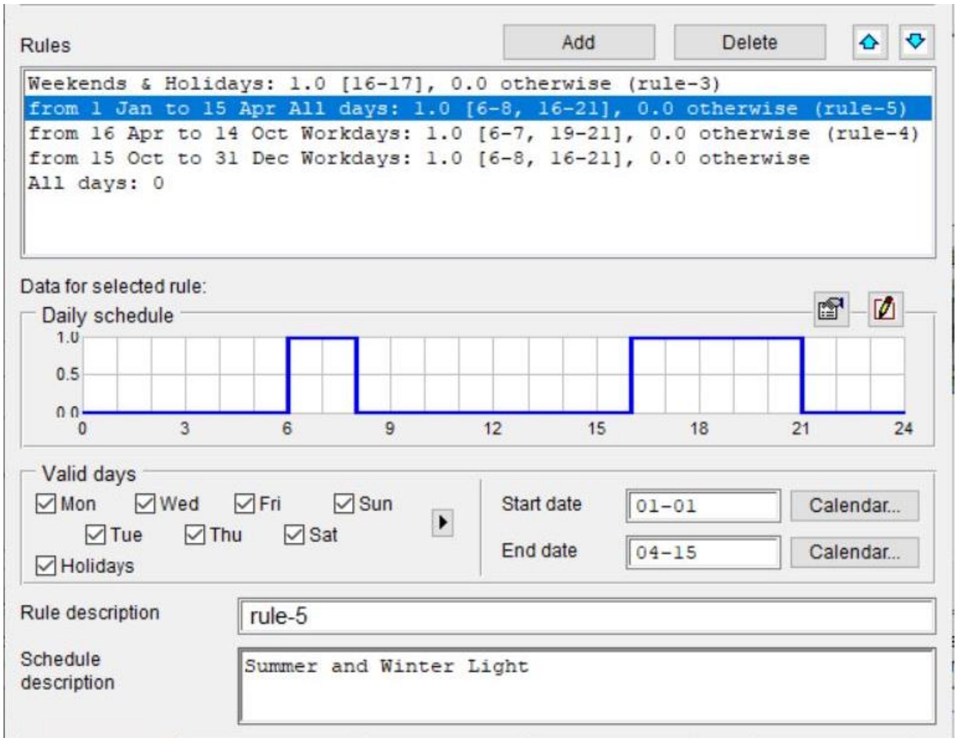
For all comparative analysis and further developments, the same thermal bridge characteristics have been implemented. Considering the reference model the poor level of thermal bridges has been chosen as shown in fig. 21.



```
Weekends & Holidays: 1.0 [16-17], 0.0 otherwise (rule-3)
from 1 Jan to 15 Apr All days: 1.0 [6-8, 16-21], 0.0 otherwise (rule-5)
from 16 Apr to 14 Oct Workdays: 1.0 [6-7, 19-21], 0.0 otherwise (rule-4)
from 15 Oct to 31 Dec Workdays: 1.0 [6-8, 16-21], 0.0 otherwise
All days: 0
```

☑ Mon ☑ Wed ☑ Fri ☐ Sun
☑ Tue ☑ Thu ☐ Sat
☐ Holidays

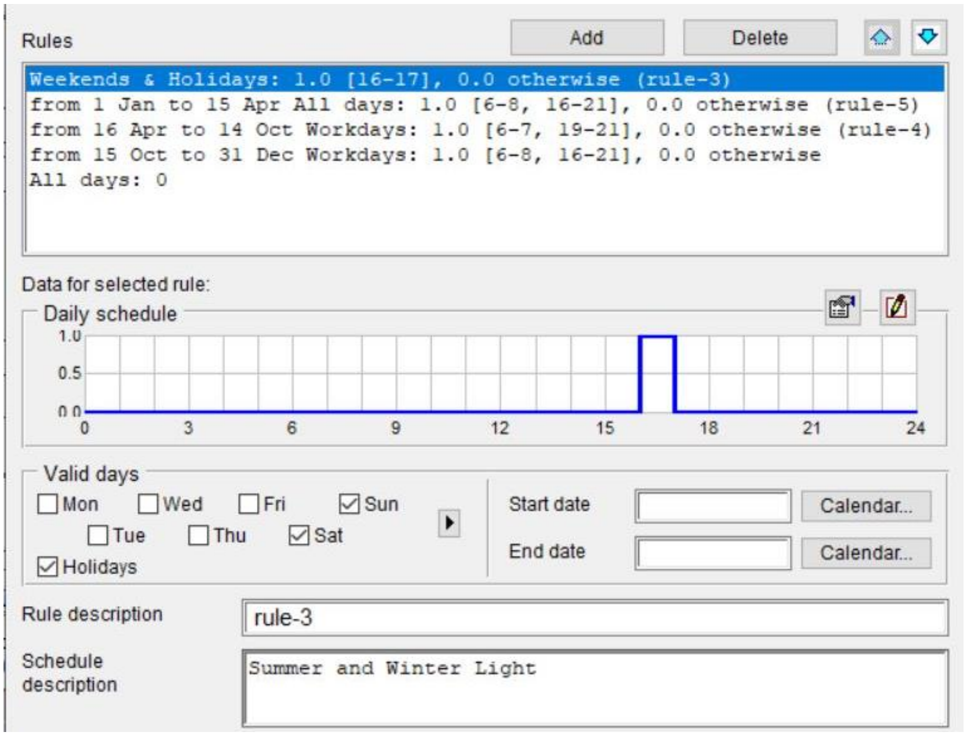
Start date: 04-16
End date: 10-14
Rule description: rule-4
Schedule description: Summer and Winter Light



```
Weekends & Holidays: 1.0 [16-17], 0.0 otherwise (rule-3)
from 1 Jan to 15 Apr All days: 1.0 [6-8, 16-21], 0.0 otherwise (rule-5)
from 16 Apr to 14 Oct Workdays: 1.0 [6-7, 19-21], 0.0 otherwise (rule-4)
from 15 Oct to 31 Dec Workdays: 1.0 [6-8, 16-21], 0.0 otherwise
All days: 0
```

☑ Mon ☑ Wed ☑ Fri ☑ Sun
☑ Tue ☑ Thu ☑ Sat
☑ Holidays

Start date: 01-01
End date: 04-15
Rule description: rule-5
Schedule description: Summer and Winter Light



```
Weekends & Holidays: 1.0 [16-17], 0.0 otherwise (rule-3)
from 1 Jan to 15 Apr All days: 1.0 [6-8, 16-21], 0.0 otherwise (rule-5)
from 16 Apr to 14 Oct Workdays: 1.0 [6-7, 19-21], 0.0 otherwise (rule-4)
from 15 Oct to 31 Dec Workdays: 1.0 [6-8, 16-21], 0.0 otherwise
All days: 0
```

☐ Mon ☐ Wed ☐ Fri ☑ Sun
☐ Tue ☐ Thu ☑ Sat
☑ Holidays

Start date:
End date:
Rule description: rule-3
Schedule description: Summer and Winter Light

Figure 20 - Light schedules, top summer, middle winter and bottom weekends and holidays

Envelope area definition

○ Internal
○ Overall internal
○ External
● External incl. floor slab
○ Preserve wall volume

Thermal bridges

External wall / internal slab	0.1314	W/K/(m joint)*
External wall / internal wall	0.1314	W/K/(m joint)*
External wall / external wall	-0.0058	W/K/(m joint)
External windows perimeter	0.4	W/K/(m perim)
External doors perimeter	0.4	W/K/(m perim)
Roof / external walls	0.2219	W/K/(m joint)
External slab / external walls	0.7	W/K/(m joint)
Balcony floor / external walls	0.8	W/K/(m joint)
External slab / Internal walls	0.1314	W/K/(m joint)*
Roof / Internal walls	0.127	W/K/(m joint)*
External walls, inner corner	0.1558	W/K/(m joint)
External slab / external walls, inner corner	0.1415	W/K/(m joint)
Roof / external walls, inner corner	0.1381	W/K/(m joint)
Total envelope (incl. roof and ground) (alternatively enter W/K/(m2 floor area))	0	W/K/(m^2 envelope)

Figure 21 - Thermal bridges characteristic

3. RESULTS AND DISCUSSION

3.1. Comfort

3.1.1. Thermal Comfort

According to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), thermal comfort is “the condition of the mind in which satisfaction is expressed with the thermal environment” (Noël, et al., 2010).

In all models, the average annual number of hours performing a PMV category B (or II) is calculated by an area-weighted averaging of the annual hours of category B (or II) for each thermal zone, as presented in the equation (Solangi, et al., 2011).

$$N_{PMV} = \frac{\sum_{i=1}^{i=n} N_i \cdot A_i}{\sum_{i=1}^{i=n} A_i}$$

Where N_{PMV} means the average annual hours of PMV, category B for the whole model, N_i represents the number of annual hours of PMV, category B for thermal zone I, A_i the total area of each zone [m^2], “n” is the total number of thermal zones of the model (Elhadad, et al., 2020). For the RM scenarios, the PMV in category B results is presented in Figure 17. The calculated thermal sensation results are continuously rising in all ISOCF models. ISOCF 1 shows a 17% improvement in comparison to ISOCF 3 case (Fig 22) because with 78-25 % smaller transparent courtyard façades the successively descending average WWR lets less solar load penetration into the interior during summer (from May until the beginning of September). Figure 23 presents the difference between ISOCF 3 and ISOCF 1 operative temperature performance during the year with characteristic discomfort in summer. Figure 17 demonstrates a linear correlation between the WWR and number of occupancy hours performing operative temperatures of class B of ISOCF models, the more WWR the less thermal comfort performance.

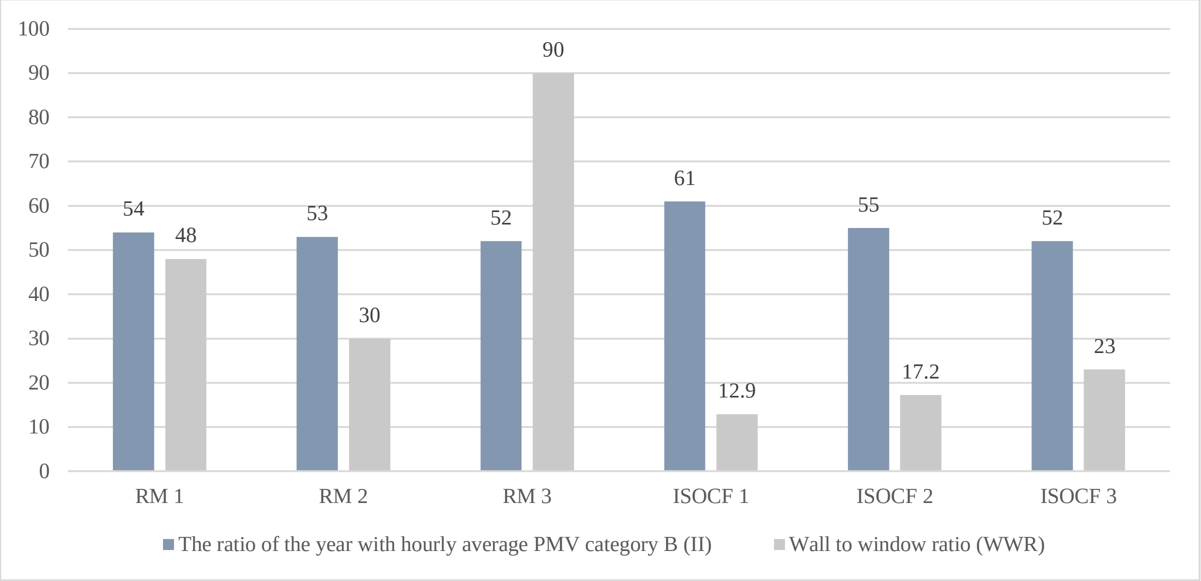


Figure 22 - The ratio of the year with hourly average PMV category B (II), Wall to window ratio (WWR) in the ISOCF models in all zones of the buildings [%]

Comfort category	No. of occupancy hours
I (best)	1351
II (good)	4243
III (Acceptable)	4642
IV (Unacceptable)	161

Figure 23- No of occupancy hours performing Top Category B

3.1.2. Visual comfort

Daylight performance intensely depends on the illuminance under direct correspondingly diffuse sky conditions (Elhadad, et al., 2020). At the same time window glazing plays a vital task in thermal comfort and has an important effect on the overall building energy consumption. Heat flow through a glazed window contributes to the heat increase due to incident solar radiation, which finally enhances the cooling load (Ming-Tsun, et al., 2013). To find an acceptable correlation between the daylight provision vs. cooling demand contradiction, this study investigates the daylight factor performance in the scenarios. For this purpose, daylight factor (DF) under mixed sky conditions and daylight autonomy (DA) under direct illuminance (clear sky conditions) are assessed in the spaces via lighting simulations.

The DF value is a ratio that represents the amount of illuminance available indoors relative to the illuminance level present outdoors at the same time, under an overcast sky (Waldram, 1925). The required value of DF for the investigated location is 1.66, by applying the calculation according to EN17037 Daylight in Buildings (Elhadad, et al., 2020).

Figures 24 and 25 presents the percentage of floor area performing DF above the minimum allowed value. In the RM 1 and 2 cases, the adequate DF is provided in approximately half of the floor area, while in RM3, due to enlarging the WWR from 30% and 48% to 90%, the DF-area improves to 83.5%. In contrast to the ISOCF models performing DF of 14.7 – 16.6%, the RM scenarios possess a significantly higher ratio of the floor area with adequate DF (49.5 – 83.5%) (Fig. 26). All courtyards in the ISOCF models were disabled to provide sufficient floor space with a DF over the minimum threshold value (1.7). With increasing the number of courtyards, the DF value is descending successively due to decreasing WWR.

The DA value represents the area ration of the net floor space possessing an illuminance level greater than a certain threshold (Nabil & John, 2006). In the case of DA, the average value on the 21st day of each month is assessed, at 12:00 o'clock and afterward, an average is calculated, considered as a yearly representative value. In this way, the solstice and equinox time points are assessed and the remaining 8 months' simulations complement the whole year. Instead of the 500 lx minimum indoor illumination threshold (Light, 2002) in a particular study, this value was set to 300 lx, due to the idea that today`s IT dominated workplaces do not require as much light (and hence additional cooling energy can be conserved).

Figure 24 presents the percentage of the floor area performing DA above the (300% lux) set threshold value. In the reference models, with growing WWR, there is a gradual increase to obtain from approx. 50 to 90% of the floor space in the RM models are well naturally lighted. In contrast, the ISOCF models perform significantly weaker, due to the limited solar exposure of the transparent facades of the inner courtyards. ISOCF 1 can provide 25.89% of the floor space with adequate illuminance and the percentage has been descending to 22.03% and 20.48% in the case of ISOCF 2 and ISOCF 3.

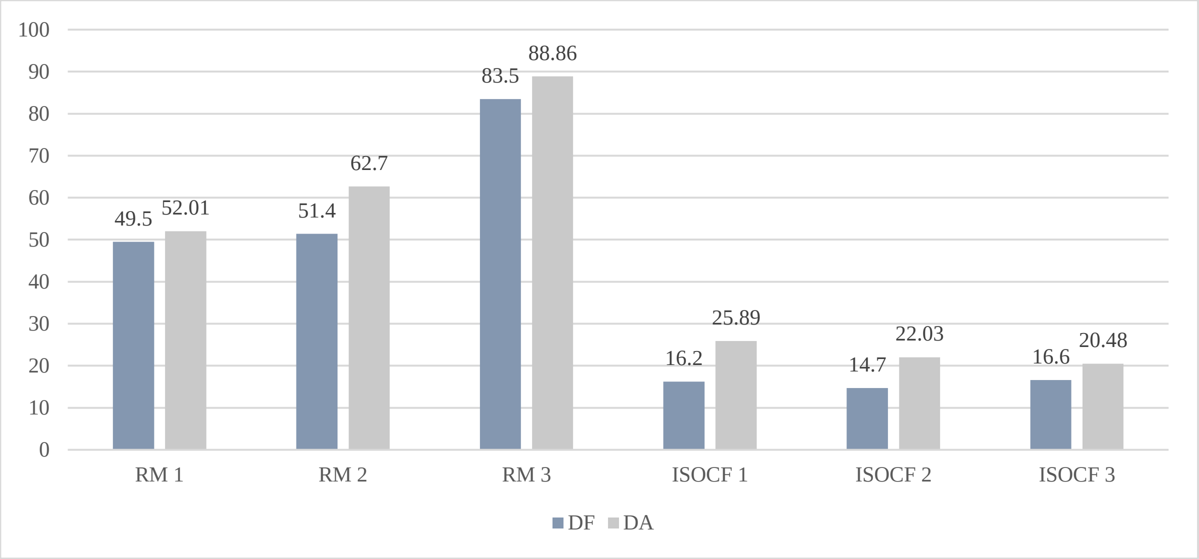


Figure 24 - Daylight factor above 1.7 and Daylight autonomy above 300 Lux %

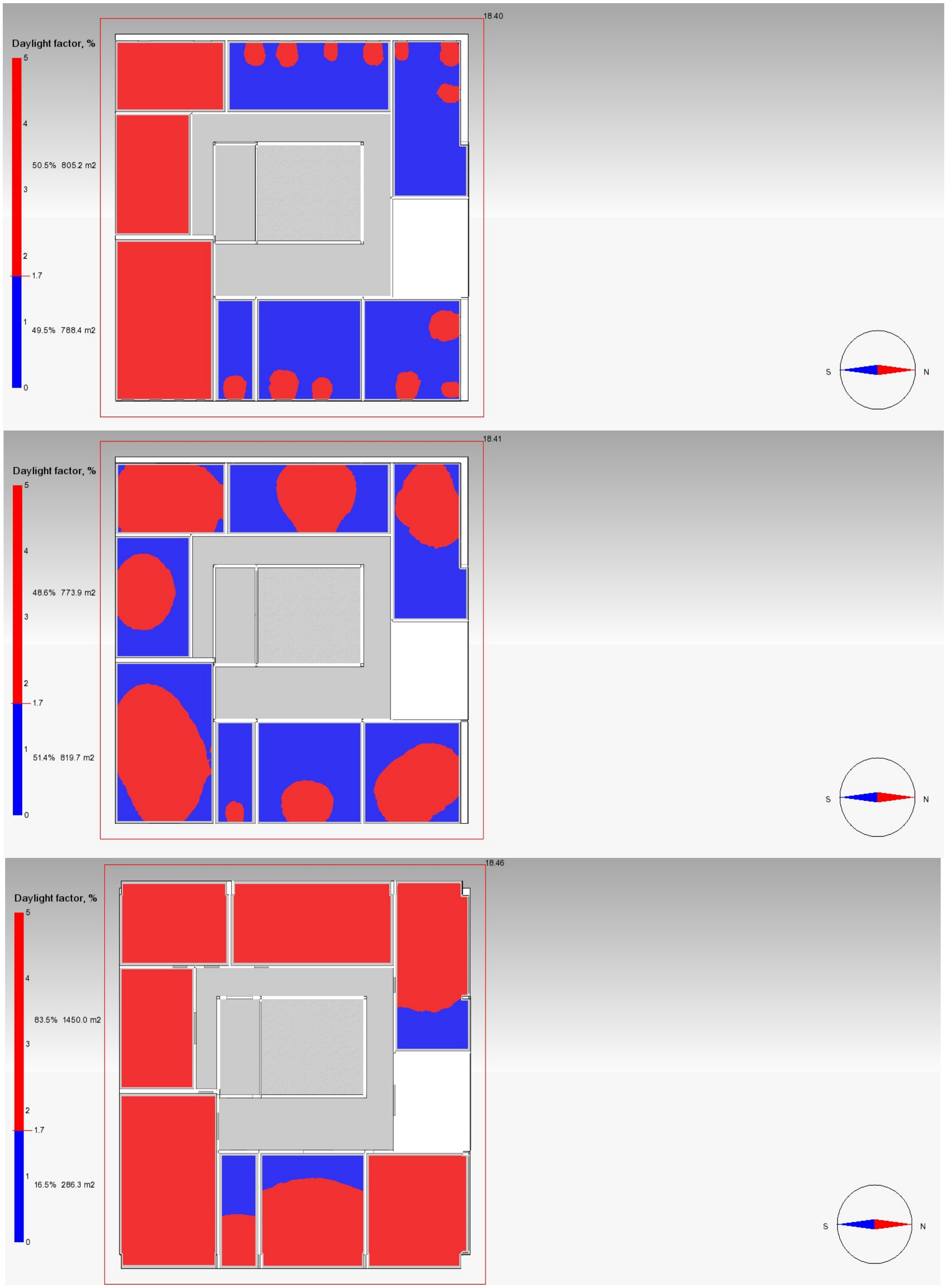


Figure 25 - RM models daylight factor characteristics, top RM 1, middle RM 2, bottom RM 3

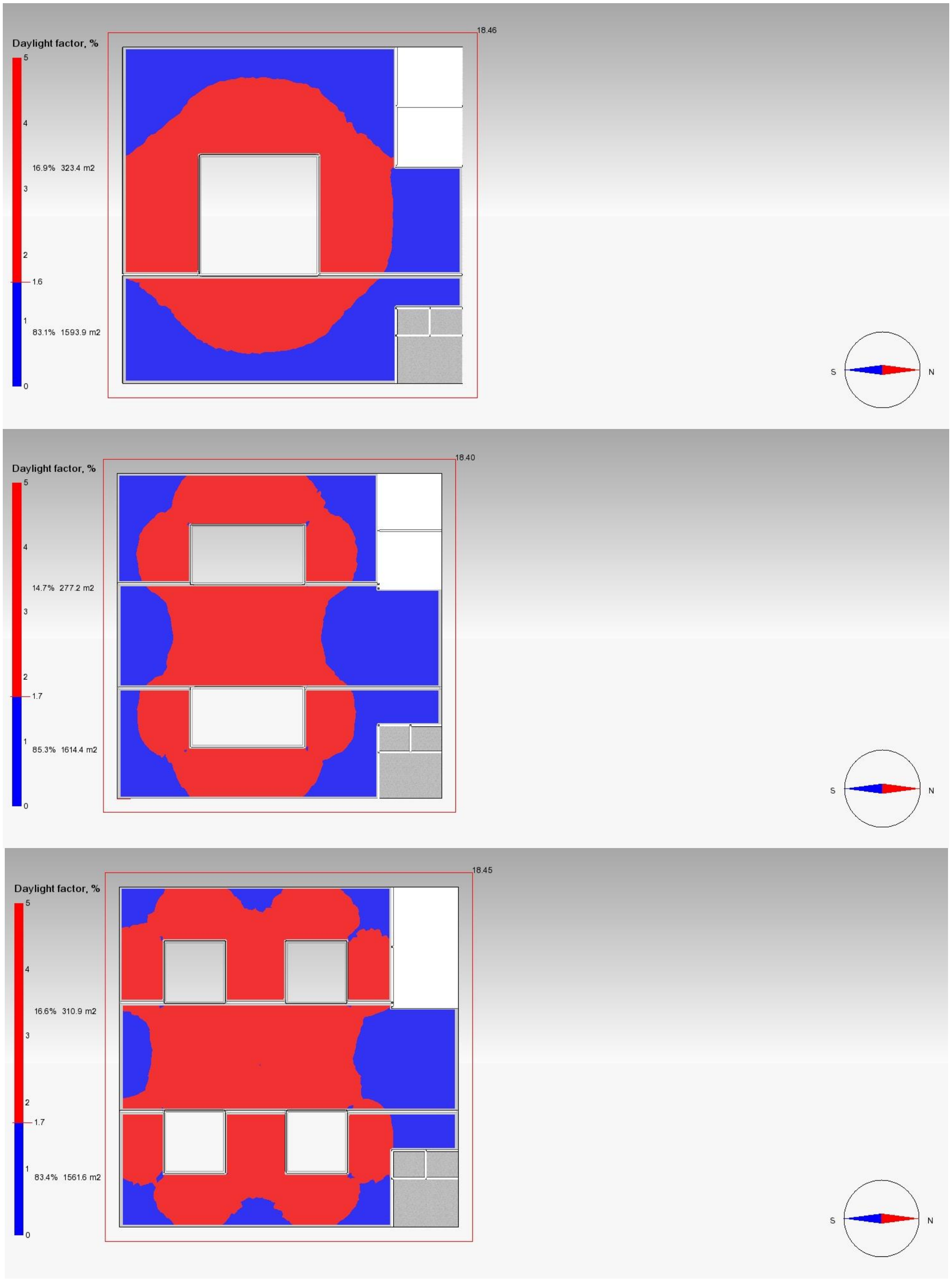


Figure 26 - ISOCF models daylight factor characteristics, top RM 1, middle RM 2, bottom RM 3

3.2. Energy

As the final energy intensity of the equipment and mechanical ventilation is constant between the cases due to similar settings, heating, cooling, and lighting energy demand are the crucial factors to compare. Figure 27 Represents the yearly final energy demand of the tested cases. RM 3 performed best in heating and lighting energy demand due to its largest WWR resulting in greater solar gains and daylight profit. In cooling demand, RM 3 has the highest value, based on larger heat gains. However, in total final energy, RM 1 and RM 3 are performing similar because in both models the South oriented fully glazed facades dominate the gains and losses balance. RM 2 required 7% higher total final energy demand with its lowest WWR (30%). Vajda, et al. have reported a similar finding of WWR that affects essentially the cooling and heating demands in moderate climates. They reported that with the increase of WWR, the heating and lighting energy consumption reduced, whereas the cooling energy consumption is increasing (Obrecht, et al., 2019).

Chiesa, et al. report similar results, complemented with the conclusion that the size of the window area can ensure a considerable saving of lighting energy as well (Chiesa, et al., 2019).

The ISOCF scenarios provide a significant improvement in heating and total delivered energy due to external window elimination while cooling remained practically the same. At the same time, the lower WWR causes in case of lighting higher requirements. Fig. 27 additionally illustrates that ISOCF1 has performed in the best heating, whereas its consumption was 21% less than the ISOCF 2 case and 54% lower in comparison to ISOCF 3. This is due to 15-30% lower heat losses through thermal bridges, 41-96% less window transmission losses as a result of single courtyard design (Fig 28). However, in the case of lighting energy consumption, ISOCF 3 has shown the best performance between all ISOCF scenarios and it could save 57% and 4% of lighting energy consumption in comparison to ISOCF 1 and ISOCF 2, due to 78% and 33% greater WWR respectively (Fig. 22), as well as better daylight distribution as a result of more courtyards distributed in the building. The growing number of courtyards (and hence the greater WWR with higher joints) significantly increases the heating and the total final energy demand of the ISOCF models, while lighting and cooling energy demand benefits.

The ISOCF scenarios show considerable savings in terms of heating and total energy demand in comparison to the RM scenarios, whereas the best ISOCF 1 scenario compared to the best RM 1 scenario decreased energy heating demand to 48% and 22% in yearly total energy demand, while in cooling required 32% more cooling demand. In lighting energy demand the ISOCF scenarios increase by 163% due to the use of artificial lighting to compensate for the visual comfort. However, depending on the models, the share of cooling and lighting is only 4-7% and 6-11% of the total energy, while heating dominates with a rate of 80-90 % of the total energy consumption values.

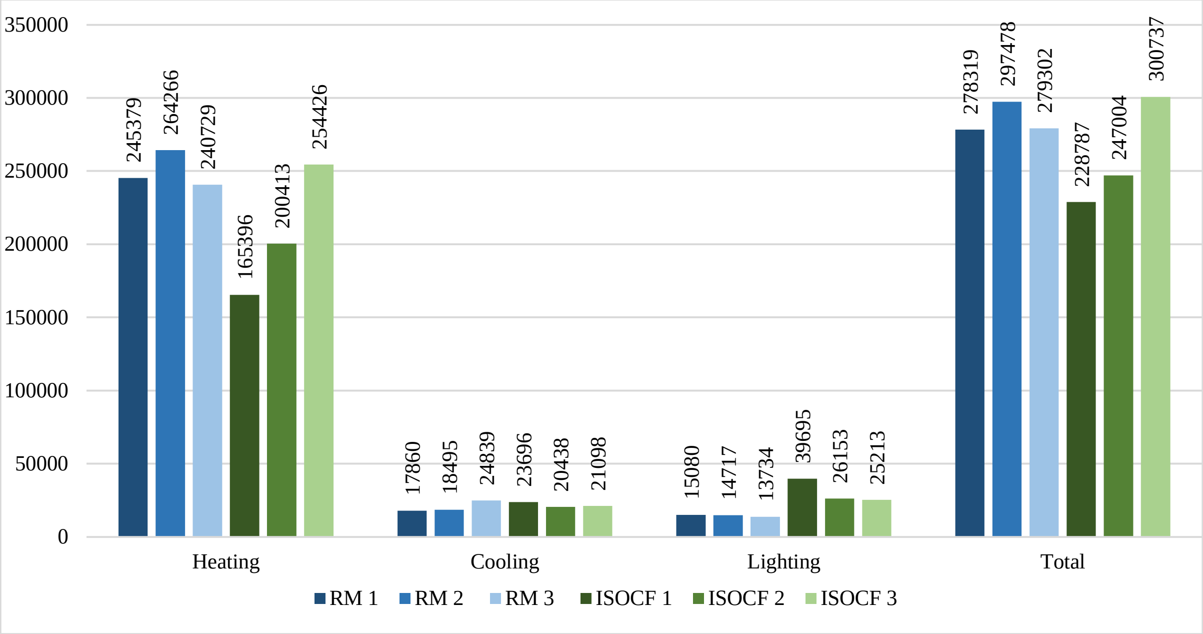


Figure 27 - Final energy demand performance [kWh/m2a] in the RM and ISOCF scenarios

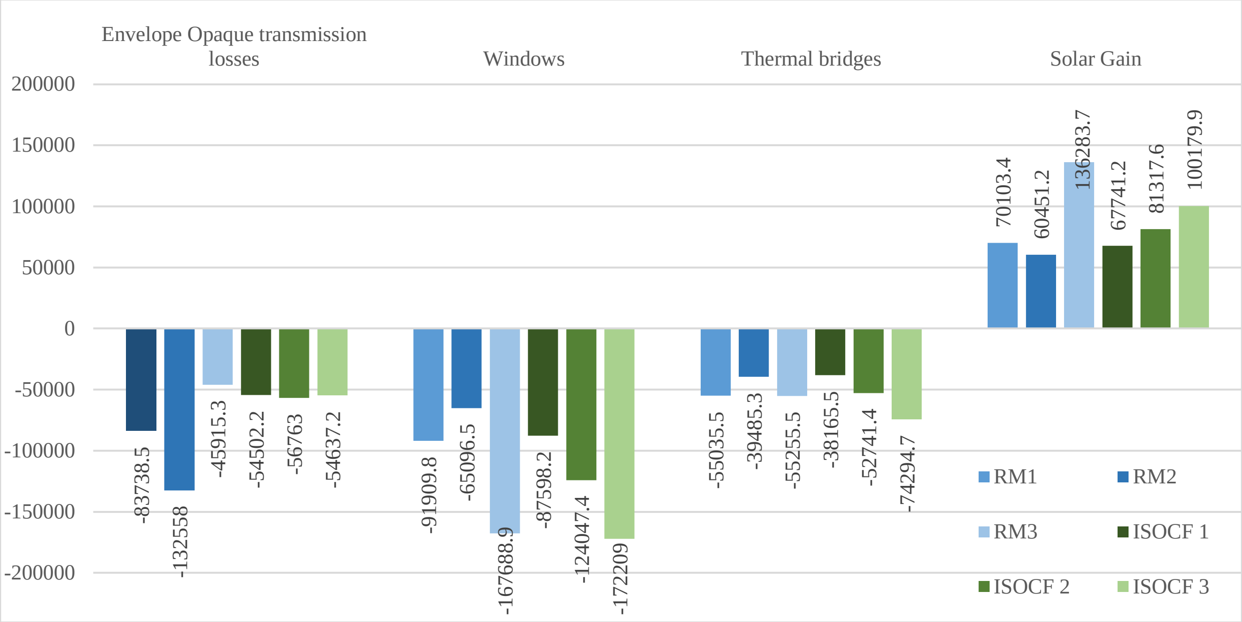


Figure 28 - Heat balance: transmission heat losses through the opaque envelope, heat losses through thermal bridges, heat losses via Fenestration, and solar heat gains through the glazing

Although the energy performance of the ISOCF concept could provide significant conservation, the strong drawback in visual comfort performance implies the requirement for further improvement of the architectural concept. Since the courtyard is not able to ensure appropriate DF and DA performance compared to the RM model's, further courtyard optimization is necessary to achieve the most optimal solution. Two optimization concepts were proposed:

- ISOCF 4: Enlargement of the courtyard`s horizontal dimensions in the best performing ISOCF model (ISOCF 1) (Figure 29)
- ISOCF 5: Changing the angle and size of the courtyard`s glazed facades by broadening the courtyard`s vertical section towards the top (Figure 29).

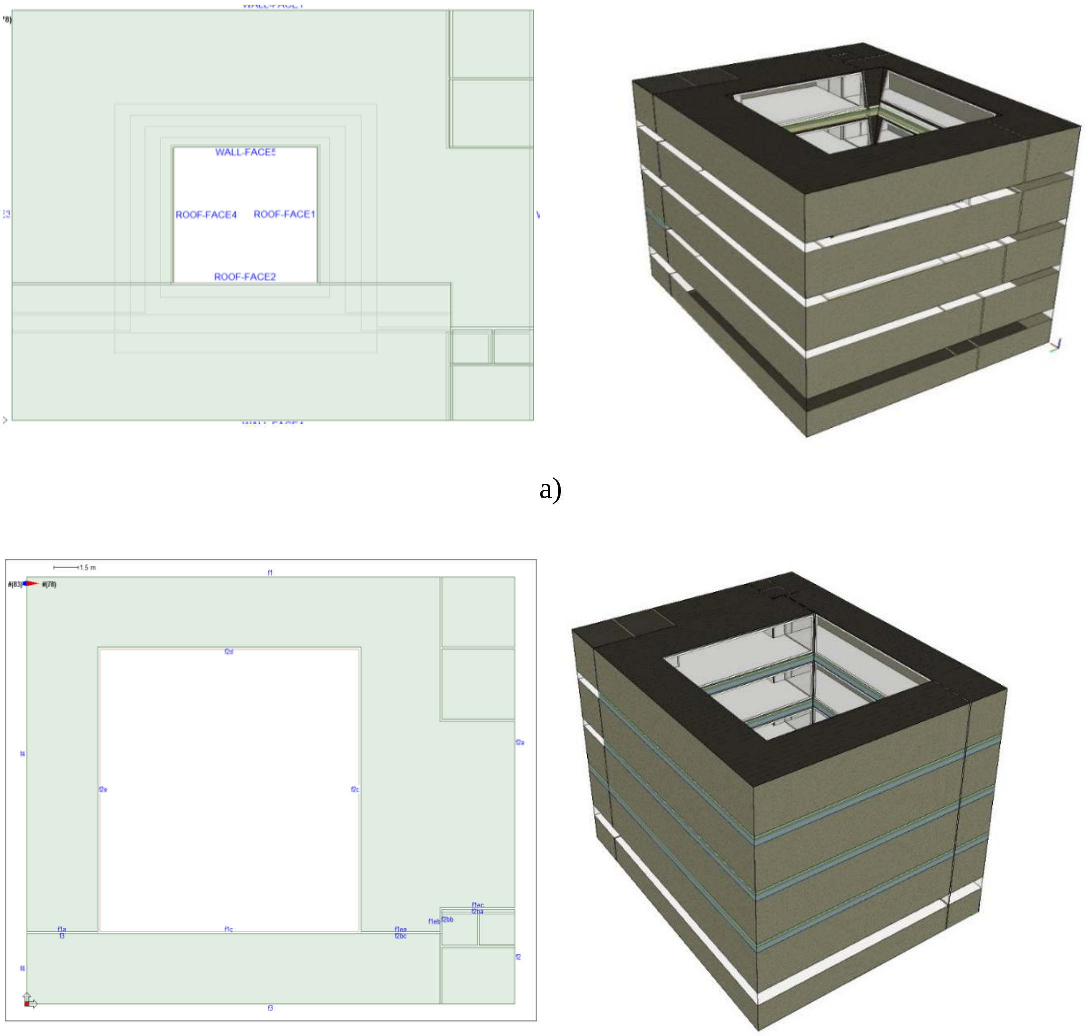
3.3. Courtyard Modifications

This section presents the further development of the ISOCF concept to ensure appropriate DF and DA performance in comparison to RM models. Ghasemi, et al. listed the six factors affecting the daylight distribution within the adjoining spaces of atriums as following:

- The sunlight availability and sky conditions.
- The roof shape, fenestration in atria, and glazing.
- The physical properties of the atrium including its type, geometry, and relative proportions.
- Self-shading effects of the building shape and geometry.
- The reflectance properties of enclosing atrium surfaces.
- The design of adjoining space such as types, layouts, surface reflectance, or geometries and furniture (Mohsen, et al., 2015).

In a similar study Hossein, et al. investigated atrium size enlargement for three different models with the same size and in three height levels. They show that in the highest scenario with 3 story height, the atrium size has a significant impact on the daylight level of the atrium space and their neighboring spaces (Omrany, et al., 2020).

These findings motivate this study for further optimization, leading to implement a larger-sized courtyard and investigate the effects of energy and comfort. In both ISOCF 4 and ISOCF 5 scenarios, the impact of doubling the size of the perimeter will be investigated: the courtyard is enlarged from 8 x 8 m to 16 x 16 m. For comparison purposes, it was necessary to enlarge the courtyard size that required an enlarged net floor area in the comfort zones a well. While the net floor space remained the same, the external perimeter size of the building is increased from 25 x 24 m to 29 x 24 m (Figure 29), meaning that one side of the building layout grew by 14% respectively. Besides, in the case of ISOCF 5, the section shape of the courtyard is modified on each floor due to the courtyard walls` inclination of 86° towards the sky. The smallest size possesses 8 x 8 m and the largest is 16 x 16 m. This approach inevitably enlarges the internal area in ISOCF 5 by 14%, by increasing one of the perimeters of the building body by only14%. The rest of the boundary conditions remain the same.



a)

b)

Figure 29 - Simulation model of ISOCF a)4 and b)5, main story layout (left), 3D view (right)

3.4. Comfort

3.4.1. Thermal Comfort

Figure 30 shows, ISOCF 4 and ISOCF 5 were able to perform slightly (12,5%) lower level of thermal comfort in comparison to ISCOCF 1, by maintaining 52% of the average annual hours of PMV, category B in the complete building. The reason for slight descending summer discomfort directly relates to WWR enlargement and the increasingly transparent surface towards direct solar radiation penetration (Fig. 30). Besides, due to the reduction of zone depth in the case of ISOCF 4 and 5, summer discomfort harms PMV, mostly on top floors. Figure 24 illustrates increasing the WWR, has a direct correlation to the number of occupancy hours performing operative temperatures of class B has been decreasing.

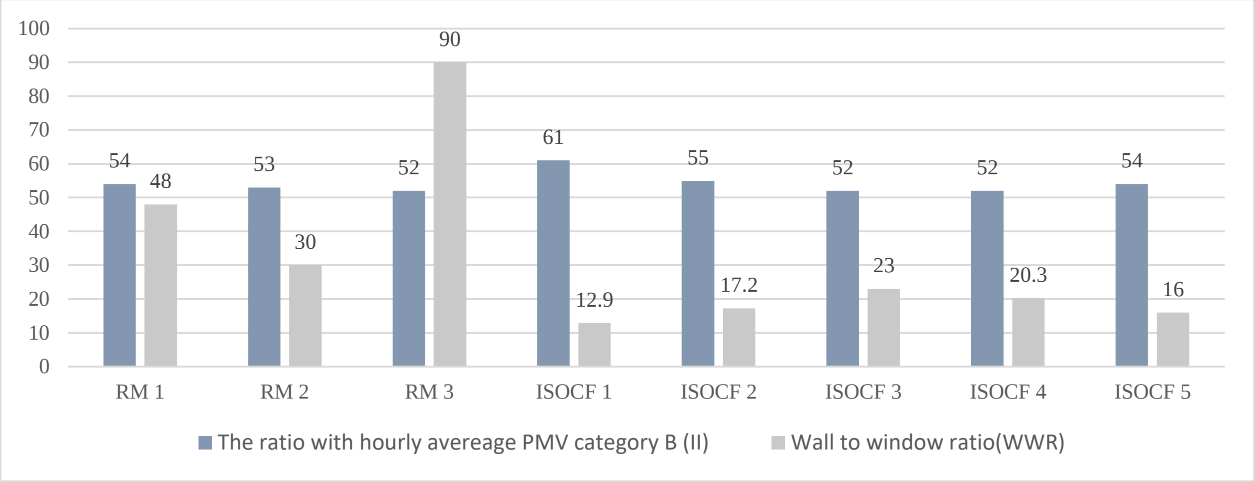


Figure 30 - The ratio of the year with hourly average PMV category B (II), Wall to window ratio (WWR) in the ISOCF models in all zones of the buildings [%]

3.4.2. Visual Comfort

Due to larger WWR, ISOCF 4 was able to improve the DF by 230% and DA by 180% in comparison to the best-case scenario ISOCF 1 (Fig. 31 and 32), and ISOCF 5 was also able to increase the DF by 172% and in the case of DA, it was able to improve by 122%. Figure 18 shows in the case of ISOCF 4 and 5 that solar penetration is significantly larger than in other ISOCF models, and as a result, this increases the illuminance level which at the same time negatively will affect glare effects. In a similar topic, Freewan illustrates that the modification of courtyard walls geometries can optimize the daylight performance of the courtyard, while it may harm glare (Freewan, 2011). The enlarged courtyard geometry enables not only increasing WWR but also the significantly greater grade of solar exposure of the glazed facades, leading to the DF and DA improvements.

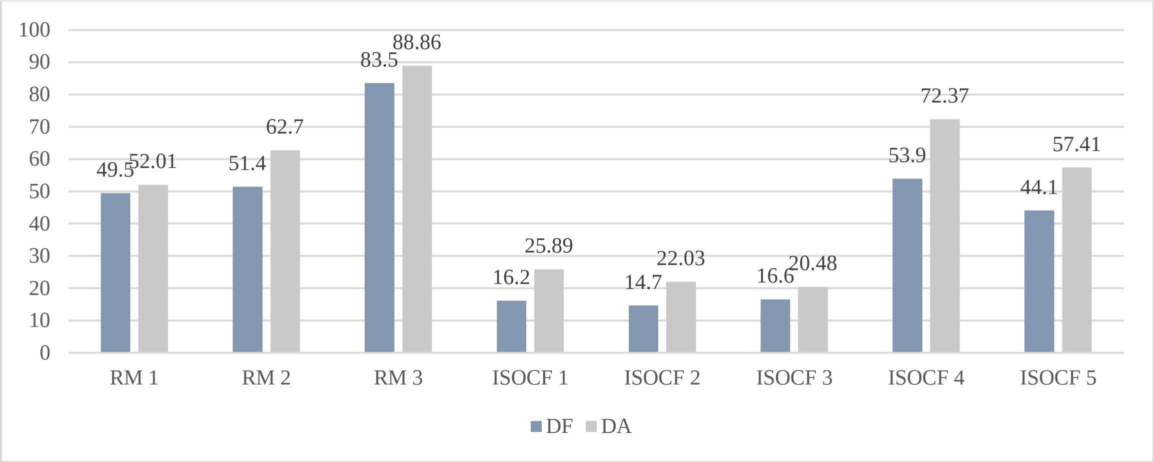


Figure 31 - Daylight factor above 1.7 and Daylight autonomy above 300 Lux % Models

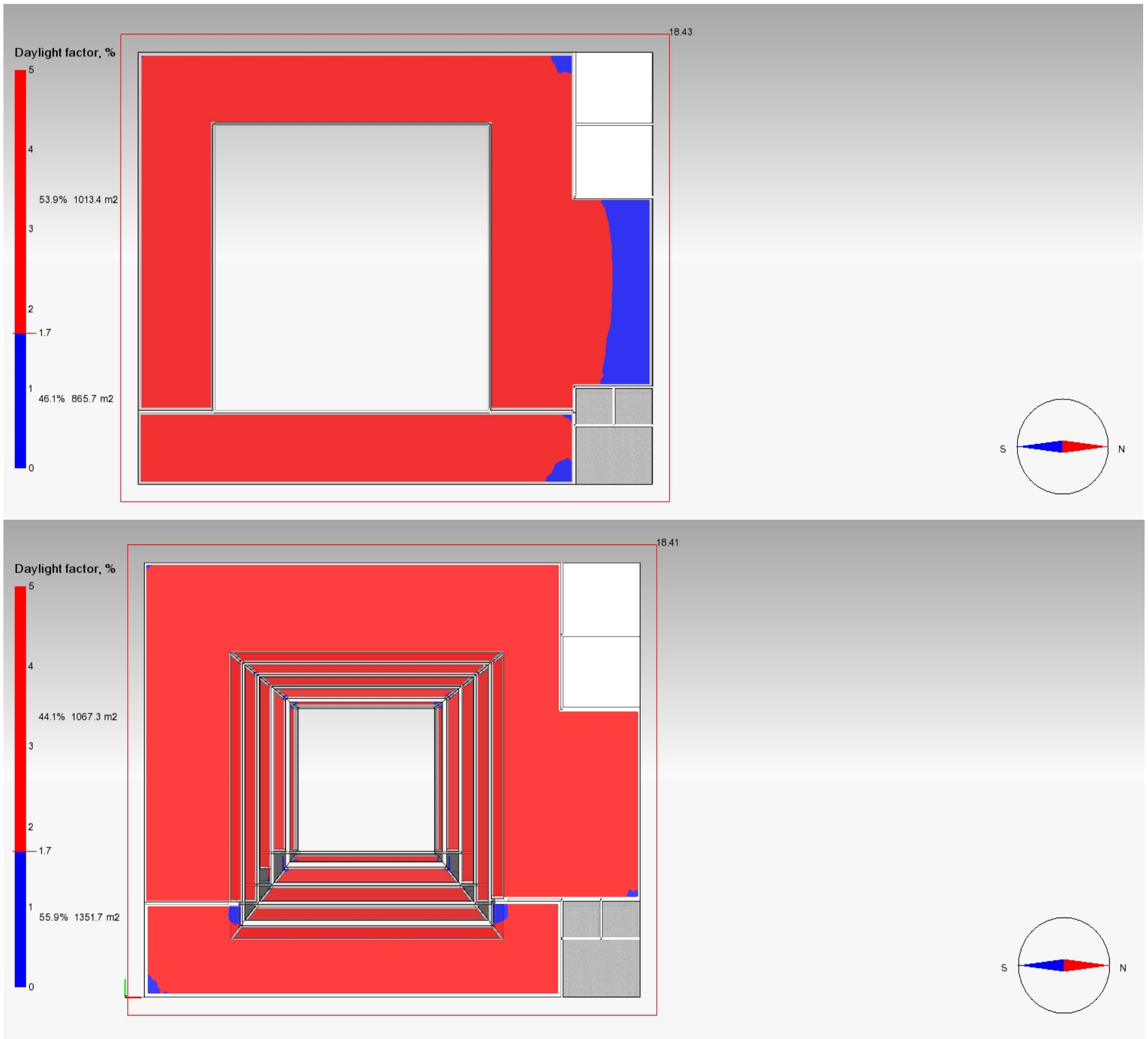


Figure 32 - Models daylight factor characteristics, top ISOCF 4 and bottom 5

3.5. Energy

Although ISOCF 4 and 5 were able to significantly improve visual comfort, they were unable to maintain a good level of energy demand. In comparison to ISOCF's best case scenario (ISOCF1), ISOCF 4 and 5 performed with a 30% heating energy demand increase. This is due to the 30% higher WWR, as well as higher transmission heat losses of larger transparent and opaque envelope surfaces and thermal bridges (Figure 33). In summer, the increased solar gains required 42% more cooling demand in ISOCF 4 and 5. However, in the case of artificial lighting demand, ISOCF 4 and 5 show 71% improvement, thank larger WWR, providing greater daylight penetration and hence lower artificial light need. The modification of courtyard size and walls inclination harmed the total energy demand, resulting in 19% more consumption in ISOCF 4 and 13% in ISOCF 5. Figure 34 shows that even though the further developed cases were able to improve visual comfort, in terms of the energy they possess disadvantages. ISOCF 4 and 5 performed almost the same total energy results. Based on the results, the next improvement modeling step was necessary to achieve the acceptable energy performance of the final energy demand. Compared to ISOCF 5, ISOCF 4 shows 18% better DF and 20% higher DA performance, therefore ISOCF 4 was selected for further modification. On the other hand, due to the ISOCF 5 adjacent walls inclination it was inevitable to enlarge the net floor area, which works against the rest of ISOCF models boundary conditions. However, the results show ISOCF 5 performed better in the case of energy considering kWh/m^2 and this can be the subject to further investigation.

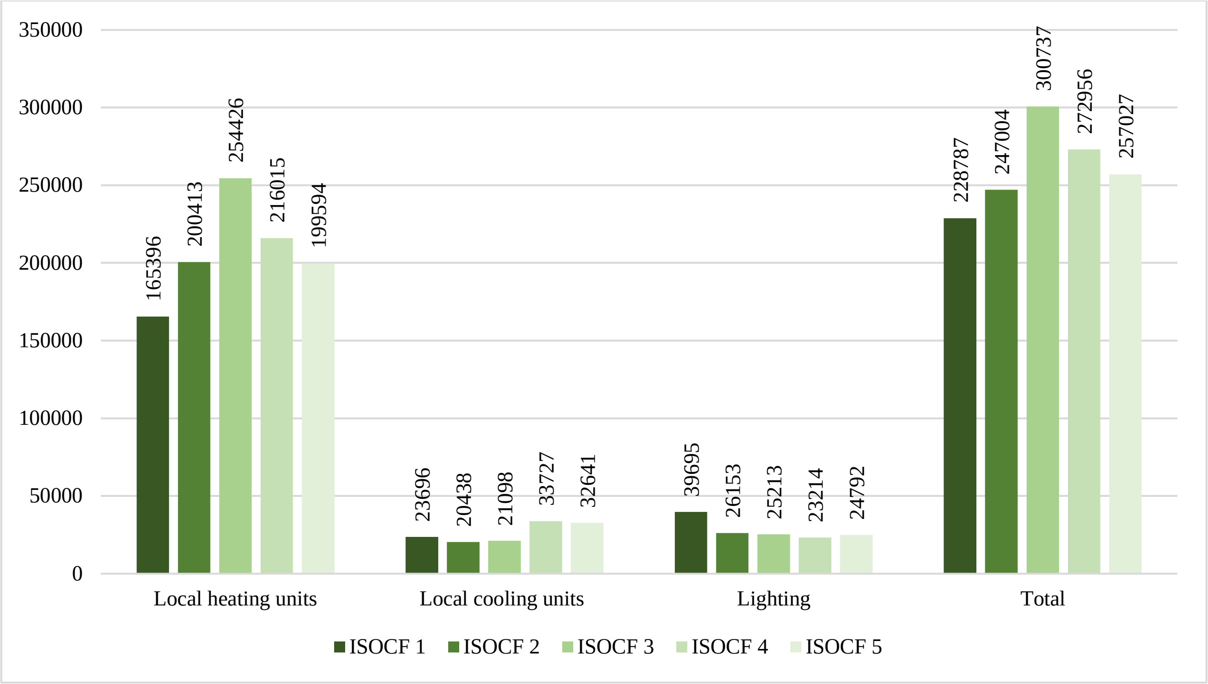


Figure 33 - Final energy demand performance [kWh/m2a] in the ISOCF scenario

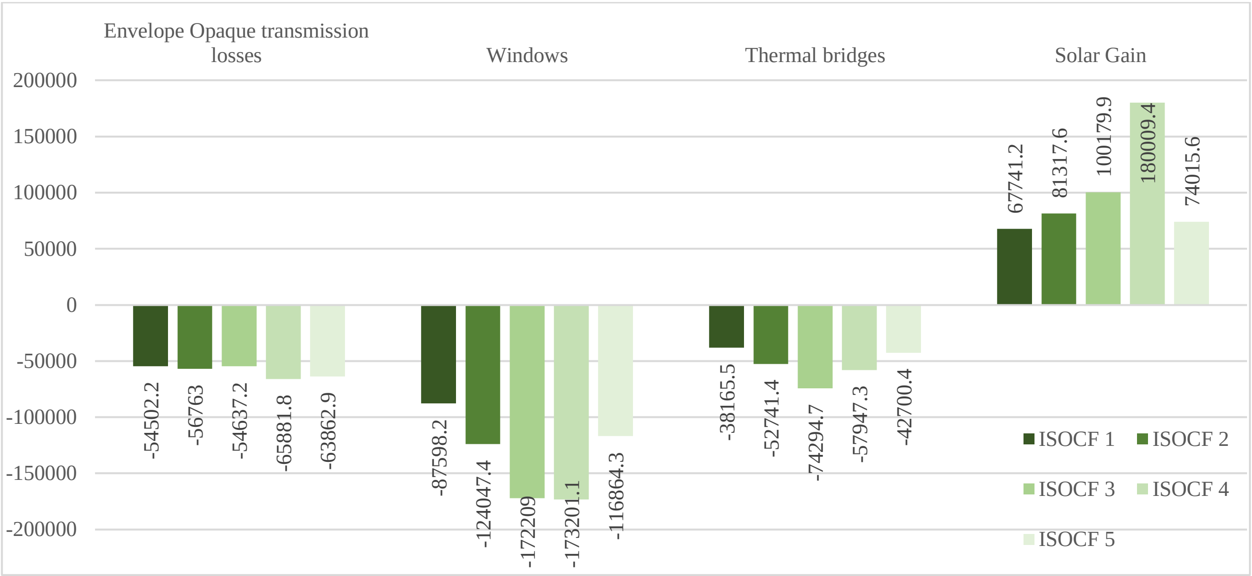


Figure 34 - Heat balance: transmission heat losses through the opaque envelope, heat losses through thermal bridges, heat losses via Fenestration, and solar heat gains through the glazing

3.6. ISOCF 6 – The Atrium Concept

Yasa et al. illustrate in case of using courtyards, external exposure increases, and consequently heat loss increase through wall and windows which are not preferable in this climate (considering that heating-dominated the whole energy consumption). The study also discussed that atrium makes a transitional space in which its indoor temperature is always higher than the outdoor temperature, as an effect of solar gain through the skylight. Therefore, heat losses decrease, and the stored heat in the atrium can be transferred to the building by conduction and convection through the walls and windows (Yasa & Vildan, 2014). On the same topic, Leila et al. stated that atrium components and configurations, such as opening control, can drastically improve thermal comfort, as well as indoor air quality (Leila, et al., 2014). In this study, ISOCF 6 model was created (Fig. 35), whereas the open courtyard of ISOCF 4 was transformed into an atrium with a controlled skylight opening. With this solution, the courtyard heat losses should decrease. This approach will have control over the atrium top opening schedule (natural ventilation) while maintaining the acceptable achieved level of visual comfort as shown in table 8.

Table 8 - Skylight Opening Schedule ISOCF 6

Date	**Time**	**Intensity**	**Close/Open**
January 1st _March 13th	Always Close	100%	Close
March 14th _ April 23rd	12:00-16:00	50%	Close & Open
April 24th _ September 30th	Always Open	100%	Open
October 1st_ December 31st	Always Close	100%	Close

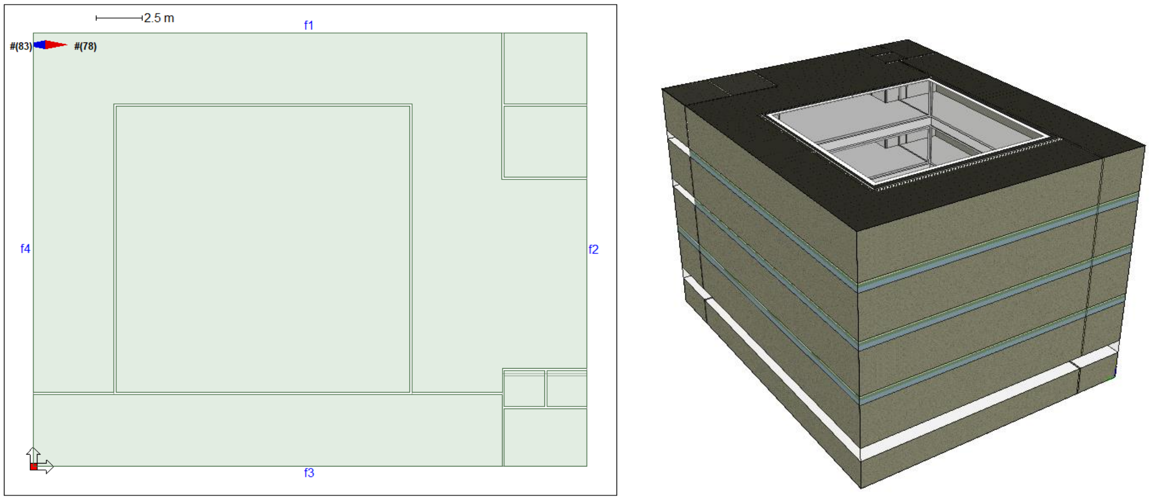


Figure 35 - Simulation model of ISOCF 6, main story layout (left), 3D view (right)

3.7. Comfort

3.7.1. Thermal comfort

Figure 36, Shows, that ISOCF 6 was able to maintain the level of hourly average PMV category B at the same level of the ISOCF best case scenario (ISOCF 1). Figure 36 also Illustrates that ISOCF delivered better PMV performance by 18% compared to RM 1, 2, and 5% related to ISOCF 1 and 23% compared to ISOCF 4. Even though the WWR has been increased, the transitional atrium space successfully works as a buffer zone, delivering he best PMV performance, because the opening control closed the skylight during the wintertime (Table 8), and the atrium adjacent wall windows are acting as internal windows and the opaque walls as advantageous thermal masses, Heat losses were reduced.

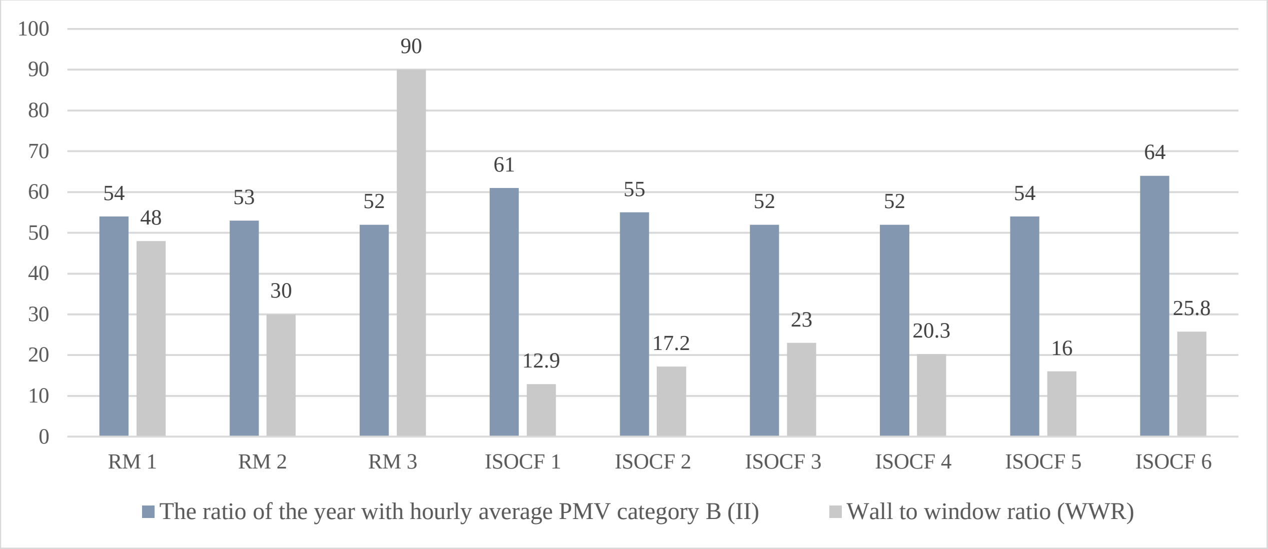


Figure 36 - The ratio of the year with hourly average PMV category B (II), Wall to window ratio (WWR) in the ISOCF models in all zones of the buildings [%]

3.7.2. Visual Comfort

In the case of DF and DA, Figures 37 and 38 exposed that ISOCF 6 performed slightly at the same level as ISOCF 4 and delivered higher visual comfort compare to models RM 1 and 2 thresholds. In DF ISOCF 6 improves by 8% compared to RM 1 and 2, slightly the same level in comparison to ISOCF 4 and it was able to improve ISOCF 1 by 230%. In terms of DA, ISOCF was able to deliver better performance, whereas, it was able to perform 32% better compared to RM 1,2, a similar level as ISOCF 4 and 172% improvements compare to ISOCF 1. However, a neglectable amount of decrease compared to ISOCF 4, due to the diffusion effect of the top glass opening.

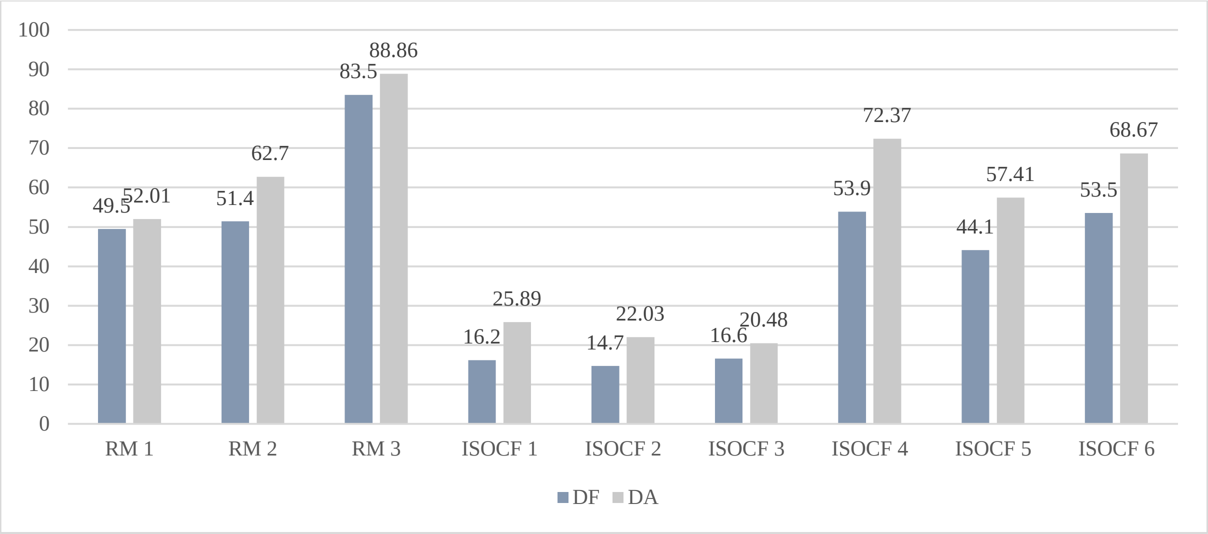


Figure 37 - Daylight factor above 1.7 and Daylight autonomy above 300 Lux % Models

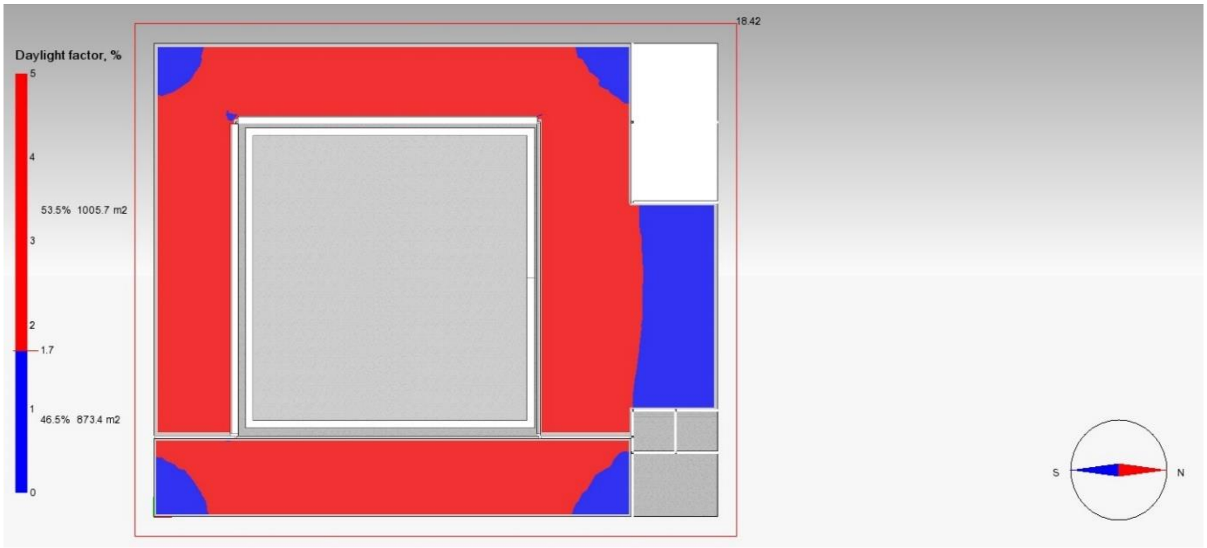


Figure 38 - ISOCF 6 daylight factor characteristics

3.8. Energy

ISOCF 6 improves energy demand performance drastically, whereas in heating energy demand, (responsible for 80-90% of the total energy consumption) it delivered 140% lower heating demand compared to RM 1and 2, and 80% in total annual energy demand (Fig. 39). In comparison to ISOCF 1, it was performed 60% better in heating and 47% in total annual energy demand. It also delivered a 110% improvement in heating and 75% in total annual energy demand compared to ISOCF 4. On the other side, the results also illustrate that ISOCF 6 required more cooling and lighting energy, whereas, in comparison to RM1 and 2, it required 40% and 80% more cooling and lighting. At the same time, it required 10% more cooling and provided 50% better lighting energy demand compared to ISOCF1, and compared to ISOCF 4, it required 30% less cooling and 14% more lighting energy demand Fig. 39. Due to figure 40, ISOCF 6 was able to maintain a good level of solar gains while the thermal bridge and heat losses performed the best. In terms of bridge ISOCF, 6 performed 200% better in comparison to RM 1 and ISOCF models.

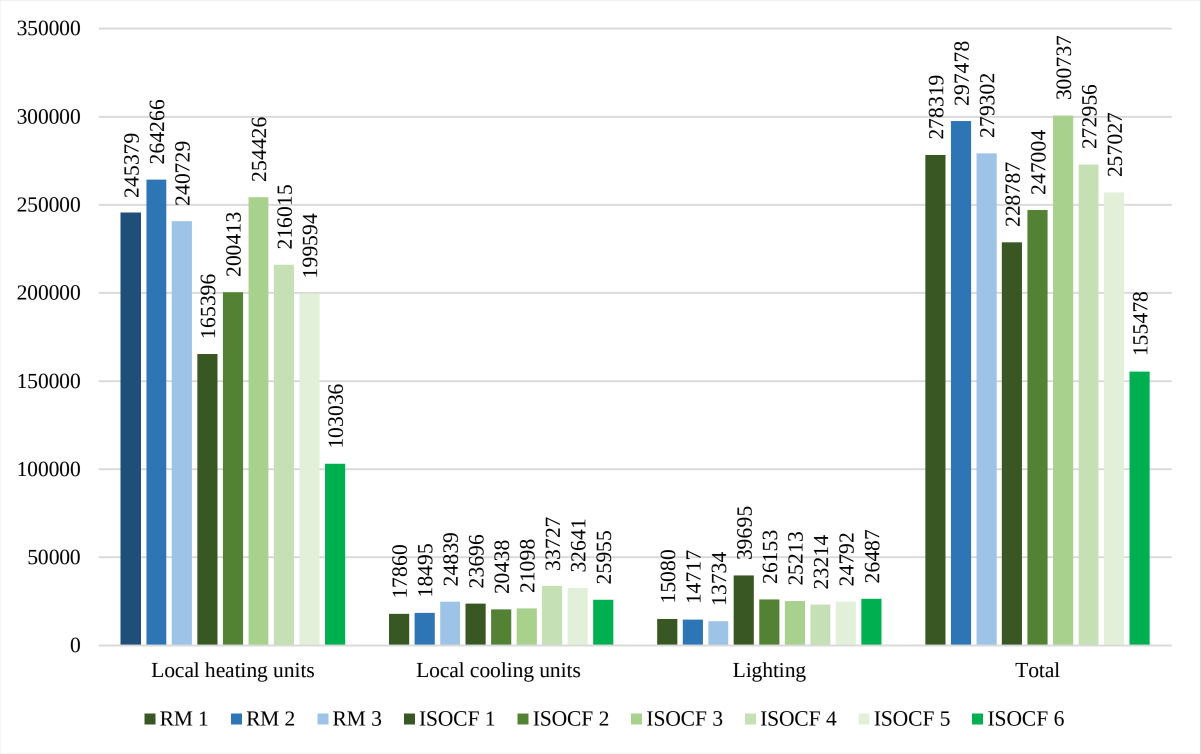


Figure 39 - Final energy demand performance [kWh/m2a] in the RM and ISOCF scenario

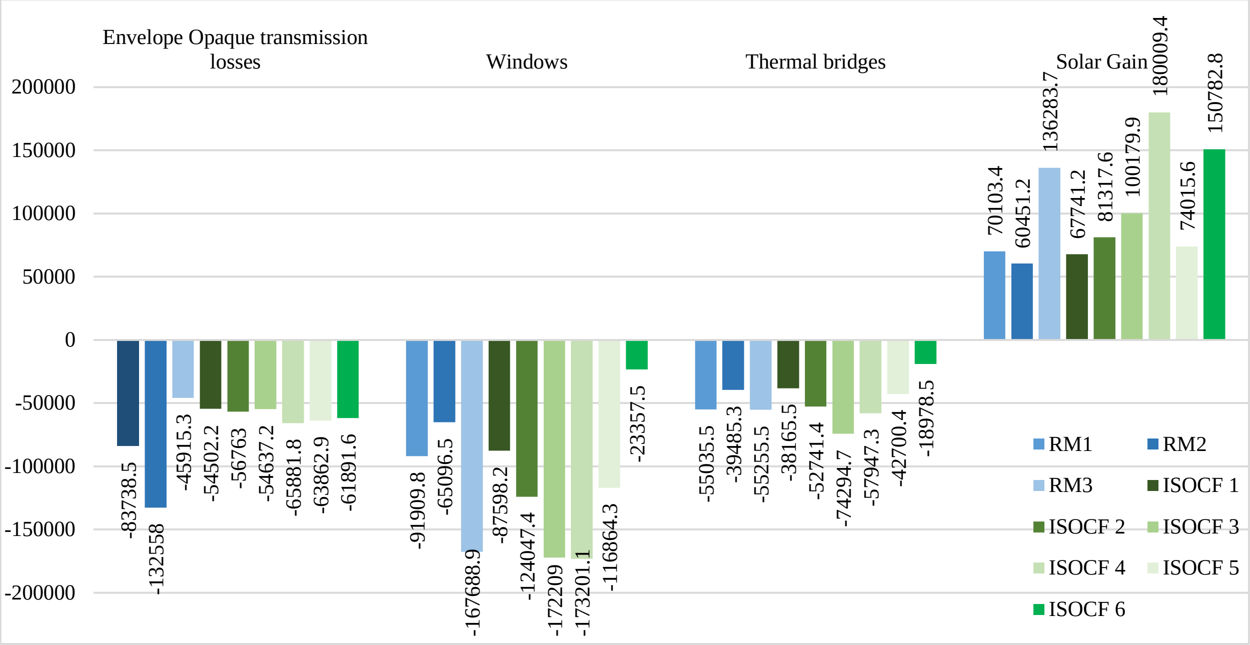


Figure 40- Heat balance: transmission heat losses through the opaque envelope, heat losses through thermal bridges, heat losses via Fenestration, and solar heat gains through the glazing

4. The architecture of the ISOCF building type

Kolozali et al. state that, designers ought to be the first professionals to implement sustainable development subjects into their practices. Design decisions for buildings have environmental costs and the obligation of responsibility rests heavily on the designers' shoulders since the building product is a result of their novelties (Kolozali, 2016). E. Conte also demonstrates, besides complex building systems and technologies, architects must be more conscious and capable of arranging a wide selection of fields of knowledge to design outcomes that suffice as sustainable (Conte, 2018).

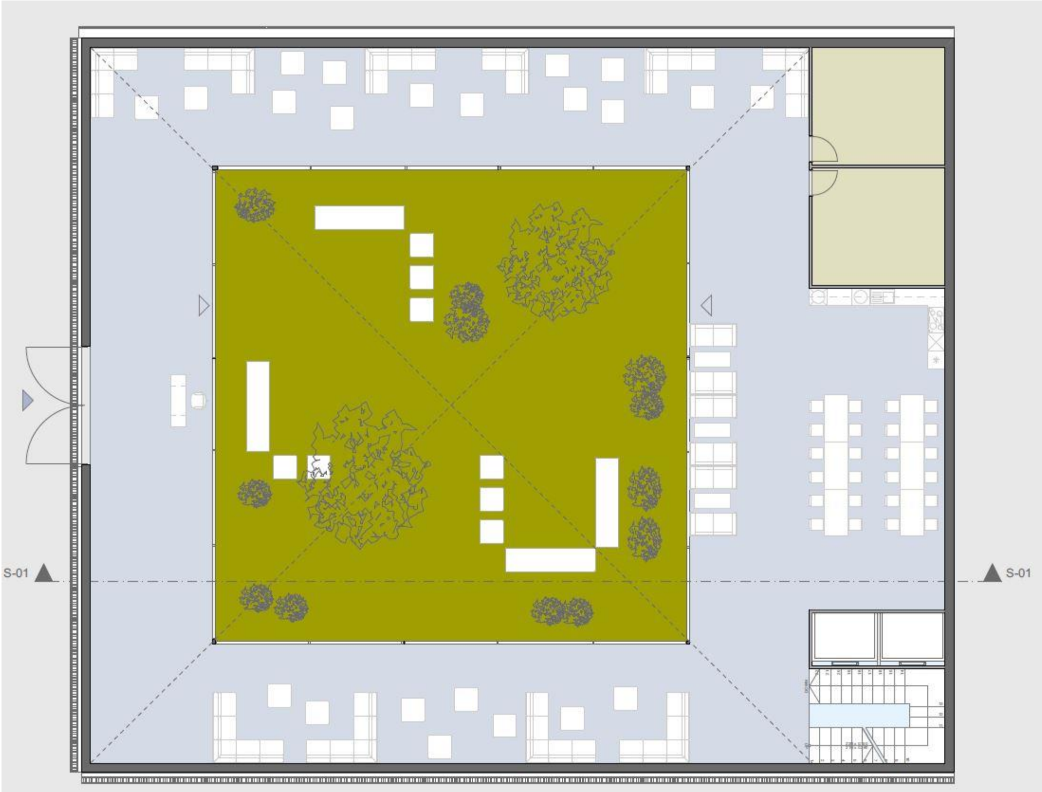
The final result has been evaluated precisely from the scientific point of view and it is proven that ISOCF 6 was able to perform more efficiently in terms of comfort and energy.

The basic architectural criteria such as space functionality, movement circulation, aesthetics, and other fundamental design impacts are as important as the energetical performance of the building.

The study proposed a set of architectural drawings (Fig. 41) to demonstrate one of the many potential final architectural solutions. There are only two types of floor planes representing the ground and first floor, figure 41 shows the ground floor as a public floor of the building is responsible for the main entrance, courtyard connection’s to the building, sitting, dining, consultation area, and will provide the space for potential shops. However, in the case of 1st-floor spaces are performing as open workspaces, whereas space ‘A’ is established as some temporary workstations, space ‘B’ represents the group working and consultation area, and space ‘C’ is performed as the manager and key roles of offices.

In ISOCF building type, atria can maintain the comfort level of 18° in at least 6 months of the year, however, it is recommended to study further development in case of heating the atria zone to be able to have a permanent arrangement in the atria even in the coldest month of the years. (Fig. 41 and 42)

The exterior envelope of the building body has great potential to benefit from, such as PV implementation on the surface to observe maximum possible solar radiation as shown in fig. 43.



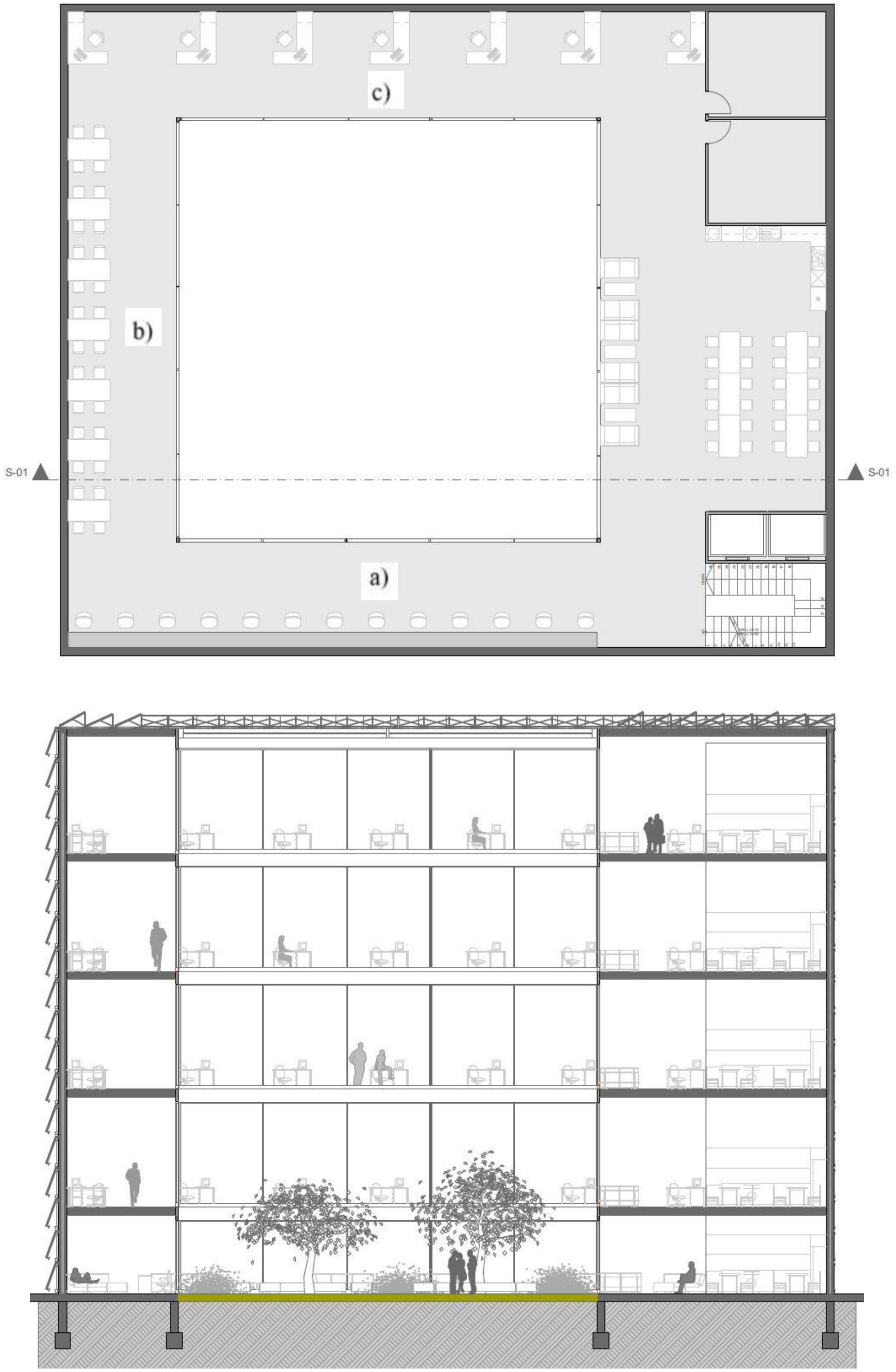


Figure 41- ISOCF 6 Architectural Floor Planes, top ground floor, middle first floor, and bottom section

Figure 42- ISOCF 6 Interior 3D graphics

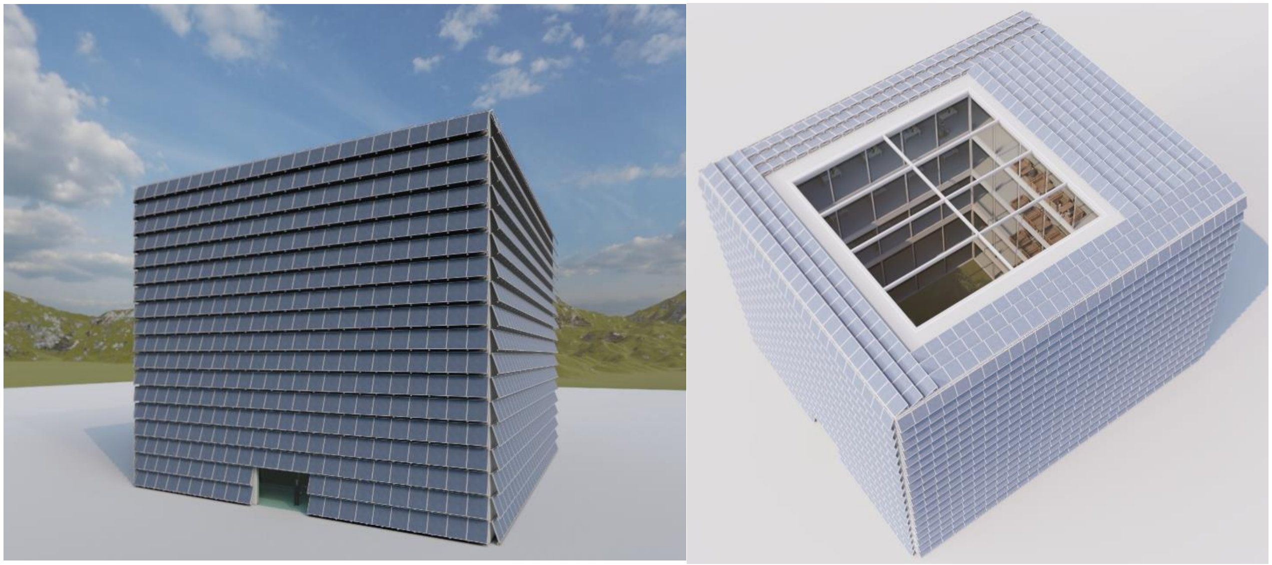


Figure 43- ISOCF 6 External appearance, PV Implementation

5. CONCLUSIONS

Under the moderate climate, the new introverted open space with closed facade (ISOCF) strategy has been investigated to meet the necessary level of thermal and visual comfort while improving the level of energy demand. The study investigated under conventional office building boundary conditions and compared to existing sophisticated multistory office building, Szentágothai Research Centre office located in Pecs, Hungary. The following statements have been established:

5.2. Statements

1. Rethinking and redesign elementary architectural design factors can significantly improve today`s characteristic comfort and energy drawbacks in the office building sector. These design contents are under moderate climate are as follows:

    - The proposed office building type becomes a completely closed façade surface to avoid winter heat losses and summer heat loads.
    - The completely closed facade requires the perforation of the building body to be able to deliver missing daylight and passive ventilation provision in form of courtyards/atria. Since the passive ventilation possibility and natural lighting provision should be ensured through the courtyards, the internal space organization should provide accessibility for daylight and ventilation operation all over the interior space. This can be achieved by the open office spaces organization that ensures long term future functional flexibility.

2. A new architectural design concept is proposed, including an introverted space organization with a closed façade (ISOCF), an integrated courtyard, and an open interior workspace organization. In comparison to today's conventional multistory office building, the ISOCF represents a new multistory office building type that can deliver 80% less total annual energy demand (heating, cooling, and lighting). The main contributor is the heating energy consumption (a share of more than 80% of the total energy consumption), which is 140% lower in the ISOCF performance. The thermal comfort in the ISOCF office building performed a 20% higher number of occupancy hours with PMV-values, class B (II). The

daylight performance reaches a 10% improvement in daylight factor ($DF_{1.7}$) under mixed sky conditions and 32% better daylight autonomy (DA_{300}) under global radiation circumstances.

3. In the ISOCF model development, different numbers and sizes of courtyards were tested to analyze the thermal and energy performance. Cases with 1, 2, and 4 courtyards were simulated in the experiments. Under the same building dimension boundary conditions, by increasing the number of courtyards, their WWR is enlarging as well, lowering the PMV performance by 12%, while the total energy intensity becomes 35% larger. The heating demand performance here is the greatest ratio as well, representing more than 80% of the total energy demand, whereas heating is increased by 54%.
4. In the ISOCF building concept, 1 courtyard can maintain the appropriate level of $DF_{1.7}$ and DA_{300} distribution, by simultaneously lowering the energy consumption, when the dimensions of the courtyard geometry are properly sized. In the framework of the ISOCF experiments, the model with 1 courtyard has to be modified to ensure not only thermal comfort and energy improvements but also visual comfort, since the daylight qualities in that concept were suffering due to undersized courtyard and hence WWR. The courtyard layout was gradually increased to double size, while it was necessary to narrow the depth of the adjacent office zones by 50% and the external perimeters of the building at one side needed enlargement of 16%. It can be stated that 5-storey ISOCF office buildings under a moderate climate require a depth ratio of approx. 0,25 between the average depth of the office comfort zones and the mean courtyard/atrium depth to deliver the achieved improved level of comfort and energy performance results.
5. Under moderate climate circumstances, typical modern multistory office buildings possess significantly greater heating demand, compared to cooling. The open perforation of the building body (courtyard) increases transmission and thermal bridges based heat losses in winter. Therefore, the closing of the courtyard with a skylight creates significantly lower (110%) heating consumption, as well as an external multifunctional space for communicative functions (brainstorming, project office) in at least 60% of the year without space conditioning.
6. The particular investigation focused on a 5-story office building with a compact width to length ratio. The concluded insight and design rules are accordingly limited to buildings with a width to length ratio of around 1 and the mentioned building height. With an increasing

number of levels, the daylight provision starts to decrease, while lower buildings with a decreasing number of levels show higher daylight qualities. Besides, a lower with to length ratio results in a less compact (e.g. elongated or splining) building shape that cannot integrate a sufficient sized courtyard.

7. This research was conducted under moderate climate conditions with its specific solar radiation and daylight path properties, therefore the conclusions are limited to this climate zone. Further research using various climate profiles can broaden the adaption of the developed building type under further climate locations.

8. The proposed ISOCF office concept represents a fundamental basis for the development of a comprehensive future ISOCF multistory office building typology and design guidelines.

5.3. Contributions

Scientific contribution

- The prior literature in the multistory façade optimization strategy lacked a comprehensive new building type, using radical and elementary passive architectural strategies as a completely closed building envelope according to the reorganization of the interior spaces. This research contributes to the multistory office and workspaces in literature with the innovation and knowledge about the proposed new office building type.
- The following research provides a direction for further investigations on multistory office building typology and energy design guidelines.

Social contribution

- The new building type provides a friendly work atmosphere and due to its open workspace, it increases the positive interactions between co-workers and colleagues, resulting in more efficient group work.
- The new multistory office building type has improved the indoor thermal comfort and energy performance for the working spaces.

Architectural contribution

- With the integration of an atrium, a kind of multifunctional `transition-space` with communicative functions (brainstorming, project office) is created, performing acceptable thermal comfort in at least 60% of the year without space conditioning.
- Using the open workspaces, various required temporary functions can be utilized and the new building type is convertible to any other suitable temporary and permanent functions.

5.4.Future directions

- In the future, further investigations about daylight performance will help to improve the visual comfort level of the new multistory building type.
- It will be useful to analyze the atrium aerodynamic conditions using computational fluid dynamics (CFD) software. This will complete the new building type to increase hygienic comfort (indoor air quality, IAQ) together with lower energy consumption.
- Since the building envelope is free of external windows, it is suggested to use the envelope surface and to investigate the effect of the implementation of PV-technology on the façade surface to improve energy efficiency.
- An energy-positive yearly balance is aimed to be reached by implementing further investigations including HVAC-systems, environmental sources utilizing systems, etc.
- Future studies in terms of interior architectural and temporary visual and acoustical separations in the floor plan will provide more efficient space optimization.

List of Publications by Mohammad Reza Ganjali Bonjar

Information as of November 4, 2020

Published:

1. Potential analysis of active system operation in large scale office buildings

Author: Mohammad Reza Ganjali, Bálint Baranyai, István Kistelegdi, Kristof Roland Horvath
Journal: Pollack Periodica, Hungary

2. Passive system optimization in office buildings a reference tested building
Author: Mohammad Reza Ganjali, Bálint Baranyai, István Kistelegdi, Kristof Roland Horvath
Journal: Pollack Periodica, Hungary

3. A review and systemization of the traditional Mongolian yurt (Ger)
Author: Gantumur Tsovoodavaa, Rowell Ray Lim Shih, Mohammad Reza Ganjali Bonjar, István Kistelegdi
Journal: Pollack Periodica, Hungary

4. Comfort and energy performance analysis of a heritage residential building in Shanghai
Author: Chu Xiaohui, Ganjali Bonjar Mohammad Reza, Gantumur Tsovoodavaa, Rowell Ray Lim Shih, Balint Baranyai
Journal: Pollack Periodica, Hungary

5. Energie-Design-Fachplanung in einem Tech-Lab-Projekt: Planungsunterstützung in Form von thermischen und strö- mungstechnischen Simulationen anhand eines Fallbeispiels „NOÉ“ Tech-Lab an der Universität Pécs, Ungarn
Author: István Kistelegdi, Bálint Bachmann, Gabriella Medvegy, Tsovoodavaa Gantumur, Mohammad Reza Bonjar Ganjali, Bálint Baranyai, István Ervin Háber
Book: Bautenschutz, Nachweismathoden und Anwendungen, Germany, 2018, ISBN 978-3-00-060009-8
Language: German

Under Review:

1. Analysis of the closed façade strategy to improve comfort and energy performance in office buildings under moderate climate
Author: Mohammad Reza Bonjar Ganjali, Javad Ganjali Bonjar, Istvan Kistelegdi
Journal: Buildings

2. The effect of floor diffusers configuration in under floor air distribution system on thermal comfort in an educational space.

   Author: Mohammad Reza Ganjali Bonjar, Hamed Moslehi , Sevil Berenji , Javad Ganjali Bonjar, István Kistelegdi

   Journal: Building Engineering

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Abed, A.-. W. H., Abdelatif, M., Nadége, T. & Richard, B., 2019. Combined use of dynamic building simulation and metamodeling to optimize glass facades for thermal comfort. *Building and Environment*, Volume 157, pp. 47-63.

AbuBakr, S. B., Patrick, A. B. J. & Mark, F. J., 2008. Potential of emerging glazing technologies for highly glazed buildings in hot arid climates.". *Energy and Buildings*, 40(5), pp. 720-731.

Adrienn, G. & András, R., 2015. Climate-based performance evaluation of double skin facades by building energy modelling in Central Europe. *Energy Procedia*, Volume 78, pp. 555-560.

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