Thermal Performance of the Atrium Building in Hot and Humid Climate

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ABSTRACT

The proper atrium design can be an optimum way for providing maximum users' satisfaction and energy efficiency throughout different seasons. In a hot and humid climate, using a buffer zone as the atrium caused a thermal performance problem. One of the problematic issues can conclude as fluctuation in indoor conditions which is caused discomfort hours. This research investigates the thermal performance of the atrium building in a hot and humid climate based on different design parameters. Furthermore, this research deals with the ASHRAE (2018) - ISO 7730 - EN 25251 standards of energy performance and users' thermal comfort for the atrium in single-floor, medium-rise, and high-rise office buildings. It applies different proportions of office and atrium volumes in finding the optimum design and assessing the different atrium window opening ratios, internal condition systems, and atrium orientations throughout a year. The EDSL Tas software was used for dynamic thermal simulations. The goal of this study to propose the optimum atrium and office volumes for buildings in a hot and humid climate based on thermal performance in the different seasons. The findings of this research illustrate that when the internal condition of the building is natural ventilation, the single-floor and medium-rise atrium buildings with an atrium proportion 1/2 of the office proportion with south-east (single-floor) and center (medium-rise) atrium placements had maximum occupants' satisfaction (users' comfort). However, when the internal condition of the building was mechanically conditioned (basic air-conditioning) and the atrium proportion was 1/3 and 1/4 of the office proportion, especially with the center (single-floor) and north-east (medium-rise) atrium placement, it had an acceptable internal comfort throughout the year. Furthermore, the high-rise atrium building with a natural internal condition and an atrium proportion 1/4 of the office proportion in the north-east placement, and the mechanically conditioned (basic air-conditioning) 1/3 atrium proportion of the office proportion in the center placement had more internal thermal comfort than other dynamic simulation scenarios during the year.

Keywords: Atrium Volume, Atrium Orientation, Naturally Conditioned Building, Mechanically Conditioned Building, Hot and Humid Climate, EDSL Tas.

ÖZ

Atriyum tasarımı ile maksimum ısıl konfor ve enerji verimliliği yüksek olan, tüm mevsimlerde kullanılabilen sürdürülebilir bina tasarlayabiliriz. Bu tezin kapsamında ASHRAE (2018), ISO 7730, EN 25251 uluslararası standartları kullanılarak tek kat, orta ve yüksek katlı ofis binaları incelenmiştir. Optimum tasarım için farklı pencere açılış oranları, iç mekan koşulları, farklı atriyum yönledirmeleri ve farklı ofis-atriyum oranları yıl boyunca EDSL Tas yazılımı ile bulunması bu tezin amacıdır. Bu araştırmanın bulguları, doğal havalandırma kapsamında tek ve orta katlı ofis binasının yarı hacmi atriyum olduğunda ve güney-doğu yönü ile maksimum kullanıcı konforu sağlanabilmektedir. Mekanik havalandırma kullanıldığında ise 1/3 ile 1/4 atriyum ile ofis oranı ve merkezi atriyum-tek katlı bina, kuzey-doğu ile orta katlı bina olduğunda maksimum kullanıcı memnuniyeti sağlandığı görülmüştür. Ayrıca, doğal havalandırmalı yüksek katlı bina için ofis hacminin 1/4 oranında kuzey-doğu yönünde atriyum tasarımı ile 1/3 oranında mekanik havalandırmalı merkezi konumu olan atriyum tasarımı olduğunda her iki senaryoda yıl bazında tüm diğer simülasyonlar içerisinde en fazla ısıl konfor sağlamıştır.

Anahtar Kelimeler: Atriyum Hacmi, Atriyum Oryantasyonu, Doğal Havalandırılmış Bina, Mekanik Havalandırılmış Bina, Sıcak ve Nemli Iklim, EDSL Tas.

DEDICATION

To my lovely Family...

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INTRODUCTION

In recent years, building thermal performance has emerged as an important consideration in the building sector, especially in the early design stage. Presenting a suitable internal climate condition (thermal condition) is important and necessary for the success of the building, not only in terms of users' satisfaction but also determine the energy usage of the building. On the other hand, the overuse of energy supplies that produced global concern has created awareness of the need to apply strategies for diminishing and controlling energy consumption (Nicol & Humphreys 2002. Lotfabadi, Alibaba, and Arfaei 2016).

For the building sector, investigating a solution for decreasing energy usage using passive strategies without considering occupants' comfort cannot be useful and beneficial (Kini, Garg and Kamath 2017). Consequently, as the building sector accounts for approximately 40% of energy usage, assessing the effective parameters of building energy performance is an important issue (Ghasemi et al. 2015). For instance, buildings with an office function account for a significant amount of energy consumption and thus play an important role in national and regional energy usage patterns (Mikulik, 2018). The Heating, Ventilation, and Air conditioning (HVAC) system is responsible for the majority of energy used in buildings for generating thermal comfort and needs to be considered a problem in any attempt at reducing energy consumption (Kini, Garg and Kamath 2017. Sudan et al. 2015). Virtually all phases building generates some form of environmental pollution and affects ecological balance, leading to a focus on the need for a new design strategy to solve these problems. Accordingly, this can be achieved by focusing efforts on increasing energy-saving while simultaneously improving the quality of internal thermal comfort (Bellia et al. 2016).

The buildings sector consumes massive amounts of energy, thus the use of un-renewable energy sources and producing greenhouse gases causes problems worldwide (Hung & Chow 2001). Accordingly, renewable sources can be a suitable strategy. Building openings as windows has an important and effective role in building energy usage (Hee et al. 2015). Regarding this point, natural light has a significant role to play in decreasing the total cooling energy amount as it generates less heat per unit of illumination than artificial lighting and can easily be used as a replacement for artificial lighting (Ghasemi et al. 2015).

Consequently, for assessing building thermal performance it is vital to use the acquired physical model which is described as the real phenomena (Hawila & Merabtine 2020). Simulation and analysis software can be used as a way of analyzing possible solutions. By simulating the building, it is possible to investigate the energy performance and thermal comfort of the building. Building performance has both a direct and indirect impact on energy consumption, energy costs, and greenhouse gas emissions, and so designing the appropriate model is an important consideration (Albatayneh, Alterman & Moghtaderi, 2018). By containing different technics as dynamic simulation and statically models can provide adequate results without wasting cost, time, and built real building, with presenting details of advantages and drawbacks (Hawila & Merabtine 2020).

In the building sector, the atrium can be classified as a passive green design strategy due to its incorporation of a proper environmental approach, natural light, and energy-saving into the building (Hung 2003. Wang, et.al 2017). Atriums have become a substantial part of contemporary architectural design styles, capable of responding to environmental problems. Atriums have the potential for bringing natural light into the deep areas of a building, including office buildings (Rezwan, 2015). The important issue in the design stage of the atrium, especially in a hot and humid climate, is the consideration of the heat gain indicators (overheating) (Galal, 2019). In terms of thermal performance, compact building forms have performed better; however, large volume buildings can increase the amount of light permitted into the building using an atrium (Laksmiyanti, & Salisnanda 2019).

A considerable point in the use of the atrium as part of a passive cooling strategy is that the air movement generated is buoyancy-driven and consequently performs weakly in a hot and humid climate; consequently, it needs to be integrated with other strategies. An alternative solution for preventing solar heat gain involves changing the physical attributes of the atrium and applying a hybrid condition. (Moosavi, Mahyuddin, & Ghafar, 2015. Ray, et.al 2014). Thermal performance in the atrium building can be a controversial issue in a hot and humid climate. The atrium building had a discomfort condition for users, in the hot climate especially in the top glazed part of the top floor atrium due to its high-temperature stratification, Moreover, this problem still exists when controlling only for solar gain. Additionally, the size of the surface of the atrium building has been direct relation to increasing the discomfort internal conditioned accordingly (Abdullah, et.al 2009). The center atrium building which just the atrium roof changed between top-lit and side-lit in a hot and humid climate depicted that the atrium with a top-lit roof had a more severe overheating problem than the side-lit atrium roof type (Baharvand, et.al 2013). In the hot and humid climate, the atrium building had a serious overheating issue, especially in the upper level, which caused discomfort conditions for occupants, while the roof of the top-lit atrium had a 36.82^{o}C to 39.08^{o}C air temperature, the side-lit atrium had about 30^{o}C in all atrium zones (Baharvand, et.al 2013).

Accordingly, a side-lit atrium (side opening) provided a better performance (users' comfort) in the hot and humid climate. Furthermore, overheating and temperature fluctuations were the most problematic issues for the atrium in a hot and humid climate, especially in the low building volume (Baharvand, et.al 2013. Liu, Lin, & Chou, 2009. Abdullah, et.al 2009).

The semi-attached atrium with a single-floor natural ventilation model without any side-lit in a Mediterranean climate, with the atrium in the north-east and south-east placements, provided thermal comfort while all windows were opened at 25% and 50%. Although there was no thermal comfort during warm seasons in the atrium building with the same design parameters at different orientations and all windows opening ratios. However, in terms of the energy performance as 25% and 50% opening ratios have approximate average in heat loos and remarkable contrast in heat gain in both atrium placements models (Aram & Alibaba 2019). As another point regarding the window to wall ratio, 40%, 60%, and 80% are generally used as acceptable ratios for the atrium building in a hot and humid climate, although there is no optimum recommendation for the window opening ratios for this climate based on the thermal performance (Tabesh & Sertyesilisik 2016).

While the application of a hybrid internal system that can fill the gap of the cooling strategy and reduce the total energy load is an important issue for atrium buildings, the buoyancy-driven nature of using natural ventilation in maintaining the indoor air quality for the users remains a major problem (Wang, Huang & Cao, 2009). Thus, as mechanical indoor conditioned has the same issue for instance the estimation of cooling load in atrium building can be complex thermal phenomena (Pan, et.al 2010). So, the proper atrium design can be used with the combination as a technical solution for generating thermal comfort solved the problem as passive (natural ventilation) and active performance (Drapella-Hermansdorfer & Gierko 2020).

As an example, the vertical temperature in large spaces such as an atrium needs to be investigated in order to propose a suitable ratio for the openings (Wang, Huang & Cao, 2009). Also, the passive strategy as a shading device has highlight effects into the building thermal performance but integrating the suitable shading device ratio with windows opening of buildings needs to be defined in the early design stage for hot and humid climate (Alhuwayil, Mujeebu, & Algarny, 2019). As another point, the atrium of a multi-story building with an office function incorporating a vertical space design for natural ventilation using a solar chimney caused controversial design issues as to the proper dimensions, the challenge of airflow, and heat interaction between different building zones (Acred & Hunt 2014).

From an energy efficiency perspective, determining the atrium shape can predict the cooling and heating loads. Thus, the shape of the atrium can directly affect energy consumption in different climate conditions. For instance, in cold and hot-arid conditions, the elongated, narrow, and rectangular atrium type performed better than other atrium shapes. Although the length to the width and height ratios are the most effective design parameters (Ahmad & Rasdi, 2000. Aldawoud, 2013).

1.1 Problem Statement

In a hot and humid climate, using the atrium as a transitional space and semi-opened area in the building can be a useful climatic strategy provided the related design issues are resolved. Despite the advantages of atriums, such as converting natural light, natural ventilation, visual comfort, etc., they also involve design problems, such as overheating (excessive resultant temperature), glare, and high solar gain, which all lead to a rise in energy demand of the building. Temperature fluctuations in the building also get progressively worse with each increase in the building floor, leading to massive discomfort conditions for users on the uppermost floors. As the atrium building size increases from a single-floor to medium and high-rise buildings, the surface for transferring heat between the indoor and outdoor environments also increases, especially due to the transitional space provided by the atrium. Consequently, its accurate placement in either the center, north-east, north-west, south-east, or south-west of the building can affect thermal comfort and energy performance during the year. The present study attempts to address the problem of the optimal atrium placements and proportions for single, medium, and high-rise buildings in a hot and humid climate specifically for semi-attached and center atrium types.

Another important problem related to the use of an atrium for natural ventilation in the hot and humid climate involves the high risk of an indoor discomfort situation due to external heat and solar penetration. As such, the passive performance in the atrium building for this climate requires a suitable ratio of external facade window openings. An understanding of the optimum window opening ratio is vital because the ratio is responsible for the degree of air movement and can change the indoor temperature, thereby providing indoor thermal comfort in the atrium and adjacent zones. In terms of energy performance, zone heat transfer and filtration or ventilation also rely on the openings of the building. Thus, building window openings that allow solar penetration cause increased heat gain and remarkably affects indoor temperature, leading to an increase in energy demand for cooling indoor zones as needed for providing thermal comfort. Although, thermal performance in the atrium can also be improved by installing shading devices. In addition to the different configurations of the atrium, all of which need to be defined based on the climate and indoor thermal system for each project, the adjacent spaces conditioned with the atrium also need to be defined and linked to the atrium design model. This requirement reveals another important problem resulting from the lack of atrium related guidelines for the passive, active, or hybrid performance of the building based on different design model factors and specifications on periods during which these need to apply.

All of the aforementioned parameters directly rely on the indoor conditioning system, which could be either mechanically conditioned or in a natural ventilation condition. One valid solution used in the mechanical indoor condition is air conditioning (HVAC); however, while applying this condition is necessary for this climate, the yearly requirements for how much and during which time remain undefined. Atrium thermal performance remains a controversial issue for the hot and humid climate. Furthermore, thermal comfort and energy performance need to be considered simultaneously to provide a maximum level of users' thermal satisfaction in the long term while minimizing energy usage in the atrium building. Consequently, there is a need to rectify the lack of knowledge about the impact of different design parameters and the internal conditions of atrium building on the total thermal performance.

1.2 Research Hypothesis

The hypotheses of this research are as follows:

- The design parameters of the atrium building directly affect the thermal performance of the building during a year.
- The placement of the atrium in the building plan, window opening ratios, atrium proportion, and atrium shading device ratio are important factors in determining the internal condition system of the building.
- The suitable selection of atrium proportion and placement (orientation) can decrease energy demand due to heat loss and gain throughout a year.

1.3 Thesis Objectives

The current research objective focuses on the thermal performance of atrium buildings located in a hot and humid climate in determining a practical strategy of atrium design based on various parameters using a hybrid internal building condition during a year. Consequently, the fundamental objectives of this research are to:

- Determine the optimum proportion for the atrium in single, medium, and high-rise buildings according to thermal performance.
- Illustrate the suitable atrium placement in the building, such as center, north-east, north-west, south-east, and south-west, for providing acceptable thermal performance.
- Define the suitable atrium internal condition for the single floor, medium, and high-rise buildings based on the users' comfort.
- Determine the optimum window opening ratios for the atrium building.

1.4 Significance of the Research

This thesis contributes to enrich the sufficient information according to thermal performance in the atrium building based on the different design variables, which are used to determine the conditions for optimal thermal performance of the atrium building in a hot and humid climate for each dynamic simulation scenario. The findings of this research can be utilized in the creation of a useful document of information for field related students, architects, and researchers alike.

Furthermore, the results of the current thesis can be used in determining the suitable atrium building design for the hot and humid climate based on the different design parameters, which include the atrium proportion, placement, building height category, window opening ratios, shading device ratios, and indoor thermal condition. Importantly, the thermal performance methods used in this thesis can fill the gap in the lack of atrium design information based on microclimate, and can also be applied and further developed for various other atrium building configurations and climate conditions.

1.5 Research Scope and Limitations

1.5.1 Scope of the Research

In terms of its scope, this research investigates the thermal performance of the atrium building, specifically in the hot and humid climate of Famagusta, North Cyprus. All of the atrium building cases are categorized as either single, medium, or high-rise, for which the atrium parameters of proportion (1/2, 1/3, and 1/4), placement (five main building plan direction), and shading device ratio (percentage) have been changed accordingly. Furthermore, the total window openings ratio (percentage) and indoor conditions for the building were also alternated between natural ventilation and basic air conditioning. The measurement parameters consist of thermal comfort methods (Adaptive, PMV, and PPD), and energy performance (BHT, MRT, Infiltration ventilation) factors.

1.5.2 Limitation of the Research

All of the dynamic simulation models analyzed in this thesis were based on the hot and humid climate. Additionally, all of the building construction materials are the same for the whole simulation and analysis process. The properties of opaque and glass construction thermal mass for all of the atrium simulation models are also the same. However, the atrium volume, orientation, and window opening ratios of the atrium and office zones were changed accordingly to propose the optimal results for each scenario. Furthermore, the shading devices were applied just over the external atrium facade and up to 50% on each facade. The atrium towers in all simulation models have a 1-meter height over the atrium zone.

The thermal comfort parameters of active performance (basic air conditioning system) and passive performance (natural ventilation) were analyzed based on the ASHRAE 2018, ISO 7730: 2005, and EN 15251: 2007 standards. All of the parameters used in this research include the Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD), and Dry Bulb Temperature, for the thermal comfort analysis section, and the Infiltration/ Ventilation gain/ loss, Building Heat Transfer (BHT), and Mean Radiant Temperature (MRT) for the energy performance analysis section. The fire and smoke spread parameter of all of the simulation models are not considered in this research.

1.6 Research Methodology and Structure of the Thesis

A multilayered methodology is deployed in conducting the results and discussions. This thesis utilizes a quantitative method; therefore, descriptive statistics are used in developing the samples and proofing them, while deductive analysis is used subsequently. In Figure 1, illustrating the outline process of this thesis.

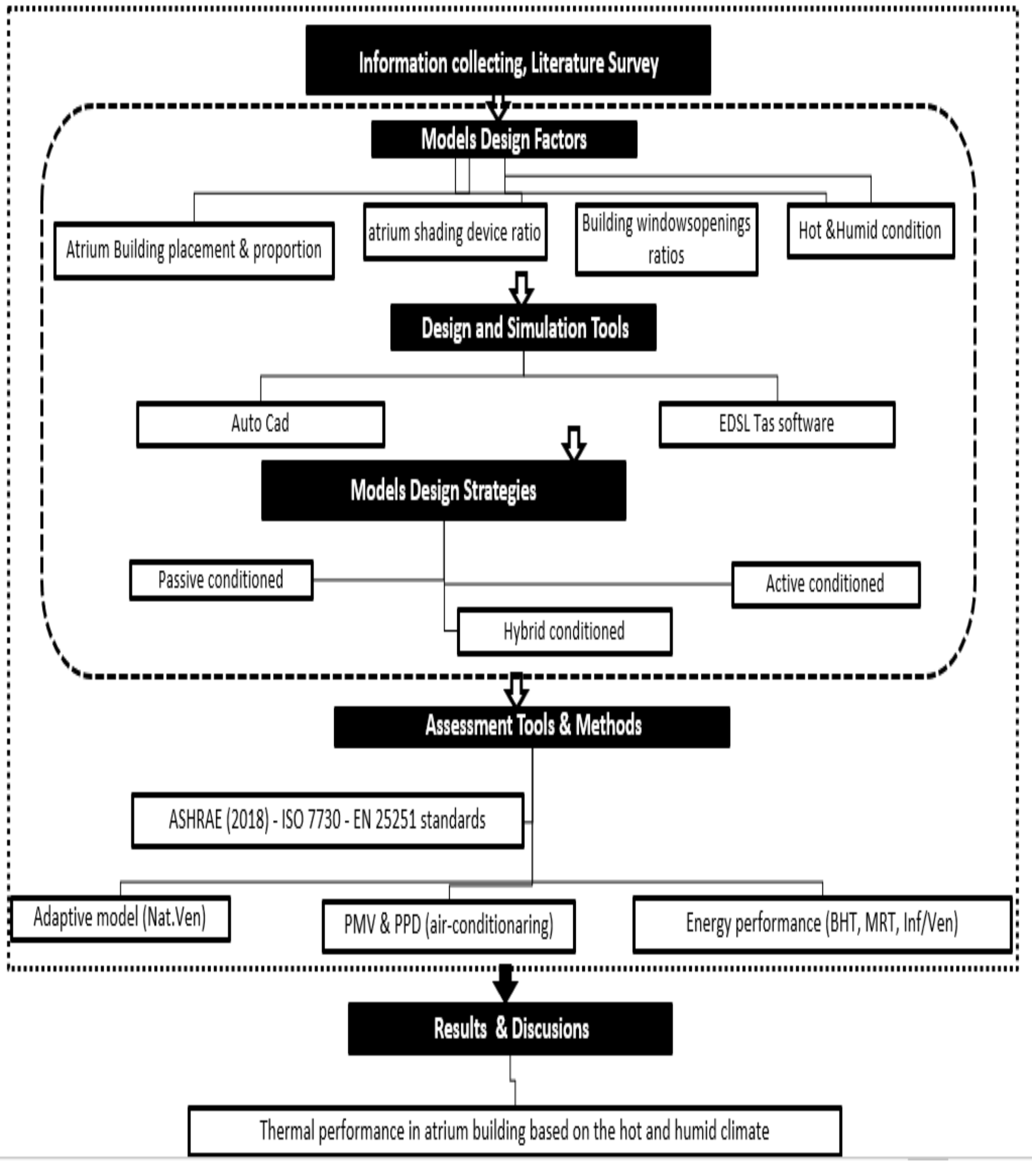


Figure 1: Structure of the thesis process.

The structure of this thesis process consists of different parts. At first, the information collection was done in the form of a literature survey applied to investigate the substantial research objectives, keywords, and parameters. Library studies and web searches were utilized in uncovering the necessary information. The data collection has been classified as chapter 1 in the section of explaining the problem background, chapter 2 up to chapter 4 explaining this thesis subject. In the next part, by distinguishing the stages and steps for generating the dynamic simulation model as the atrium building based on different atrium design factors (placements and proportions, window opening ratios, and shading device ratios), which were all tested in the hot and humid climate conditions of Famagusta, North Cyprus, an island in the Mediterranean Sea lying at 35 Latitude and 33 Longitude (AbuGrain & Alibaba 2017).

The tools used for designing and simulating all the cases included the following computer software: AutoCAD (AutoCAD, 2018), and EDSL Tas 9.4.4 (EDSL Tas, 2019). Furthermore, the model design strategies consist of passive performance (natural ventilation), active performance (basic air conditioning), and the final stage for determining the proper model as hybrid indoor conditions. Assessment tools and methods: ASHRAE (2018), ISO 7730, and EN 25251 standards, were subsequently applied for all of the dynamic simulation cases. In the last part, by evaluating all information of chapters, analysis stages result and discussions, the illustrative finding of thermal performance in atrium building based on the hot and humid climate was presented.

Chapter 2

THERMAL COMFORT AND ENERGY PERFORMANCE

2.1 Thermal Comfort and Scale

Thermal comfort involves more than the mental perception of physical environmental parameters (ASHRAE 2018. Pitts 2013). Thermal comfort is an important element for the designer and the building owner, necessitating the knowledge and analysis of the human bio-climate, which consists of the thermal comfort and the climate (Morillon-Galvez et al. 2004). Alternatively, the thermo physiological view of comfort involves the firing of a thermal receptor in the hypothalamus and the skin. From this perspective, comfort is defined as the condition for which the minimum rate of signals from the receptors was received (Mayer, 1993. Hoppe, 2002). ASHRAE Standard 55 defines thermal environmental conditions for human occupants as the combination of the indoor environmental space and personal parameters. Consequently, a thermal comfort condition is considered when the average satisfaction of occupants in the space is at least 80% (ASHRAE 55, 2017. De Dear, Brager, 2002).

Human thermal comfort refers to the degree of satisfaction expressed within a thermal environment. This definition highlights the importance of “mental condition” and “satisfaction”, two variables consisting of many parameters that affect the psychological, and physiological of thermal comfort (ASHRAE Standard 55). Environmental factors such as indoor parameters are affected by humans’ functions as received by the nervous system (Bluyssen, 2013). These factors are referred to as indoor environmental quality (IEQ). IEQ consists of air quality, heating, cooling, lighting, etc. (ASHRAE Standard 55. Geng, Lin, & Zhu, 2019). A thermal comfort scale denotes the degree of comfort, which ranges from -3 cold to +3 hot based on the ASHRAE standards. A more recent paper proposed an extension of the ASHRAE-based scale ranging from -10 very cold, to +10 very hot. This extended thermal scale rating can cover and assess more degrees for users as his or her thermal feelings express (Antonio Faria, et.al 2016).

2.1.1 Thermal Comfort Models and Concept

In the thermal comfort model, it is vital to consider Indoor Environmental Quality (IEQ) in assessing users' comfort. The thermal comfort models distinguished as Fanger model, adaptive model, PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied), UCB Model (Upper Confidence Bound), and the Physiological and Psychological Model (Antonio Faria, et.al 2016). According to Figure 2, the scale of the human feeling sensation ranges from -7 very cold to +7 very hot. Users' comfort conditions throughout different temperatures and indoor environmental factors are defined by this range. This range can be divided into cold, cool, slightly cool, neutral, slightly warm, warm, and hot, in describing the personal sensation (Schweiker, et.al 2020).

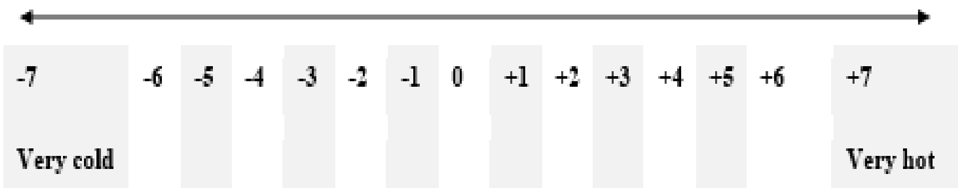


Figure 2: Proposed scale for assessing persons' thermal feelings (Antonio Faria, et.al 2016. Reproduced: by author).

According to the standards, human thermal sensation relates mainly to the users' thermal balance. This human thermal balance occurs as a result of clothing and physical activity. Furthermore, environmental factors such as the mean radiant temperature, air temperature, air humidity, and air velocity all influence the comfort balance (ISO 7730, 2005. EN 15251, 2007).

2.1.1.1 Fanger Model

Regarding human thermal balance, the comfortable temperature rate for human skin optimal sweat, and exhausting rate were utilized by Fanger in establishing a heat balance equation and an index called PMV, which depicts the thermal sensational index generated by the combination of the environmental parameters (Fanger & Melikov 1989). To do this, Fanger utilized four main physical variables: radiant temperatures, air temperature, relative humidity, and air velocity, as well as personal variables like clothing and activity. Formulae of Fanger for calculating the PMV and PPD are: (ASHRAE 2018. Chowdhury, Rasul, & Khan 2008).

PMV = 3.155 [0.303e-0.114M + 0.028] L

PPD = 100 – 95e [-(0.03353PMV4 +0.2179PMV2)] (ASHRAE 2018).

The mean comfort vote is changed less by the indoor temperature from climate to climate than might be expected. Furthermore, adaptive thermal comfort is important for providing the most functional temperatures in the building zones (Nicol, Humphreys, 1973. 2002). The other important factor which has a direct effect on indoor thermal comfort is the building envelope. Due to the varying format of the envelope and the heat gain, it is necessary to maintain a stable thermal comfort (Mao et.al 2017). According to the Fanger model, predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) can predict a more accurate temperature based on the air condition in the building compared to other thermal models (Sadafi, et.al 2011) (Fanger & Toftum 2002).

2.1.1.2 Adaptive Model

The adaptive model is the linear regression that relates the indoor design temperatures or the acceptable temperature ranges to the outdoor meteorological or climatological parameters (De Dear & Brager, 1998). This method for analyzing environmental thermal comfort in naturally ventilated buildings is applied just for users whose spaces are controlled naturally and meet the following criteria (ASHRAE 55, 2017):

a. There are no mechanical systems for cooling, such as air conditioning, desiccant cooling, or radiant cooling.
b. Representative users have metabolic rates ranging from 1.0 to 1.3 met.
c. Delegate that users are free to adapt their clothes to the indoor or outdoor environmental conditions within the range of 0.5 to 1.0 clo.
d. As depicted in Figure 3, the prevailing mean outdoor air temperature is higher than 10 °C and lower than 33.5 °C (ASHRAE 55, 2017).

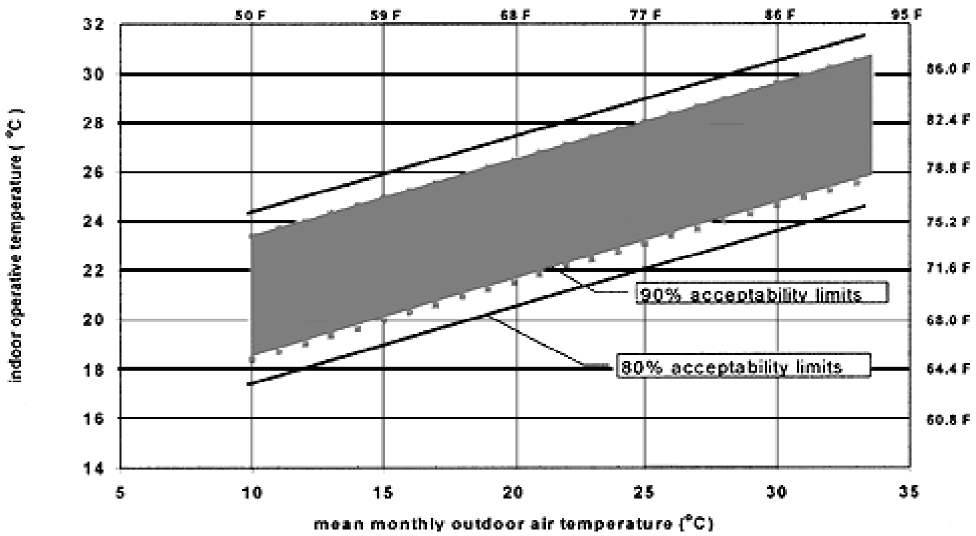


Figure 3: Acceptable operative temperature range of natural ventilation conditions of spaces (ASHRAE 55, 2017).

2.1.1.3 Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) Method

This method is used for spaces in which the users have activity ranges resulting in an average metabolic rate between 1.0 and 2.0 met and are also wearing clothing that applies 1.5 clo or less of thermal insulation. The ASHRAE thermal sensation scale: +3 Hot, +2 Warm, +1 Slightly warm, 0 Neutral, -1 Slightly cool, -2 Cool, -3 Cold, is used for quantifying people's thermal sensation and is illustrated as follows (ASHRAE 2018).

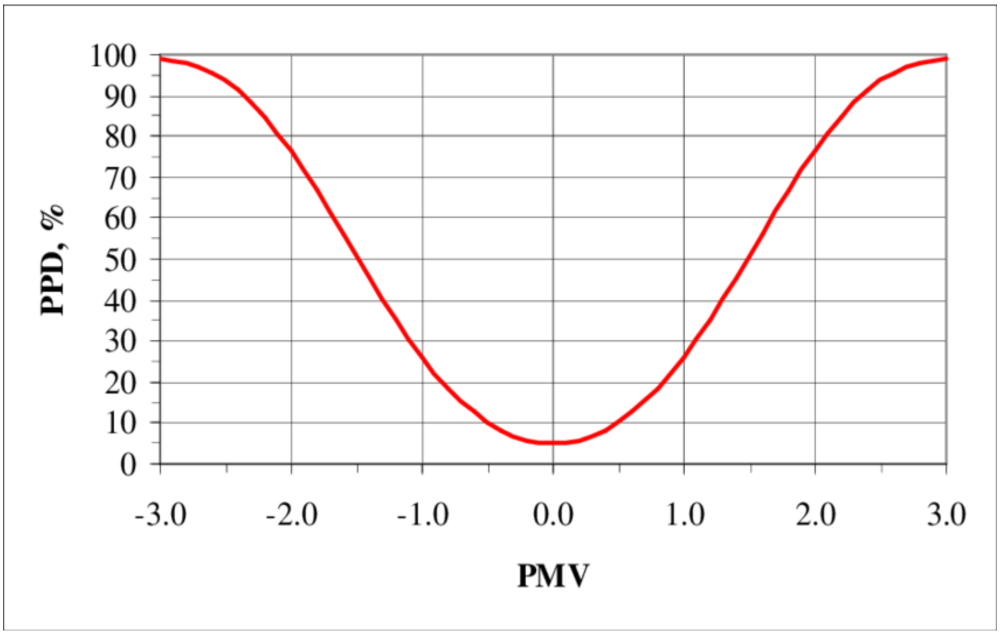


Figure 4: Predicted Percentage Dissatisfied (PPD) as a function of Predicted Mean Vote (PMV) (ASHRAE 2018).

As shown in Figure 4, the PMV method used for heat balance presents six key factors for the thermal comfort of the average response of occupants according to the above scale (ASHRAE 2018). The PMV and PPD method can be suitable for air-conditioned and free-running buildings (Zhang, et.al 2019).

2.1.1.4 UCB Model (Upper Confidence Bound)

The UCB model was developed by the University of California-Berkeley Center for the built environment (URL 1). The Berkley comfort model presents localized thermal comfort which is derived for individual body segments computed as temperature predictions of the human thermal extension as can be seen in Figure 5 which is reproduced by the author. Users' feelings based on the different conditions are represented by each point on the scale (Zhang, et.al 2010). The scales are applied to assess the personal experience of the thermal conditions in the built environment. Accordingly, it can describe the relationship between subjective thermal sensations and physical factors of the indoor environment.

Bedford 7 points scale		The extended 9 points scale (UCB) model	
		4	Very hot
Much too warm	3	3	Hot
Too warm	2	2	warm
Comfortably warm	1	1	Slightly warm
Comfortable	0	0	Neutral
Comfortably cool	-1	-1	Slightly cool
Too cool	-2	-2	Cool
Much too cool	-3	-3	Cold
		-4	Very cold

Figure 5: The UCB model which is based on extension of 9- point scale and bedford 7-point scale (Almesri, et.al 2013. Reproduced: by author).

2.1.1.5 Physiological and Psychological Model (Human Thermal Model)

The physiological model consists of a physiological mechanism that includes vasoconstriction, vasodilation, metabolic heat production, and sweating. Conduction, convection, and radiation between the human body and the environment are also included independently. In terms of comparison with the Berkeley comfort model that is based on a Stolwijk model of the user's thermal regulation, it covers substantial segments despite the fact that the physiological mechanism comprises an unlimited number of body segments. Consequently, these segments are modeled as different layers which consist of fat, muscle, skin tissues, and core, in addition to the clothing layer (Huizenga, Hui & Arens, 2001). The psychological model developed representing human multi-tasking behavior is explained. In this psychological framework, it is important that human performance is considered as a source of quantifying and identifying it (Deutsch & Adams 1995).

The adaptive model, predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) Method, commonly applied for predicting accurate analysis of the users in the building. The PMV model well works for the air conditioning system except for the natural ventilation but the adaptive model suitable for the passive internal condition because it can cover a large range of temperatures (Yang, Yan, & Lam, 2014).

2.1.2 Thermal Comfort Zone

The level of occupants' satisfaction in the building is based on indoor environmental quality (IEQ) (Godish, 2016. Wong & Mui, 2009). The indoor environmental quality influenced by the verity parameters such as sound, light, thermal environment, texture, indoor air quality, visual comfort, etc. (Tang, Ding & Singer, 2020). Accordingly, the comfort condition is the satisfaction of the mind with a thermal environment (thermal comfort zone). For instance, the predicted mean vote (PMV) and the predicted percentage of dissatisfied (PPD) illustrate that dissatisfaction can be generated by the sensation of being too cool or too warm in the whole body. The unwanted heating or cooling of a particular part of the body can also cause dissatisfaction. Also, because of individual differences, a particular thermal environment can not satisfy everybody (ISO 7730, 2005). According to the ASHRAE standard 55, the effective temperate

(ET), the thermal comfort zone is 22.8 ^oC < ET < 26.1 ^oC in the summertime, and 20.0 ^oC < ET < 23.9 ^oC in the wintertime (ASHRAE 55, 2017. Wafi & Ismail, 2008). Thermal comfort zone and factors exist and are affected by the thermal transition between the indoor spaces of the building with the outdoor environment. The common factors affecting indoor thermal comfort include heat radiation, heat convection, and heat conduction (Wafi & Ismail, 2008).

2.2 Energy Performance in Building

Energy is a fundamental motivation for development in science, national defense, agriculture, technology, and industry. Consequently, energy can be the main source material for increasing the quality of human life (Cai, et.al 2019). One common assumption about energy usage in the building sector is that the concept refers entirely to electricity consumption. However, electricity has just been one part of the total energy picture. Light and heat are two other main types of energy that are transported, utilized, and produced daily. As an example, daylight (sunlight) is a well-known energy source for harnessing electricity, heat, and light (Wright, et.al 2010). A detailed description is required for predicting building energy consumption, including: the geographical placement of the building, construction materials, outdoor weather conditions, air-conditioning system, operation schedules, and artificial lighting (Gonzalez, et.al 2011). As a common internal building system, heating, ventilation, and air-conditioning as a common account for a massive amount of the energy consumed in many countries located in a hot and humid climate (Al-Sanea & Zedan, 2008). Importantly, energy usage increases dramatically in a hot and humid climate when the mechanical system is used for cooling at lower temperatures (Saidur, 2009). Achieving energy reductions in the building sector is possible through the implementation of several proposed technical solutions relying on different building systems. However, the advantages of such solutions have not been entirely confirmed (Li, Menassa & Karatas, 2017).

2.2.1 Energy Performance Metrics

Investigating building energy performance is a necessary issue in contemporary life because building energy usage accounts for about 30% of CO^2 emissions in the world (Urge-Vorsatz, et.al 2007). Population is a key factor affecting energy metrics, which include building energy usage per capita and the building energy usage per floor space (area) (TASKGROUP, 2015).

The collection of data on the total floor area per capita is vital for combining it with the population per capita in calculating the floor per capita of building energy usage, a measurement of the building energy performance. For instance, improvements in building elements or envelopes such as insulation, optimum windows, and air sealing can decrease total building energy usage based on the building energy usage per floor area (TASKGROUP, 2015).

2.2.2 Energy Efficiency

The target of forecasting energy consumption of the building is achieving a useful policy for improving energy efficiency in the building sector (Bakar, et.al 2015). Energy efficiency plays an important role in maintaining a comfortable internal environment and decreasing cost due to controlled energy consumption (Parameshwaran, et.al 2012). For instance, energy-efficient building construction and renovating old buildings every 10 years will help store more than 4700GWH of electricity and save 2.3 million tons of CO^2 emissions up to the year 2050. Also, new buildings constructed based on an energy-efficient policy can store more than twice the energy than renovating, making it vital for developing countries to make it the priority rather than renewing older buildings (Kamal, Al-Ghamdi & Koc 2019).

2.3 Thermal Comfort and Energy Performance

Thermal comfort is more achievable when considering energy efficiency based on un-uniform thermal conditions rather than uniform conditions in an environment (Cheng, Niu & Gao, 2012). A controversial issue worldwide in the building industry is energy reduction and improving indoor thermal comfort. Buildings protect their users against outdoor weather conditions by providing indoor thermal comfort conditions. Nowadays, the main common method for generating thermal comfort is the mechanical system, used for heating, ventilation, and air-conditioning for inside the building (Vesely & Zeiler 2014).

Thermal comfort requirements are prescribed by standards such as ASHRAE standard 55 and ISO 7730, all of which are based on the average values of large groups participating in laboratory conditions (Vesely & Zeiler 2014). This method, however, causes significant energy usage and is consequently costly (Vesely & Zeiler 2014). Unsuitable thermal conditions not only affect users' well-being and productivity directly but also influence the operation and level of building energy consumption (Atzeri, et.al 2016). Accordingly, the large consumption of the energy used in thermal comfort. For instance, the active conditioned (air conditioning building) caused the variation of heating or cooling requirements in different climates or regions (Yang, Yan, & Lam, 2014).

In terms of the relationship between energy efficiency and thermal comfort, mechanical energy usage systems are used to provide warm or cold conditions in indoor spaces, as well as facilitate ventilation which provides thermal comfort (Wafi & Ismail, 2008). Also, the temperature in one effective and common factor in both thermal and energy dimensions (Sun, et.al). Distinct from temperature, indoor air quality plays an important role in building users' thermal comfort. Consequently, good indoor air quality results in a healthy indoor environment. Conversely, poor indoor air quality causes different problems, such as sinusitis, eye irritation, allergic reactions, etc. As such, certain parameters need to be considered to integrate these points and indoor air quality, such as source control, infiltration, and ventilation (Wafi & Ismail, 2008).

The indoor environment quality (IEQ) in an office building, for example, plays an important role in occupants' productivity. Consequently, a high amount of energy is used in heating, cooling, lighting, etc. For generating the maximum level of IEQ (Geng, Lin, & Zhu, 2019). The window is a fundamental and important element in office buildings. Also, windows are often the most important factor affecting office building energy consumption, generating thermal comfort, and optimum illumination. Employing an efficient window design can decrease a massive amount of unwanted solar heat and also permit a satisfactory level of natural light into the office building (Huang, Niu, & Chung, 2014) A combination of natural lighting with artificial lighting can reduce the total energy consumption in office buildings. For instance, applying daylight into the office building sector can save 20% to 30% of the electricity used just for lighting (Kheiri & Arch, 2013). The important design alternatives in an office building included transitional spaces, glazing systems, building shape and orientation (especially for the hot and humid climate where the south facade of the office building is important for thermal performance), building schedule, building envelope, and building infiltration (Al-Homoud, 1997).

PMV (Predicted Mean Vote) and PPD% (Predicted Percentage of Dissatisfied) based on ASHRAE standard 55, EN 15251 and ISO 7730, can provide an accurate model for evaluating the thermal comfort conditions of heating, ventilation, and air-conditioning (HVAC) system since the resulting method is generated according to the average of occupants in the mechanical condition. Furthermore, thermal comfort metrics such as the Predicted Mean Vote (PMV) include variables like clothing insulation and metabolic rate (Rana, et.al 2013), and so applying these points can generate more reliable and suitable results. The adaptive model of ASHRAE standard 55 used in assessing thermal comfort for naturally ventilated building conditions is accurate for this research and the 80% and 90% acceptability limits. The models used in evaluating thermal comfort include an adaptive model to cover natural ventilation because they necessarily include the acceptable limit conditions, which the adaptive model clearly illustrates. The PMV (predicted mean vote) and PPD% (predicted percentage of dissatisfied) for mechanical conditions using heating, ventilation, and air-conditioning systems have a suitable sensation scale for analyzing occupants' average indoor thermal comfort.

2.4 Indoor Environmental Parameters Involved in Thermal Performance

The indoor environment criteria in building design rely on occupants' comfort, health, and productivity, which all have direct effects on building energy consumption. Any energy statement without consideration of the indoor environment makes no sense. The European Directive for Energy Performance of Buildings (EPBD) recommends that the energy saving of building must not sacrifice the users' health and comfort. Furthermore, it characterizes the value of building design in the indoor environment based on environmental comfort and energy consumption (Olesen, 2007). The environmental quality factors distinguished as physical and non-physical parameters. The physical parameter consists as internal thermal comfort (which including air temperature, relative humidity, globe temperature, and air velocity), indoor lighting (such as luminance level and glare index), acoustic environment (as sound level) and air quality (that consist: CO_2 concentration, $PM_{2.5}$ concentration, formaldehyde, and volatile organic compounds) (Clausen & Wyon, 2008. Geng, et.al 2019). Consequently, those parameters that affect building thermal comfort include light, acoustics, visual comfort, materials, and texture. Accordingly, the building envelope has the same important function for the indoor environmental parameters as the building parameters since the building envelope affects the physical condition of the indoor environment, including light, sound, and heat (Oral, Yener, & Bayazit, 2004). The un-physical factors in the IEQ area can be mention as the privacy, space layout, furnishing, facilities, cleanliness, and view (Geng, et.al 2019). For this research, the physical factors of the indoor environmental quality applied for proposing a proper thermal performance model limited as section 2.4.1.

2.4.1 Indoor Temperature, Air and Ventilation Quality

The temperatures of thermal comfort are different between men and women, and also range differently based on the internal condition system of the building (Maykot, Rupp & Ghisi, 2018). Experimental research using the Griffiths method found that the suitable comfort temperature in an office building is 24.0 °C for females and 23.2 °C for males. However, in a building with a mixed-mode internal condition, the comfort temperature is higher for females (23.7 °C) than for males (23.0 °C) (Maykot, Rupp & Ghisi, 2018).

Furthermore, in a fully air-conditioned internal building system, the comfort temperature difference was found to be 24.2 °C for females and 23.4 °C for males. It is noteworthy that when the internal building condition changed to natural ventilation, the comfort temperature range became lower for females and males in comparison to other internal condition systems with the same building operations (Maykot, Rupp & Ghisi, 2018).

Ventilation system energy requirements are considered specifically when calculating energy usage for the design load. The ventilation system starts before users to provide acceptable indoor air quality (Olesen, 2007). Ventilation can be defined as the process of supplying clean (fresh) air to users in enclosed (indoor) spaces. As such, the acceptable indoor air quality (IAQ) is explained as air that is without any pollutants, induce sickness, or discomfort the occupants (Wafi & Ismail, 2008). Because the hours of ventilation system usage can exceed user hours, the building operation pollutants are often generated. As such, the level of infiltration applied in this condition is one of the factors used in calculating indoor ventilation and air quality (Olesen, 2007).

2.5 Environmental Factors Determining Thermal Comfort

2.5.1 Mean Radiant Temperature (°C)

Mean radiant temperature (MRT) is the parameter that measures an occupant's perception of the radiant temperature in the space. MRT is calculated as the weighted average of the space surface temperatures, modified by the influences of radiant gains (plant, incidental gains, and the diffuse component of solar gain). MRT is illustrated in degrees Celsius (EDSL Tas, 2019).

2.5.2 Temperature (°C)

Temperature is the intensity or degree of internal heat (Dictionary & Idioms, 1989). The temperatures included in this research are the dry-bulb temperature and resultant temperature. Dry bulb temperature is measured in degrees Celsius, while the resultant temperature is the average of the mean radiant temperature and the dry bulb temperature, also illustrated in degrees Celsius (EDSL Tas, 2019).

2.5.3 Infiltration Ventilation Gain (W)

Infiltration ventilation gain illustrates the heat gained (as negative, lost) by space throughout the air exchange between the indoor spaces and the outdoor environment. This air exchange may arise from air flows specified under infiltration or ventilation in the indoor environment, caused by either aperture flows or air movement and is represented in Watts (EDSL Tas, 2019).

2.5.4 Building Heat Transfer (W)

Building heat transfer is measured in Watts and illustrated as the sum of two sources of heat gain:

1. Heat entering a zone from a null link, link, or internal building component.

2. The heat released into the zone which has been temporarily stored in the air (positive when the air temperature is falling, negative when it is rising) (EDSL Tas, 2019).

2.6 Chapter Summary

This chapter described the thermal performance as the main subject of this study based on the two dimensions which are thermal comfort and energy performance. As an outcome of this chapter can mention that a thermal comfort is an important approach in the building sector which is defined the building energy performance. Accordingly, it needs to be considered a useful method for assessing indoor users' conditions for reaching acceptable thermal performance. Then, Thermal comfort has been defined and its scale explained according to the relevant international standards for reaching the suitable model for evaluating users' satisfaction, and the different thermal models and concept were also interpreted and then thermal comfort zone was also presented. After illustrating the different methods for predicting users' thermal comfort, the methods selected for this thesis consist of the predicted mean vote (PMV), predicted percentage dissatisfied (PPD) model, and the adaptive model because these methods can jointly provide reliable and comprehensive results for this research and covering the thermal range accordingly.

Additionally, this chapter defined energy performance in the building based on its fundamental points and metrics used for selecting the important factors in this area as using for this research. Consequently, as an important parameter in the energy sector, it explained the concept of energy efficiency and factors in the building. In reaching the thesis literature target, thermal comfort and energy performance were investigated in the same approach, subsequently distinguishing between the different indoor environmental parameters based on the physical and un-physical factors in thermal performance for reaching the substantial points. So, the relevant and proper factors as the same outline for this research selected were explained, including: the indoor temperature, air, and ventilation quality in the building sector. The last section explained and clarified the environmental factors determining thermal comfort, such as the mean radiant temperature, temperature, infiltration ventilation gain, and building heat transfer which all been used as the analysis factors in the atrium models. Furthermore, in the next chapters, all bold point achievement of this chapter study has been investigated in the atrium building based on this thesis title.

Chapter 3

ATRIUM BUILDING IN HOT AND HUMID CLIMATE

3.1 Concept, and Context of Atrium

Atrium spaces emerged as one of the architectural styles used to resolve environmental issues (Rezwan, 2015). Consequently, it has become unusual for major building developments not to include the atrium area (Sharples & Lash 2007). The bold dimensions of the atrium allow light into dark and deep corner spaces, especially in office and commercial buildings. As a common sustainable strategy, atriums are often used by engineers and architects due to their many advantages, which include ventilation, passive cooling and heating, and daylighting. Additionally, atriums have a direct effect on building energy consumption as well as decreasing the usage of artificial lighting. (Rezwan, 2015). Historically the “atrium” was used in Roman Houses for the central open area to the sky. The atrium in the Roman House was as semi-public space with a central courtyard and connects to the main entrance space. However, it was designed as completely isolated from the outside with some interaction spaces (Hung & Chow 2001. Modirrousta & Boostani 2016).

3.1.1 Atrium Typology and Alternatives

The atrium typology is based on buildings that are at least two stories high, which have an open or enclosed space with a roof and vertical volumes. Moreover, the atrium can be as a public place which is surrounded by usable spaces; this area has flexible functions for users, including meeting, walking, resting, and waiting. This buffer zone generates the vertical and horizontal circulation layers of the building, consequently requiring excessive loads of energy to provide thermal comfort (Hung, 2003.Yasa, 2017). Atriums can be categorized into four general forms according to Figure 6. The first type is the centralized atrium. This type of atrium has a centralized glass courtyard, which is located in the center of the building and is surrounded by a glass roof. The second type is the semi-enclosed atrium, in which the glass space is within the building but one of its sides is on the exterior surface of the building. In this type of atrium, the roof can be either made of glass or be open. Another type of atrium is the attached atrium, which is constructed outside the exterior walls of the building and is in contact with the outside space from three sides. The last type is the linear atrium, which is located in an area between two separated blocks with glass walls on two sides. Closed atriums are more frequently used in cases where the area of the building is massive, or there is no or a limited possibility of using the southern sides of the building (Modirrousta & Boostani 2016).

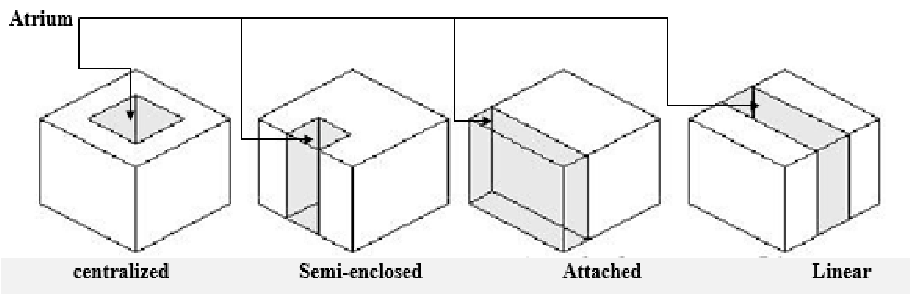


Figure 6: Atriums Types (Yunus, Ahmad & Zain-Ahmed, 2010. Reproduced: by author).

3.1.2 Atrium Development Throughout Centuries

The shape of the atrium changed during different periods, which can be divided into four main groups: the early 19th, late 19th, early 20th, and late 20th centuries (Saxon, 1983). Atriums in the early 19th century were developed in western countries where a new generation of advanced technology including glass and iron, was used in the construction of the modern atrium. During the late 19th century, a new form of the atrium emerged which used more daylight and was dominant in America. Subsequently, in the early 20th century, the four-sided atrium was designed and built to introduce filtered air into the building. Furthermore, in this period the definition of the atrium changed from a development shelter to a technological construction. In the late 20th century, the enclosed atrium emerged; it included three sides covered with glass to enhance natural light with the last side facing the external view. Furthermore, because of the focus on multi-level buildings like shopping malls, shifting from the horizontal galleria space to the vertical atrium space provided more functional space and attracted more attention with higher levels of user satisfaction (Saxon, 1983. Ahmad & Rasdi, 2000. Hung & Chow 2001). In this century, the merits of the atrium can be categorized based on their architectural, environmental, and economic aspects. Accordingly, the atrium is accepted as a green design tool (Bryn, 1995. Hung, 2003).

3.1.3 Architectural Design Aspect of Atrium and Internal Comfort

The atrium has an important and effective function for the total building. As a key element of the architectural design, the atrium comes in different forms, such as deep or narrow. Consideration of the mode of daylighting with the direction of the glare is an important issue for atriums. Other factors to be considered in atrium design include the shape of the atrium, which is an important key parameter as an excessively narrow or deep atrium design will be poorly lit. While an atrium with a wider bottom can benefit from more daylight. The higher levels of the atrium cause a particular reflectance, which increases the reflection of internal lighting (Bryn, 1993. Littlefair & Aizlewood 1998). This can be mitigated by decreasing the open spaces in the wall from the top atrium part of the glazing; reflective glazing can also be useful here. The selection of glazing areas is very important because it can gain a large amount of solar heating. The common problem with atrium areas is carrying the light into the adjoining atrium spaces. Using internal obstructions can dramatically reduce the glare of the daylight in the atrium. An investigation into a real atrium area depicted that half or more of the total light can be blocked (Littlefair & Aizlewood 1998) and effective transmittance is based on the angle of the view of the top atrium. Depending on the atrium form, controlling electrical lighting is vital because the usage of daylight in the atrium spaces is beneficial (Littlefair, 2002).

The classification of atriums is based on the atrium sides which are surrounded by the building spaces. For instance, the three side atrium models have an open end and the four side atriums are completely internal (Sharples & Lash 2007). Accordingly, the atrium has four types: the centralized atrium, semi-enclosed atrium, attached atrium, and linear atrium, (refer to Figure 6) (Hung & Chow 2001). The important parameters are the atrium type, size (proportion), and geometry (rectangular or square), all of which play an effective role in the thermal performance of the building (Aldawoud & Clark 2008. Danielski et al. 2016).

According to the atrium architectural perspective, it can be surmised that the shape of the atrium (atrium type), atrium orientation, and the glass and opening proportions of the atrium space directly affect the occupants' comfort. Actually, atrium in the building caused a decrease in the annual dwelling energy used but increased the number of discomfort hours during the summer (Taleghani et al. 2014).

The important potential of the atrium is its capacity to enhance the amount of natural light let into the building by openings and reflective materials. The complexity, however, concerns how to gradually transport daylight to the lower levels with equal intensity and optimize lighting. In particular, how the daylight quantity and different types of distribution on floors are affected by various changes in the atrium form and facade design, including establishing the glazed, optimum opaque and glazed spaces ratio based on the size and position of other elements, the usage of the daylighting systems, advanced facade and shading technologies (Samant, 2010). Natural light has various benefits, such as improving the visual quality of color features and positive psychological effects (Heschong, 1999; Freewan et al. 2014). However, it can be mention that possibilities of utilizing direct daylight inside the building instead of overusing electrical lighting (Sharples & Lash 2007. Sapia, 2013). Using natural light in indoor environmental spaces can enhance energy efficiency, lighting quality, and healthiness (Sudan et al. 2015. Mardaljevic & Christoffersen, 2017).

In atrium spaces, thermal comfort in a hot and humid climate can be distinguished via different indicators, such as the atrium dimensions, atrium type, atrium proportion to adjacent spaces, atrium decoration, lighting, density, users' lifestyle, ceiling, and floor ornaments (Kusumowidagdo, Sachari, & Widodo, 2016). The atrium throughout contemporary architecture has substantial benefits, which include environmental aspects, economic aspects, and architectural aspects, as a tall internal open area with a connection to the outside environment (Hung & Chow 2001), the atrium is typically an interior covered with glass walls or roof and surrounded via several stories. Nowadays, the atrium space is represented by its physical characteristics of fenestration and geometry, while adjacent spaces can also affect the physical characteristics of the atrium (Abdullah et.al 2009).

3.2 Atrium Building in Different Climates

The worldwide climates categorized as following: Tropical (the average temperatures are greater than18°C year-round), Dry (very dry because moisture is rapidly evaporated from the air), Temperate (mainly warm and humid summers and mild winters), Continental (warm to cool summers and very cold winters), and Polar (extremely cold) (URL 1). So according to each climate condition designing atrium needs to be considered individually. Atrium building design in the hot and arid region requires consideration of parameters different from other climates. The atrium configuration in a hot and arid (dry zone) climate for decreasing energy consumption needs to consider that adding to the number of floors can reduce the total energy performance when the atrium is placed at about 5% of the building area (Vethanayagam & Abu-Hijleh, 2019). In the hot and humid climate, the low-rise building with a centralized atrium has acceptable thermal comfort throughout cold periods but this conditioned changed in the warm periods (Aram & Alibaba, 2019).

Furthermore, in a hot climate, the atrium building height has a direct effect on building energy behavior (Vethanayagam & Abu-Hijleh, 2019). The atrium of a high-rise office building in a semi-arid climate, when the atrium is placed in the west part of the building, caused a lower annual average building energy consumption and provided indoor thermal comfort (Jaberansari, & Elkadi, 2016). An atrium building placement in a cold climate can be used to absorb direct and indirect solar energy. Consequently, the four-sided atrium can be a suitable model for receiving more radiation and the liner atrium type can be a proper model (Amani, 2018).

3.3 Atrium Design Principles in Hot and Humid Climate

The effective strategies applied to the building for heat prevention in a hot and humid climate involve the building orientation according to the sun and wind angles, the proportion of the opaque and glass surfaces of the building, the shape of the building plan and architectural building form, the thermal mass, materials, windows size and forms of the building, and surrounding vegetation (Aflaki et.al 2015). Additionally, the plan design in the hot and humid climate is an important factor, especially for multi-story buildings, as the sun angle and wind direction can directly affect building energy performance and internal thermal comfort (Mirrahimi et.al 2016). In the hot and humid climate, thermal comfort based on natural ventilation cannot just rely on stack ventilation. Actually, in this climate, stack ventilation cannot cause enough air movement (airflow) in the indoor spaces to create users' comfort (Haw, et.al 2012). It can be mention that the main design principles for a hot and humid climate are selecting suitable atrium placement, proportion, ventilation system, opening such as side-lit and windows ratios, and volume (Wang, 2012. Aram & Alibaba, 2019).

3.3.1 Atrium Issues in Hot and Humid Climate

In the hot and humid climate, thermal comfort is a serious issue. Solar radiation and air temperature are the major factors in this climate (hot and humid) which have an important effect on the building. Therefore, sun rays in this region are the primary natural source that is influenced (Sunanda, & Budiarto 2018). It can be mentioned that the effective variables in the hot and humid climate consist of solar radiation, wind, precipitation, sky condition, air humidity, and ambient temperature (Givoni, 1998). Accordingly, window orientation and size are selected based on wind and microclimate conditions. In the hot and humid climate, the window to floor ratio is recommended at 15% - 20%. The main source in the building space of heat loss or gain is the window. Consequently, the properties and U-value for preventing solar radiation from outside. Furthermore, the window design must be in such a way that a sufficient amount of daylight is permitted into the space for occupants. The parameters related to the heat gain of windows that must be considered include infiltration, convection, conduction, daylight, and radiation (Sudhakar, et.al 2019).

3.4 Chapter Summary

This chapter investigated the atrium building based on the different perspectives, including the historical background of the atrium, development throughout different centuries, and the architectural design aspect. Afterward, fundamental forms of the atrium building, it explained the environmental and thermal factors related to this sort of building. It subsequently provided an account of the architectural aspect and the model of the atrium for different climates conditions. Additionally, the atrium design principles in the hot and humid climate section specified the particular considerations for this climate and defined the atrium-related issues for this climate necessary for determining the ideal fundamental dimensions. As an achievement of this chapter can mention the important design variables such as the volume, size, and parameters that determine the indoor condition system of the atrium which is considered in the model simulation analysis for illustrating proper result. According to the impact of the atrium, the square-shaped has a better performance than the rectangular atrium type for hot and humid climate, so for this research, the atrium type has been selected based on this chapter information as a square shape with different design factors for answering the research problem.

Chapter 4

INVESTIGATION OF THERMAL PERFORMANCE IN ATRIUM BUILDING

4.1 Effective Variables of Indoor Environment in Atrium

Applying the atrium into the building can cause different effects for users. These results include natural ventilation, visual comfort, a gathering space for users, and daylight conversion. The atrium can also be a solution for heating and cooling by providing an optimum and suitable strategy. However, the atrium in the building can have a greenhouse effect, which occurs by trapping the short sunlight waves in the atrium area. As reemitting the daylight from the glass with a long wave cannot occur, this causes the temperature to increase in the indoor space. On the other hand, the atrium can cause a stack effect in the building through air movement in the form of natural ventilation from the lower levels to the upper floors (Gocer, Tavil, & Ozkan, 2006).

The use of atrium in buildings has found that the microclimate had an effective role in the indoor space condition (Nakano & Tanabe 2004). Defining the atrium placement and roof skylight opening is vital for investigating the thermal comfort and energy performance of the building (Taleghani, Tenpierik & Dobbelsteen 2014). Based on thermal performance, it has been argued that the atrium space is rarely integrated as a design parameter to help achieve the aim of energy-saving (Assadi, Dalir & Hamidi 2011). Another problem with the atrium as a glazed space in the hot and humid climate is that the glazed walls and roof can increase solar heat throughout the space (Moosavi, Mahyuddin & Ghafar 2015).

4.1.1 Passive (Natural Ventilation), Active (Mechanical) and Hybrid (Mixed-Mode) Indoor Conditions

The target of all ventilation systems is to present indoor thermal comfort for users as well as improve indoor air quality by providing fresh air and removing pollutants from indoor spaces (Almesri, et.al 2013). When investigating thermal comfort, it is necessary to compare the natural ventilation condition (NV) and the (mechanical) air-conditioned (AC) systems. The effective parameters for these internal systems (natural ventilation and mechanical condition) include building type, shape, and indoor environmental factors (Zhang, et.al 2010. Zhang. Z., Y., & Khan, 2020). When there is no outdoor wind field, the stack pressure is the only passive force that causes natural ventilation. The natural displacement ventilation occurs by raising the depth and the temperature of a warm air layer which moves to the upper level in space of the building (Holford & Hunt, 2003. Acred & Hunt 2013).

Utilizing natural ventilation in building results in several benefits, such as decreasing the total energy consumption of the building, cost, and increasing occupants' healthiness. Natural ventilation occurs through the pressure difference between the indoor and outdoor environments, as a result of wind, air movement, and buoyancy throughout the building. Natural ventilation (NV) can be a passive technique for the cost-effective performance of the building (Zhai, Johnson & Krarti, 2011). Providing the optimum quality of internal air circulation and at the same time having an acceptable range of indoor thermal comfort is important for natural ventilation conditions in buildings, especially when without any mechanical systems for Heating, Ventilation, and Air Conditioning (HVAC). Hence an acceptable natural ventilation performance can decrease energy usage (energy consumption) for HVAC, resulting in energy saving (energy efficiency) (Moosavi, et.al 2014).

Nowadays the internal condition of modern buildings is shaped as uniform, neutral, and constant thermal condition for all users by adopting heating, ventilation, and air conditioning technologies, thereby increasing energy usage (Luo, et.al 2015). This sort of energy use for mechanical indoor conditions dramatically increased energy loads in the hot and humid climate (Aflaki, Mahyuddin & Baharum, 2016). The mechanical condition system in the building for HVAC (Heating, Ventilation, and Air Conditioning) internal conditions has the highest energy consumption (Kheiri & Arch, 2013). Furthermore, the high-rise atrium building using a mechanical ventilation system has been extremely recommended due to its provision of safer indoor conditions for occupants (Alkhazaleh & Duwairi, 2015).

In the atrium building, utilizing the hybrid indoor system especially for cooling systems can incredibly decrease energy usage as well as other advantages. The hybrid system basically consists of the main two modes of air conditioning: the mechanical internal condition and buoyancy-driven natural ventilation (Hussain & Oosthuizen, 2012. Yuan, et.al 2018. Liang, et.al 2019). The benefits of the indoor hybrid building condition include providing natural ventilation and maintaining the indoor comfort level (Zhai, Johnson, & Krarti, 2011. Emmerich, 2006). It is important that the hybrid indoor system is integrated with the building design parameters, including its optimization with different building characteristics (Karava, et.al 2012).

4.1.2 Windows Opening and Shading Device Ratios

Windows are one of the elements affecting building thermal performance, due to building energy consumption for cooling and heating, and comfort (Amaral, et.al

2016). As a fundamentally free energy source, solar energy has significant effects on the internal building areas. Solar energy influences people's circadian rhythms, and physiology. Window openings are a vital aspect of indoor thermal comfort and luminosity (Xue, et.al 2019). Large openings and massive transparent spaces result in a large amount of solar heat gain and also increased heat exchange. Accordingly, the heat gain and loss via windows opening have the main impact in the indoor zones. in addition to the hot and humid climate, the ratio of the window can be an important element for taking benefits of the wind direction (Alibaba, 2016). Although, window openings in the cold and hot dominated regions have conflicting roles in terms of energy performance and daylighting. Accordingly, the proper WWR (window to wall ratio) value for the building facade and ratio of transparent areas should be carefully selected in the early step of the design process. It is proven that the WWR is directly affected by energy balance in terms of cooling and heating energy usage. For instance, adding window openings reportedly caused a 180% increase in total heating and cooling energy consumption in one instance (Fracastoro, Mutani & Perino 2002. Xue, et.al 2019). These effects are influenced by the window orientations, VT (Visible Transmittance), WWR (Window to Wall Ratio), proportion, and details (Kheiri & Arch, 2013).

Installing solar blinds has an impressive environmental effect in the indoor atrium space. The solar-blind cuts the direct radiations and defuses them. Consequently, it influences the internal temperature and mean radiant temperature (MRT). Nevertheless, these systems generate a high level of discomfort underneath the roof due to overheating in this space. Although the wall to roof void or opening can help decrease the high radiant heating, the amount of roof opening and the proper proportion still presents a problem for the atrium. Additionally, the results of the simulation building using the atrium for ventilation depicts that the side-lit models have better functions than top-lit models based on their energy performance and thermal comfort (Abdullah & Wang 2012).

The skylight or transparent roof and the ratio to the atrium definitely affect the building energy by transferring heat (Laksmiyanti, & Salisnanda, 2019). Shading devices differ and depending on the building orientation and shading percentages, influence the total thermal performance of the building (Kim, et.al 2015). However, the retractable shading system is considered an effective, economic, and simple shading device for buildings in a hot and humid climate (Wang, et.al 2014).

4.1.3 Proportion, Orientation, and Volume (Low, Medium, High rise)

The orientation of the building is one of the important issues in the building design, which needs to be considered based on solar radiation and wind direction especially in the hot and humid climate to minimize solar heat gain and maximize natural ventilation. The early stages of energy efficient building design involve the optimum selection of building orientation and placement because building energy performance is directly affected by solar radiation through the openings (windows), envelope, and opaque walls (Al-Tamimi, Fadzil & Harun, 2011). Building proportions based on the seasonal analyses depict that building height and width directly affect thermal comfort (Martinelli & Matzarakis, 2017). Also, when the building floor increases, such as in high-rise buildings, the important and effective factor is the vertical wall (Ling, Ahmad & Ossen, 2007). In the hot and humid climate, high-rise buildings are impacted by overheating issues more than other building volumes like single or medium-rise. Accordingly, the vertical surfaces received more solar radiation (Ling, Ahmad, & Ossen, 2007).

4.2 Thermal Comfort in Atrium Building

In the atrium building thermal performance when the internal condition is based on natural ventilation, there are two different categories of factors that should be considered: factors affecting thermal performance and those affecting the natural ventilation condition (Moosavi, et.al 2014). From an energy-saving perspective, while providing a full comfort situation in the atrium space needs a huge amount of energy, so by using passive strategies can do this more efficiently (Rezwan, 2015).

Adaptive and flexible thermal comfort can generate high satisfaction for occupants regarding the indoor thermal comfort of the temperature and at the same time decrease the amount of energy used for heating and cooling. If unpredicted changes occur in terms of indoor thermal comfort, users will react to their discomfort situation. So, the thermal comfort field is studying and investigating the relationship between users' satisfaction and indoor thermal comfort within their environment. However, atrium is one of the suitable places for providing thermal comfort in a building (Nasrollahi et al. 2015. Ghasemi et al. 2016. Yan, Mao, & Yang 2017. Aram & Alibaba, 2018).

Improving users' comfort in the atrium illustrates that natural ventilation can increase indoor comfort conditions. Natural ventilation as a passive cooling strategy in the atrium has received much attention as it is a buoyancy-driven phenomenon. However, the weak function of a buoyancy force has led to a consideration of this issue. Furthermore, there is another suggestion for minimizing the effects of solar heat gain by changing the physical attributes of atriums for the cold climate. Other solutions relied just on the use of a mechanical system for providing occupants comfort through cooling loads (Moosavi, Mahyuddin & Ghafar, 2015). The wall angularity of the atrium in building natural ventilation and thermal performance depicted that the atrium temperature directly affects other rooms and the thermal load. Using natural ventilation in the centralized and linear atrium can be an effective model for decreasing temperature fluctuations in the warm season (Fini & Moosavi 2016).

4.3 Energy Performance in Atrium Building

Energy has a fundamental role in human life. The current way of generating, providing, and also consuming energy is not sustainable in the long term. Using new strategies for optimization in energy usage in various stages of buildings need to be considered at every level of the designing process and building utilization. An important modern achievement is the utilization of renewable energy sources buildings, while at the same time not polluting the environment (Modirrousta & Boostani 2016).

Throughout history, natural light has been a fundamental building light source typically supplemented with burned fuels and nowadays via electrical energy sources. The atrium is the solution for harvesting light into the indoor spaces. Furthermore, using atrium spaces has a positive effect on energy efficiency and improves the internal environmental conditions against harsh outdoor conditions. Utilizing the atrium as an energy-efficient space is a suitable form; however, this sort of space should be well organized with the adjoining areas (Laksmiyanti & Salisnanda 2019). Particularly, the building roof which has a horizontal surface had the maximum solar radiation during a year in comparison with other building elements. Accordingly, it is obvious that the skylight of the atrium is an important factor in efficient building energy design. An important dimension of the successful energy-efficient building design involves reaching the maximum level of optimization in energy saving on ventilation for buildings. Also, the one-year energy usage of the building must be considered as a vital factor for building energy optimization (Laksmiyanti & Salisnanda 2019). It has been found that saving natural energy in the atrium depends on certain factors, which are (Ghasemi, Kandar, & Noroozi 2016): The sky condition and amount of outdoor daylight, The roof fenestrations and systems, The atrium well shape, type, and geometry, The atrium surface, such as floor reflectance, facades design, and walls, and the properties of areas adjoining the atrium. Overall, the shape of the atrium, its geometry, and type are important and effective factors on the total energy behavior in the atrium and adjoining areas (Aldawoud, 2013.Ghasemi, Kandar, & Noroozi 2016).

The energy performance in the atrium areas consists of dealing with the air movement, daylighting, climate, energy, glazed space, and acoustics (Tabesh & Sertyesilisik, 2015). In 1996, investigating the atrium building and glazed space which found that most atrium buildings relied on the mechanical energy required to provide a suitable thermal comfort level. As a result, there is a huge necessity for mechanical systems for heating and cooling for the whole of the year. Maintaining an appropriate comfort level within the building requires avoiding the improper design of the atrium space, which is vastly less energy efficient, and also miscalculating the effective and important atrium parameters for controlling and improving the atrium energy performance. These factors include orientation, ratio, and size of the atrium, adjacent spaces, function, atrium type, and envelope construction (Wall, 1996).

The atrium can act as a conduit for passive cooling, heating, natural ventilation, solar collector and the distributor, and cause more daylight to enter the indoor spaces. Consequently, these actions can dramatically decrease building energy usage. On the other hand, poor design of the atriums can result in uncomfortable spaces, air condition load, and unsuitable temperatures. Atrium spaces have an excessive potential for providing an environmental solution in regards to building energy performance and its physical aspects (Laouadi & Atif 1998. Calcagni & Paroncini 2004. Sharples & Lash 2007. Tabesh & Sertyesilisik 2015).

Recent technological developments have massively impacted the environment and should be considered as sustainability approaches. However, it is necessary to apply even more approaches, such as the energy efficiency of the building, which are directly related to energy security, climate change, and environmental protection. One of the reasons for climate change is the excessive emission of carbon dioxide, resulting from the usage of fossil fuels. Consequently, the optimum energy performance of the building has fewer negative effects on the environment and is vital for the modern construction industry (Abdullah & Wang 2012. Vujosevic, & Krstic-Furundzic, 2017).

4.4 Thermal Performance Consideration of Atrium and Adjacent Zones in Hot and Humid Climate

To achieve the suitable thermal performance of the atrium building in the hot and humid climate is vital that designer simulates, evaluates and tests the building performance in the initial design stage and also considers other important parameters based on occupants' comfort, like the indoor air quality, air humidity, and indoor temperature (Ab Ghafar, Gadi & Adam, 2019) (Sekhar, 2016) to address thermal and energy usage issues and solve the design related problems regarding those points. The important point is that the atrium should not be considered as a source of extra heat gain into the total building zones and should facilitate a passive cooling strategy in the hot and humid climate. Accordingly, remarkable attention must be paid to the ratio of the windows, opaque and transparent material ratios and shading devices in all building spaces. Furthermore, using an atrium in a building can significantly enhance energy efficiency if designed properly (Ahmad & Rasdi 2000. Vujosevic, & Krstic-Furundzic, 2017. Bhave, et.al, 2014).

4.5 Chapter Summary

This chapter explained the variables affecting the indoor environment in the atrium building. It also defined the various relevant parameters, including natural ventilation, mechanical condition, and hybrid indoor condition, covering the different aspects of this area. Furthermore, window opening and shading device ratios have been explained as a common strategy implemented in the hot and humid climate. Additionally, the proportion, orientation, and volume of the atrium were used in comparing the noticeable points for each building scale. Afterward, the thermal comfort and energy performance of atrium buildings were explained and investigated in the literature review to clarify the useful points. Finally, the section covering thermal performance considerations of atrium and adjacent zones in a hot and humid climate determined the point relevant for providing thermal performance in this climatic condition. As the finding of this chapter can mention that there is a need for a comprehensive study addressing the thermal comfort of natural ventilation and basic air conditioning internal system and the energy performance when the atrium proportion, adjacent space proportion, orientation, and window opening ratio are changed accordingly. The statement of using those subjects is finding the main issues and key factors and then apply them for assessing the results.

Chapter 5

PROPOSED MODEL OF THERMAL PERFORMANCE IN THE ATRIUM BUILDING BASED ON HOT AND HUMID CLIMATE

5.1 Stages and Steps of the Model

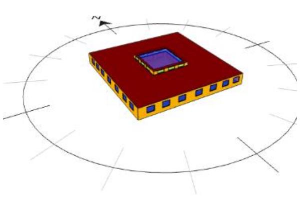
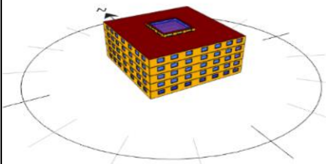
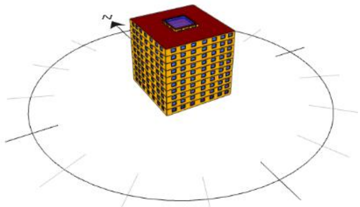
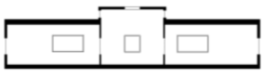
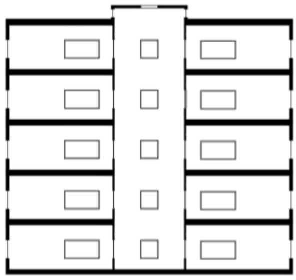
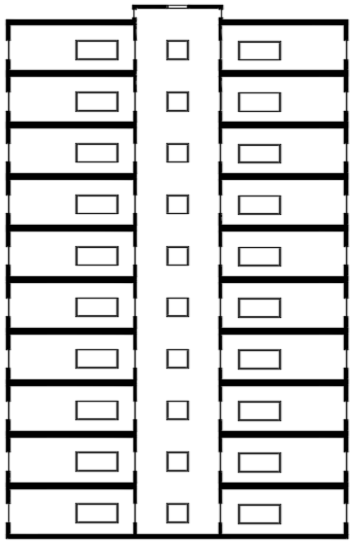
The design and parameters of the models are divided as stages in this section, each of which consists of different steps. Stage A is used in designing a model process with each step explaining the factors that are applied. The measurement parameters utilized in stage B have also been illustrated accordingly.

5.1.1 Stage A: Determining Model Parameters

5.1.1.1 Step 1: Defining Atrium Height, Proportion, and Placement

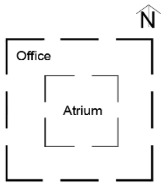
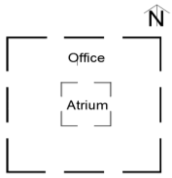
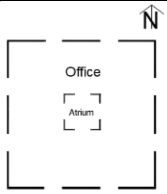
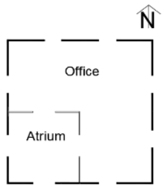
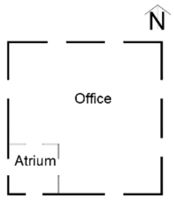
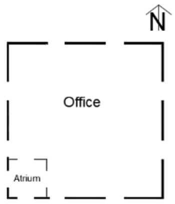
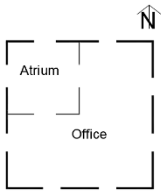
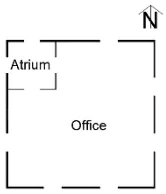
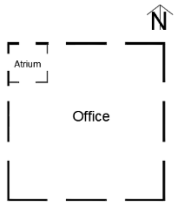
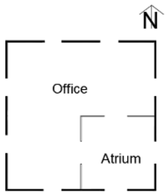
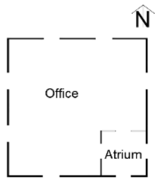
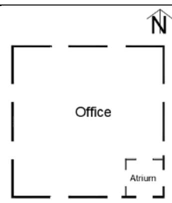
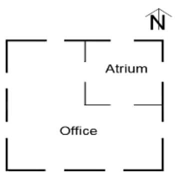
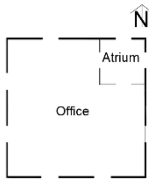
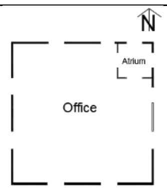
The atrium building is distinguished between main three building types: the single-floor (one floor), medium-rise (five floors), and high-rise (ten floors), all of which were combined with three types of atrium proportions with atrium 1/2, 1/3, and 1/4 of the office proportion and the atrium placement was changed between the center, north-east, north-west, south-east, and south-west. All of the models had a 1m high tower over the atrium zone, which is used as the average suitable height for all dynamic simulation scenarios. The total looks of all the floors are illustrated in one of the sample selections that consists of the 3D view and the section of single-floor, medium-rise, and high-rise atrium building, as shown in Table 1.

Table 1: The dynamic atrium building simulation models as sample volume groups.

3D model of Single-Floor (1 floor)	3D model of Medium-Rise (5 floors)	3D model of High-Rise (10 floors)
		
Section model of Single-Floor (1 floor)	**Section model of Medium-Rise (5 floors)**	**Section model of High-Rise (10 floors)**
		

As illustrated in Table 2, all of the atrium building scenarios used are based on the five main atrium placements: the center, north-east, north-west, south-east, and south-west, additionally with different atrium proportions, including the atrium as 1/2, 1/3, and 1/4 of the office proportion.

Table 2: The dynamic atrium building simulation of all models as a plan view.

Atrium Placement in Building	Atrium Proportion as 1/2 of Office Proportion	Atrium Proportion as 1/3 of Office Proportion	Atrium Proportion as 1/4 of Office Proportion
Center			
South-west			
North-west			
South-east			
North-east			

5.1.1.2 Step 2: Illustrating Model Materials

All of the dynamic simulation models in the internal zones are divided into the office and atrium zone, and because of this division, the atrium building design is based on an open-plan office building. As shown in Table 3, all the building elements and materials used were categorized as opaque and transparent materials.

Table 3: Material distinguishing for dynamic atrium building simulation models.

Building Elements and Materials	**Building Zones**
a. Opaque material: • Ground floor: *plastic, concrete, crushed brick, sand* • Ceiling • External walls: *299mm plastered block* • Internal walls: *119mm plastered block* • Roof: *plastic, concrete, crushed brick* • Windows frame: *wooden frame* b. Transparency material • Windows glass	a. Office zone: • Open plan office b. Atrium zone

All the dynamic simulation models used the same construction materials. The opaque construction layers and thermal properties (U-values) of all simulation models are also shown in Table 4. The opaque construction categories consist of the ground floor, ceiling, walls, and roof. Furthermore, Table 5 contains the properties of the glass construction layers for all the simulation models, along with the thermal properties (U-values) of the window elements.

Table 4: The properties of opaque construction layers with U-values for office simulation models (EDSL Tas, 2019).

Category	**U-Value (W/m2K)**	**Solar Absorptance**		**Emissivity**		**Conductance (W/m2K)**	**Time Constant**
		External surface	Internal surface	External	Internal		
Ground Floor	0.283	0.760	0.500	0.910	0.900	0.297	127.999
Ceiling	1.01	0.700	0.500	0.900	0.900	1.251	13.749
Walls	1.03	0.400	0.400	0.900	0.900	1.407	4.920
Roof	0.444	0.920	0.600	0.940	0.900	0.046	0.000

Table 5: The properties of transparency construction layers with U-values for office simulation models (EDSL Tas, 2019).

Category	**U-Value (W/m2K)**	**Solar Transmittance**	**External Solar Absorptance**		**Internal Solar Absorptance**		**Light Transmittance**	**Time Constant**
			External surface	Internal surface	External surface	Internal surface		
Windows (clear 6-12-6 double glazing low E)	1.803	0.498	0.173	0.135	0.227	0.097	0.760	0

5.1.1.3 Step 3: Defining Atrium Internal Condition

All the scenarios were analyzed based on two different indoor conditions as passive performance (natural ventilation) and active performance (basic air conditioning). As a natural indoor condition, there is not any usage of a mechanical system for occupants during a year. The internal comfort is generated by natural ventilation based on a tower over the atrium as side openings and window openings of the building. The basic air conditioning system is used for all building zones. This mechanical (active) condition involves basic air conditioning with no RH control. This system has an upper limit gain value: 24.0°C, setback value: 100.0°C, schedule: cooling load. Additionally, it has a lower limit gain value: 21.0°C, setback value: 10.0°C, schedule: heating load (EDSL, 2019). For determining the optimized model for thermal performance in the single-floor, medium-rise, and high-rise atrium buildings throughout a year, the hybrid atrium building was used. The hybrid condition of the atrium building consists of the passive performance of natural ventilation and active performance using a basic air conditioning system.

5.1.1.4 Step 4: Designating Atrium Building Openings and Shading Ratios

All window opening ratios were set at 0%, 50%, and 100% in the office space, semi-enclosed atrium, and tower side openings. While the window opening ratios were initially set at 0%, 25%, 50%, 75%. and 100%, the estimated results of this study led to the selection of just the remarkable windows opening ratios: 0%, 50%, and 100% because there was not any remarkable difference between the previous ratios. Furthermore, for the dynamic simulation atrium building models which did not reach thermal comfort during warm periods, shading devices were applied in percentages up to 50% over each atrium facade windows for the passive indoor condition. As a remarkable point, the active indoor performance was applied to all windows of the buildings with the facade openings completely closed and air movement facilitated just by the indoor windows openings (atrium zone). Also, the scenario of models that did not thermally comfort during warm months, shading devices were applied (up to 50%) over each atrium external facade.

5.1.1.5 Step 5: Model Design Regulation

For this thesis, the building laws considered were those of Famagusta in North Cyprus. The Building Regulation Laws (Fasil 96) of this city include the following provisions:

- Every habitable room shall be provided with windows which directly open to the outdoor areas for external air.
- The places that room windows open into a courtyard enclosed on three or more sides, the width of the courtyard measured as the front of the window to the opposite wall cannot be less than half of the wall height measured from the top of the window to the eaves or the top of a parapet of an opposite wall.
- The number of window openings in this climate should be a minimum of 5% of the total floor area.
- The amount of transparent area in this climate should measure at a minimum 20% of the total floor area (Fasil 96).

5.1.1.6 Step 6: Model Climate Condition

The weather condition of the Famagusta, Cyprus is the hot and humid climate as illustrated by the weather data in Figures 7, 8, and 9. According to the Figures, throughout August the average temperature is 27°C which is the hottest month. The coldest month is January which the average temperature is 12°C. Furthermore, December is the wettest month with the average as 94.5mm of rain. Also, the sunniest days through a year are in July, while the maximum number of sunshine hours is obtained from May to September. However, the minimum average of sunlight hours occurred from December to February. Based on the sun hours, it can be concluded that the maximum average temperature occurred between June to September and the minimum temperature from December to February. The highest number of rainy days is in November and the lowest number is from June to July based on the yearly averages (URL 3).

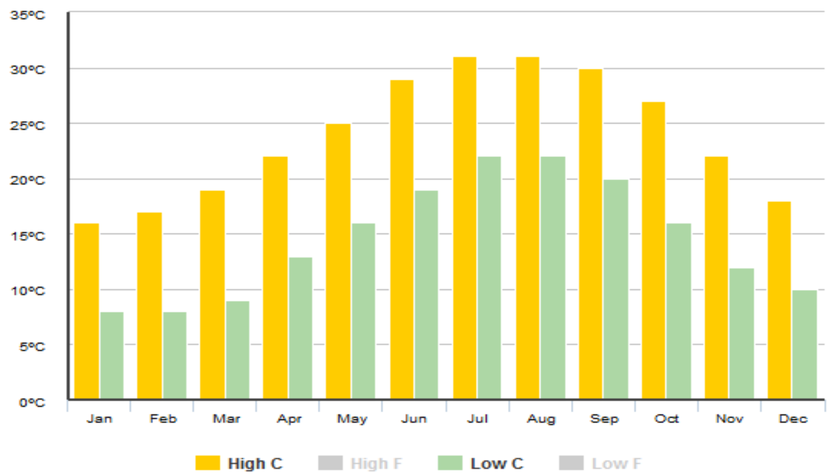


Figure 7: Famagusta average as high and low temperature (URL3).

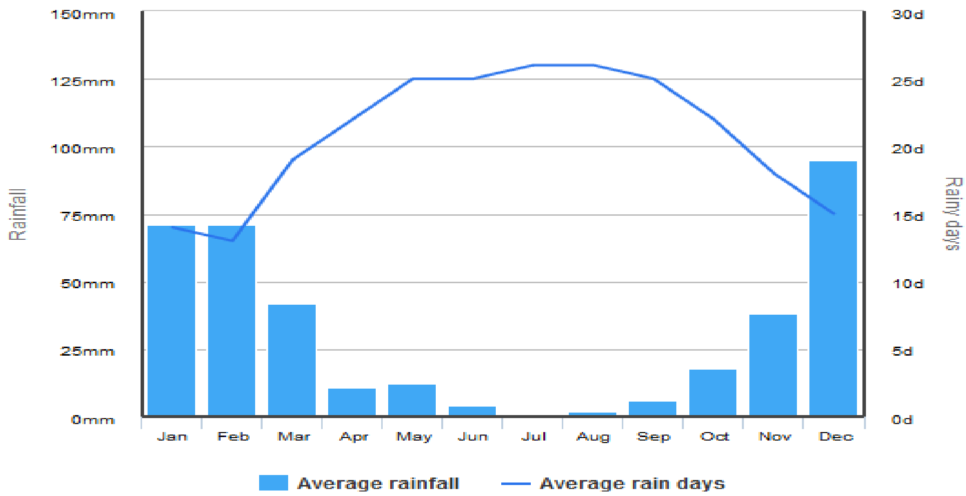


Figure 8: Famagusta average rainfall and rain days (URL 3).

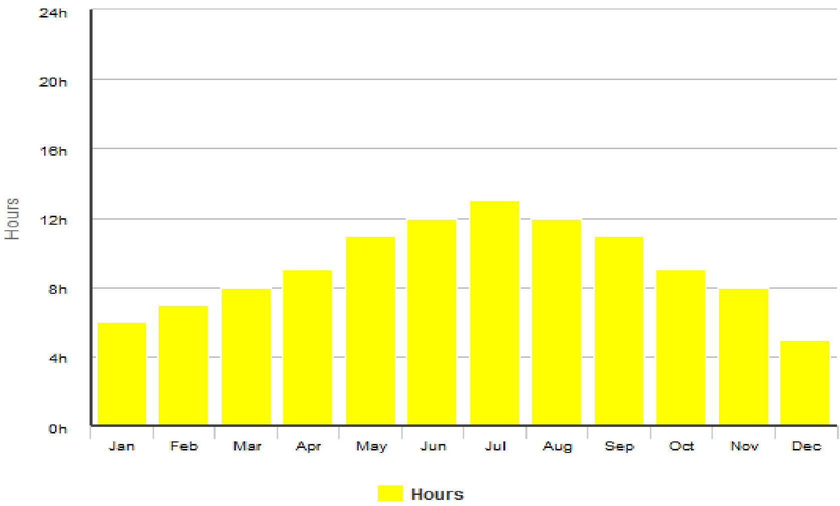


Figure 9: Famagusta average daily sunshine hours (URL 3).

In the software, wind direction path and outdoor climate condition factors for all the dynamic simulations of atrium buildings were based on Famagusta weather data as shown in Figures 10 and 11. In addition, humidity and dry bulb temperature fluctuated the most during the year in this microclimate. It was also found that strong winds occurred from north to north-east and the longest wind occurs from south-west to west. Although, it can be mentioned that wind speeds during a year did not display any remarkable differences.

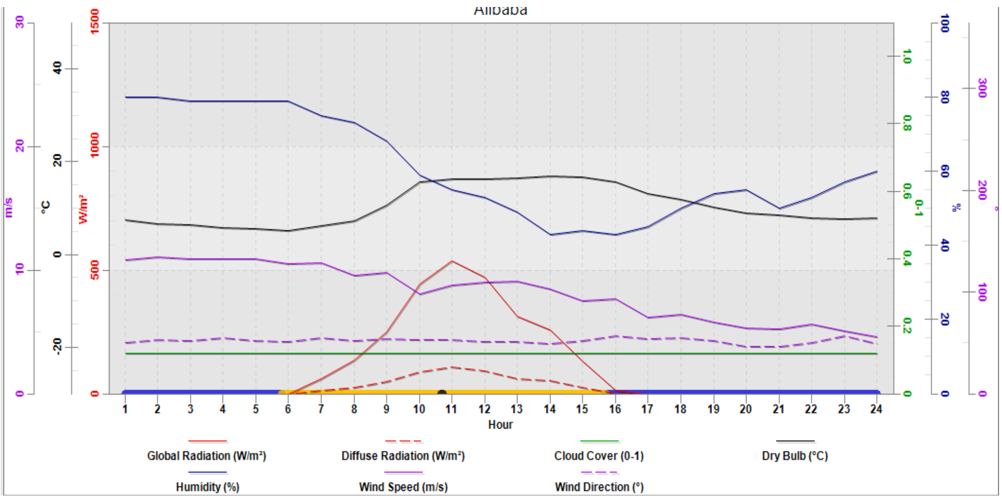


Figure 10: The Graphical description of Famagusta weather (EDSL Tas, 2019).

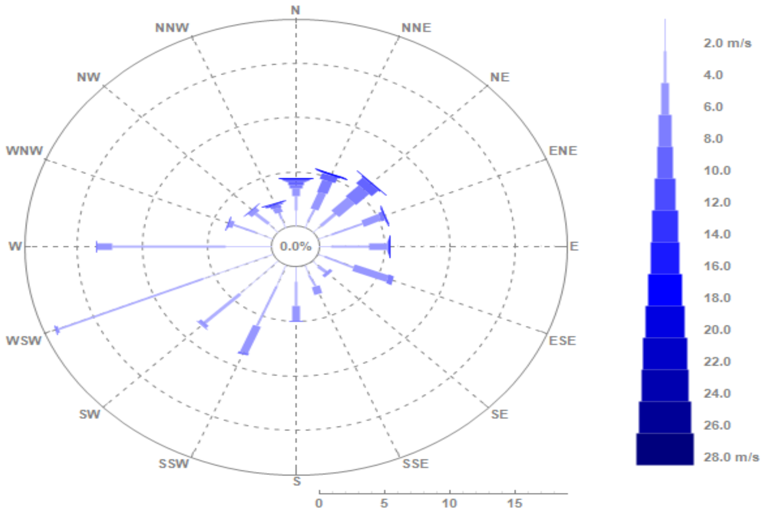


Figure 11: The Wind Rose of the full-year description of Famagusta weather (EDSL Tas, 2019).

The method applied in this thesis uses the monthly average Famagusta outdoor temperature as can be seen in Table 6. The Famagusta microclimate can be divided into cold and warm periods. The cold period occurs from November to April, while the warm period occurs from May to October.

Table 6: Famagusta outdoor average temperature ^{o}C.

Month	**Outdoor Average Temperature ^{o}C**
January	10.93 ^{o}C
February	12.77 ^{o}C
March	14 ^{o}C
April	16.23 ^{o}C
May	21.36 ^{o}C
June	26.04 ^{o}C
July	28.36 ^{o}C
August	28.43 ^{o}C
September	25.7 ^{o}C
October	22.83 ^{o}C
November	17.91 ^{o}C
December	13.65 ^{o}C

5.1.2 Stage B: Measurement and Comparing Parameters

All of the dynamic simulation scenarios compared with each other based on the thermal performance and applied the same standards. The standards used for the thesis include the recommendations of ASHRAE (2018), ISO 7730 (ISO, 2005), and EN 15251 (EN, 2007) for thermal environments.

5.1.2.1 Step 1: Adaptive Model

The thermal comfort method for passive performance used is the adaptive model. In assessing the thermal comfort level in the atrium building while the indoor condition is natural ventilation, the parameter applied to the model is the operative indoor and outdoor temperature (To), which includes both the radiant temperature and air temperature (Tdb).

5.1.2.2 Step 2: Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) Method

In this step, the thermal comfort method used is predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) for all active internal conditioned, as can be seen in Table 7. The users' factors of all the simulation models were analyzed with M: 1.2 met, an airspeed of 0.15 – 0.3 m/s, and a clothing value of 0.6 – 0.95 clo, all evaluated throughout a year.

Table 7: The recommendation of ISO 7730 (ISO, 2005) and EN 15251 (EN, 2007) of thermal environments.

Thermal State of the Body as Whole				Local Discomfort		
Category	Predicted Percentage of Dissatisfied (%)	Predicted Mean Vote Range	Percentage of Dissatisfied (PD) Due to Draught (%)	PD Due to Vertical Air Temperature The difference (%)	PD Due to Cool or Warm Floor (%)	PD Due to Radiant Temperature Asymmetry (%)
1 (A)	<6	-0.20 to 0.20	<10	<3	<10	<5
2 (B)	<10	-0.50 to 0.50	<20	<5	<10	<5
3 (C)	<15	-0.70 to 0.70	<30	<10	<15	<10
4 (D) (EN 15251)	>15	<-0.70 or >0.70				

According to Table 7. The standard categories are divided into: Category A, which is recommended in spaces for fragile and sensitive persons, very young children, and elderly people; Category B, as the normal level which is applied for renovations and new buildings; Category C, used as a moderate and acceptable level of expectation for existing buildings; and Category D, which is only acceptable for the limited part of a year (ISO, 2005. EN, 2007).

5.1.2.3 Step 3: Energy Performance Factors

In this step, for each of the individual dynamic simulation as a hybrid conditioned atrium building model based on the different atrium proportions, placements, volumes (single, medium, and high rise), window openings, and shading device ratios, the indoor energy performance analyzed separately. The parameters considered in the energy performance analysis including as office and atrium zone heat gain or loss, infiltration ventilation gain or loss, and mean radiant temperature during a year.

5.2 Analysis and Finding of Atrium Building According to the Model

5.2.1 Passive Conditioned Atrium Buildings

5.2.1.1 Single-Floor Atrium Buildings

For the single-floor dynamic simulation models, when the internal condition was based on natural ventilation, the total building temperature exceeded the external temperature during the warm period. For instance, the north-east atrium placement, when the atrium proportion is 1/3 of the office proportion and all windows on the external facade were completely closed except for the atrium windows and tower side opening, showed an overheating problem, especially in July and August when the temperature reached over 36°C in the office space. This problem was even worse in the north-west atrium placement with the same proportion and window openings which reached 68 °C in tower space. Additionally, this temperature still existed when all office windows were 50% opened to the external environment. In the south-east atrium orientation of this volume group with 50% and 100% office window openings, the average temperature in the tower space was 69 °C when the average external temperature was 29 °C in July. Although the office and atrium spaces were 45 °C and 63 °C respectively. The south-west placement with an atrium proportion 1/3 of the office proportion fared better in the hottest months of July and August; when all the windows had been opened completely, the office space was about 29 °C. In the atrium proportion 1/3 of the office volume group, the center atrium placement had a better thermal comfort than other simulation models using a natural ventilation internal condition.

Figure 12 illustrates the dynamic simulations of the single-floor atrium when the atrium was half of the total office space with a natural ventilation condition, for which the tower over the atrium space had side windows that were always opened. In this group, the center atrium placement in the office space with 0% office opening and 100% tower side opening had a 90% acceptability of thermal comfort during cold seasons and 80% acceptability of thermal comfort from May to June (21.3 ^{o}C to 26 ^{o}C). The internal thermal condition also decreased slightly from the end of May to the end of September (25 ^{o}C to 30 ^{o}C). Consequently, when all of the office windows were closed and the passive strategy was applied via the tower, there was no thermal comfort condition in the office zone. The thermal comfort in the atrium space had a better condition than the previous zone with the same parameters. When the external temperature dropped to 10.9 ^{o}C (January) from 26 ^{o}C (June), there was a complete (90% acceptability limit) thermal comfort internal condition in the atrium space. There was also approximately 80% acceptability for internal comfort throughout the month of June (25 ^{o}C to 27 ^{o}C), although there was no thermal comfort during warm seasons with temperatures above 30 ^{o}C. In this atrium proportion group with the same atrium placement, when the office window opening ratio was increased to 50%, there was a 90% acceptability for thermal comfort from 10.9 ^{o}C as the prevailing mean outdoor air temperature (January) to 26 ^{o}C (June), while July and August had 80% acceptability. Additionally, the atrium zone of this group had the same approximate thermal comfort condition as the office zone. For the final office window opening ratio at 100%, in this atrium proportion and placement group, May to September (21.3 ^{o}C to 28.4 ^{o}C) all had 90% acceptability, and from 15 ^{o}C to 20 ^{o}C in November and December had 80% acceptability of thermal comfort. Furthermore, it is noteworthy that the atrium zone had a thermal comfort internal condition throughout the year in both warm and cold seasons.

In the north-east atrium placement with the same atrium proportion (atrium 1/2 of office), the office and atrium zones had thermal comfort condition from January to

April, and from the end of May until June when all office windows were closed. The atrium zone of this group also somewhat achieved thermal comfort from 24 ^{o}C to 30 ^{o}C. Using the same parameters with a 50% office window opening ratio (atrium windows were connected to the external facade), the office zone had 90% acceptability thermal comfort from March to April as the external temperature averaged between 22.5 ^{o}C and 28.5 ^{o}C. Similarly, the atrium zone also had thermal comfort in January, April, June, July, and August. When all the windows connected to the external facade were completely opened, the office zone during March, April, June, July, and August had thermal comfort in the 80% and 90% acceptability limits, while the atrium zone also had thermal comfort internal conditions from January to April and June. In the north-west atrium placement of this group, when all office and external windows were closed, the office zone had 90% and 80% acceptability for thermal comfort in January, February, March, and April while the atrium zone had a thermal comfort condition from January to May. When the external openings were 50% open, thermal comfort was observed in the office zone from January to April and the atrium zone from February to July. When all windows to the external facade had been completely opened, the office zone in March and April, and June to August had a thermal comfort condition. The atrium zone of this model had 90% acceptability for thermal comfort from February to April, and July, while thermal comfort in May and June was based on 80% acceptability limits. In this atrium proportion group with a south-east placement, the office zone from January to April (10.9 ^{o}C to 13.9 ^{o}C, 14 ^{o}C, and about 18 ^{o}C) had thermal comfort in the 90% and 80% acceptability limits. Thermal comfort was similarly observed in the atrium zone from January to May. When all external window openings were 50% opened, the office zone had comfort from January to August, and the atrium zone had internal comfort from January to June. Furthermore, with a 100% opening of all external windows to the building facade, the office space from May to July had 90% acceptability for thermal comfort and 80% throughout April. Similarly, the atrium space from January to June had 90% and 80% acceptability in July and August. When the atrium was placed in a south-west orientation with all the same factors as mentioned above, 0% opening ratios for the office and external atrium windows, the office, and the atrium zones had thermal comfort from January to April. Additionally, the atrium zone had an 80% acceptability thermal comfort in May. However, the office and atrium spaces had thermal comfort with 50% opening from April to June, and in July in the atrium zone. When all external openings were increased to 100%, the office and atrium zones had the same performance with internal thermal comfort from January to August.

Figure 13 illustrates the dynamic simulation group for the single-floor building design with an atrium proportion 1/3 of the office proportion and a natural ventilation condition. When all of the office window openings were closed in the center atrium type and ventilation occurred through the tower over the atrium side with a 100% opening, thermal comfort was observed within the 90% acceptability limit from January to April in the office zone and from January to May in the atrium zone. When the window opening ratio was increased to 50%, the office and atrium zones experienced an even better thermal comfort condition during January, February, and March, and somewhat in September to December. However, when the office windows opening ratio was the same as the tower side opening (100%), the periods of thermal comfort remained similar to the previous simulation ratio (50% window opening ratio); here, thermal comfort in the office was observed from January to March and September to October, and January to June in the atrium zone. In this dynamic simulation group with a north-east atrium placement, user satisfaction was improved in the office zone when all external windows were closed throughout January and February during the cold season, although the atrium zone of this building had the same condition in the same period. With a 50% opening ratio for all external window openings, the office and atrium zones had thermal comfort conditions during springtime and somewhat during the cold months. Furthermore, when all external windows were completely opened, thermal comfort was within 90% and 80% acceptability limits from January to March in the office and atrium zone. There was thermal comfort from about August to October in the office zone and somewhat in the atrium space for temperatures ranging from 21.2 ^{o}C to 28.4 ^{o}C. Significantly, when the atrium was placed in the north-west and south-east orientations and all external windows were 50% opened, there was no thermal comfort condition in either the office or atrium zones. The north-west atrium placement did not have any thermal comfort when all external openings were closed. However, when all windows were opened completely, the office zone had thermal comfort during springtime and the atrium zone during January and February. The south-east atrium placement with all external windows completely closed except for tower side opening, had a thermal comfort condition throughout January to March in the office and atrium zones. However, when all the windows of the building were completely opened, there was no thermal comfort condition for this atrium proportion. There was also no thermal comfort condition for the south-west placement with a 50% opening of external windows in the office and the external facade of the atrium. However, when all the windows were closed, thermal comfort was observed from March to April and November to December in the office zone, and in January in the atrium zone. Further, when all the windows of the building were opened completely, there was a thermal comfort condition in the office and atrium zones from January to March and November to December.

Figure 14 illustrates the single-floor building simulation group with the atrium proportion set as 1/4 of the office proportion and a natural ventilation condition. The center atrium placement in this group when all the facade external windows were closed except for the tower side opening provided thermal comfort from January to March in the office zone and November to March in the atrium zone. When the opening ratio of the external window facade changed to 50%, there was no thermal comfort in both the office and atrium zones. At a 100% opening ratio for all windows, there was thermal comfort in the springtime in the office and atrium zones. However, there was no thermal comfort throughout the year for the north-west atrium placement with a 50% opening ratio for all external office zone and atrium facade side openings. Although, when all of the aforementioned windows were closed completely except for the tower side, there was thermal comfort in the office zone from November to March, and in the atrium zone in January and February. The south-east atrium placement in this group had thermal comfort from December to about April in the office zone and about 90% acceptability for thermal comfort throughout January and February in the atrium zone. In this simulation and placement, group when all the office and atrium facade side openings were set at 50% and 100%, there was no thermal comfort for occupants in all zones. In the south-west atrium placement with the same parameters, there also was not any positive internal condition for 0% and 50% opening ratios for the office and atrium facade side windows. However, when all of the side windows of the building were opened completely, thermal comfort was observed in the office zone from March to May, and throughout March in the atrium zone.

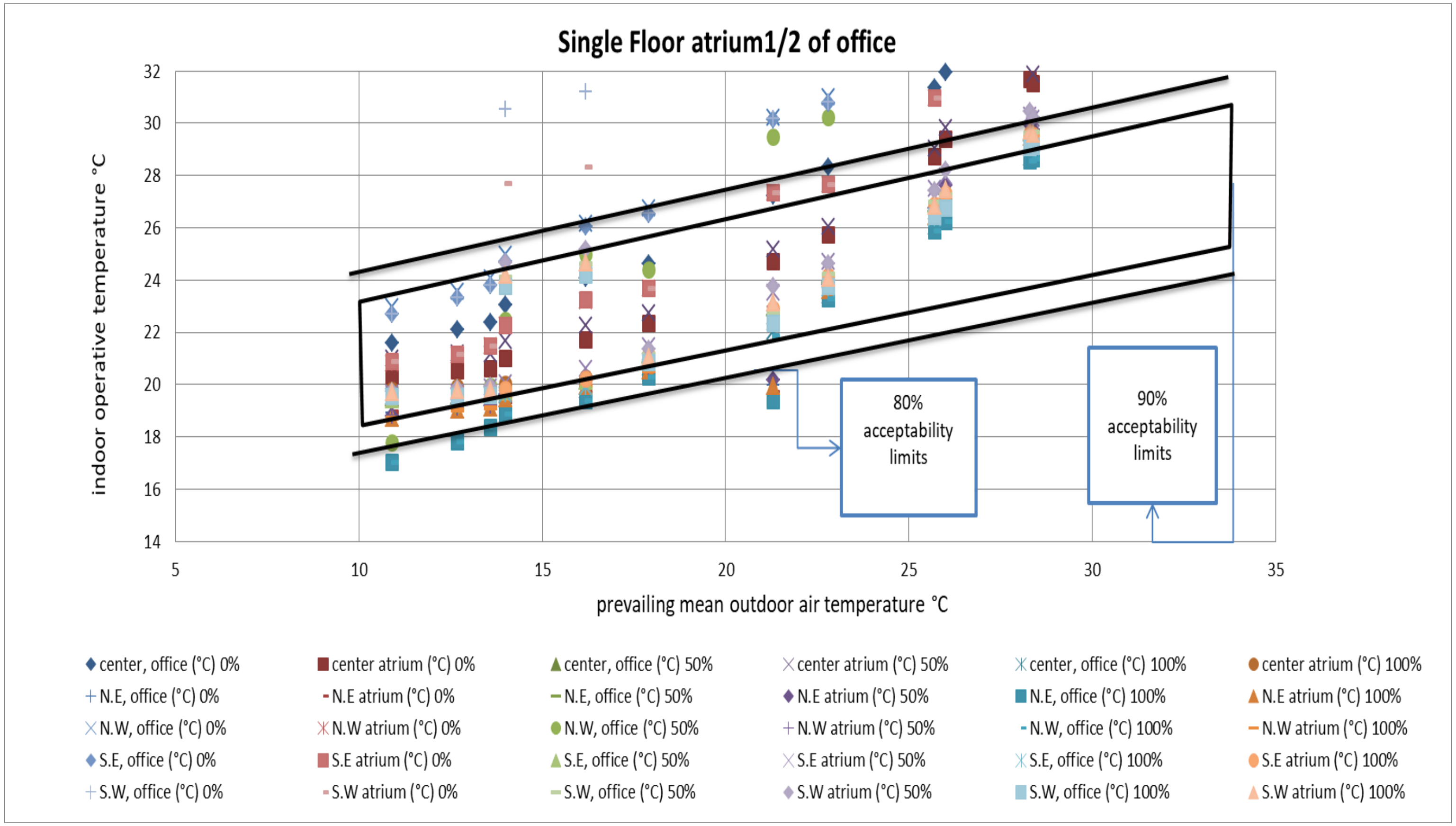


Figure 12: The adaptive model of a naturally conditioned Single-Floor building with atrium proportion 1/2 of the office space (different atrium placements and window opening ratios as 0%, 50% & 100%).

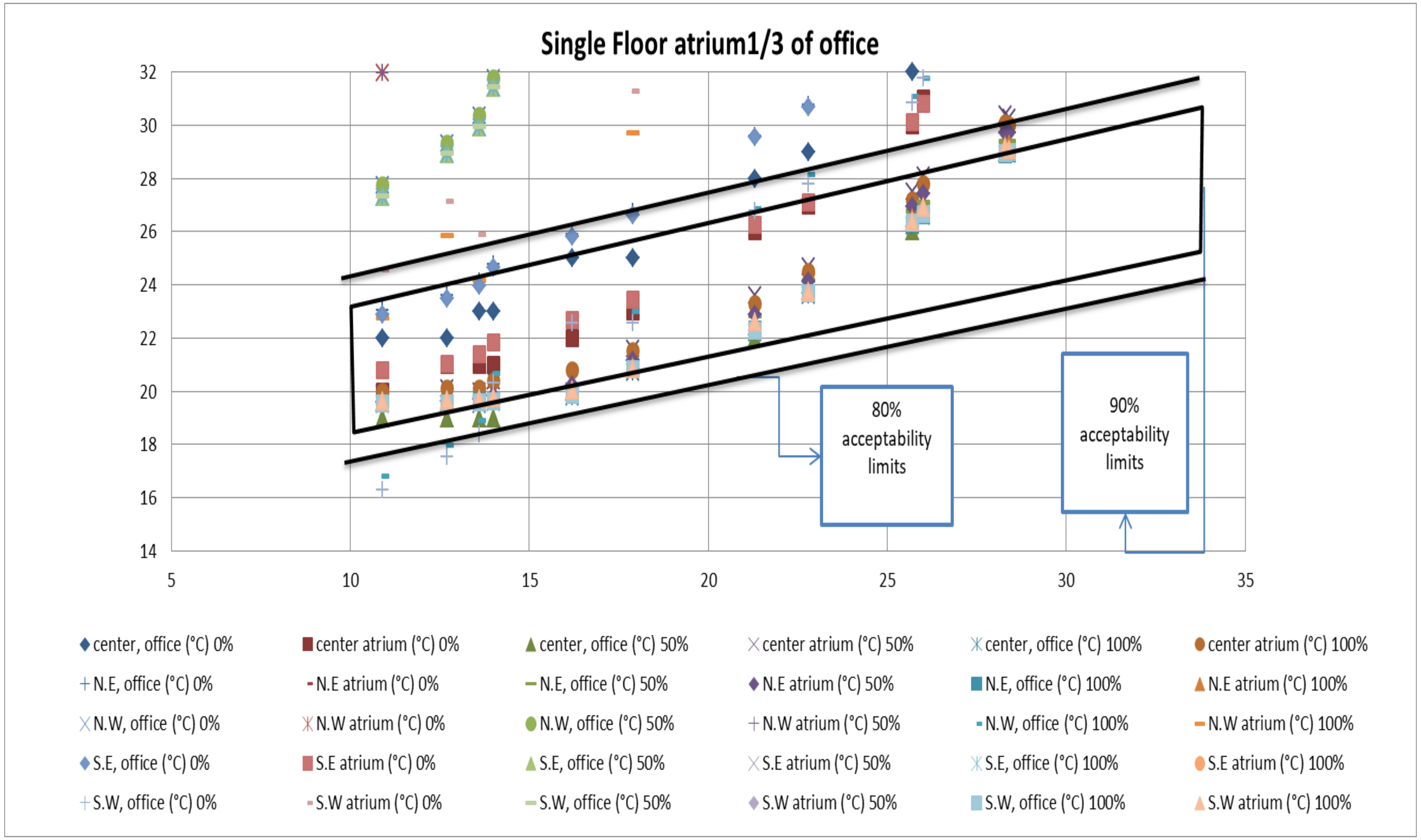


Figure 13: The adaptive model of a naturally conditioned Single-Floor building with atrium proportion 1/3 of the office space (different atrium placements and window opening ratios as 0%, 50% & 100%).

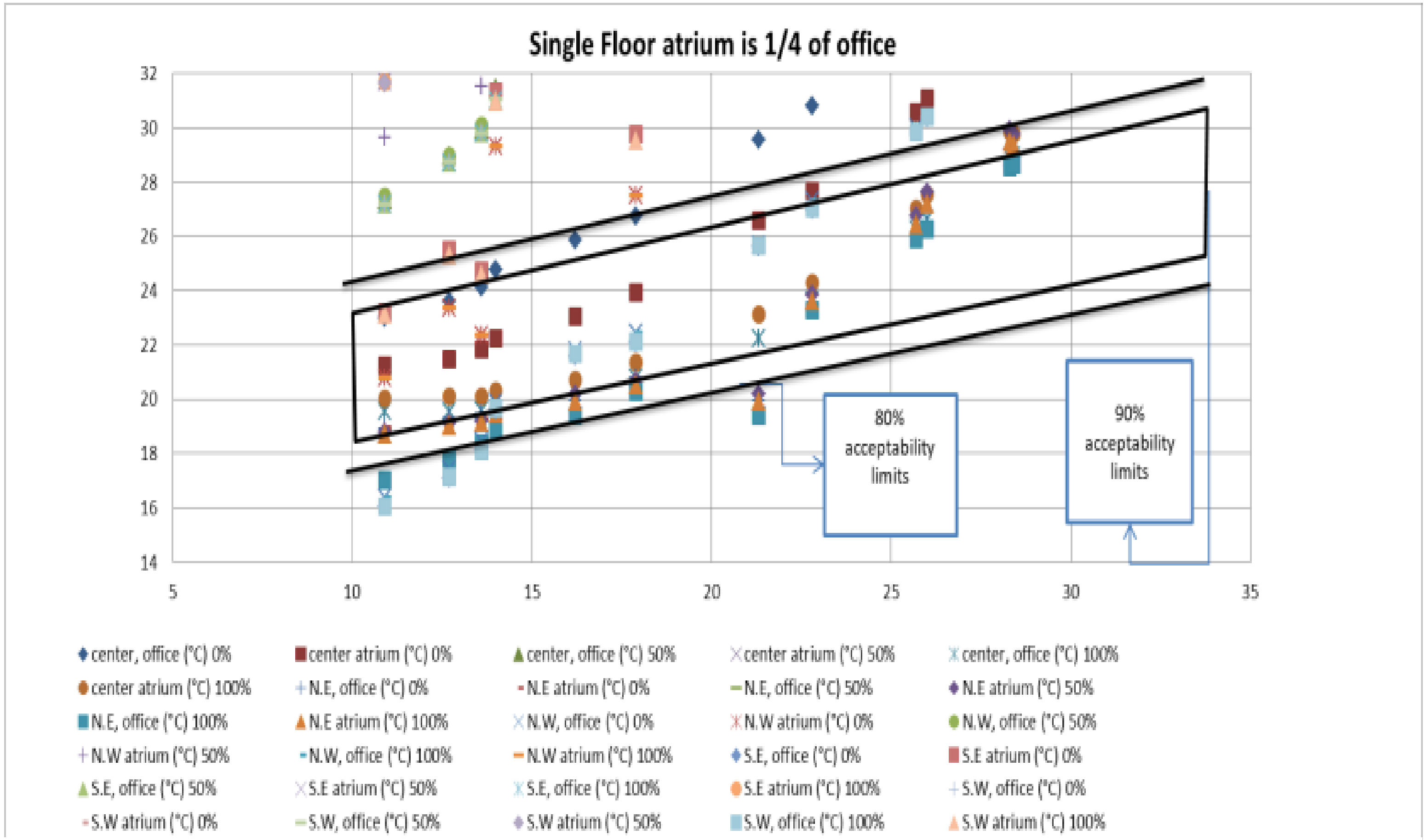


Figure 14: The adaptive model of a naturally conditioned Single-Floor building with atrium proportion 1/4 of the office space (different atrium placements and window opening ratios as 0%, 50% & 100%).

5.2.1.2 Medium-Rise Atrium Buildings

The dynamic simulation models for the medium-rise atrium building were based on a natural ventilation internal condition via the tower side opening and windows of the building. Figure 15 depicts the atrium proportion as 1/2 of the office proportion with the atrium located in the center of the building and all external facade window opening ratios set at 0%, 50%, and 100%, and for which the internal thermal comfort was approximately the same when the external temperature ranged from 25 ^{o}C to 30 ^{o}C. The north-east and north-west atrium placements had a thermal comfort condition with the same window openings ratio when the external temperature was 22 ^{o}C to 28. However, the south-east atrium placement performed better in terms of total building thermal comfort for this atrium proportion group. Notably, the upper floors had better users' comfort when the external temperature ranged from 23 ^{o}C to 29 ^{o}C.

Figure 16 illustrates the atrium proportion set at 1/3 of the office proportion in a medium-rise building, which performed somewhat similar to the previous dynamic simulation models when the atrium proportion was 1/2 of the office proportion. All of the atrium orientations had approximately the same performance with the 50% and 100% window opening ratios, providing thermal comfort conditions from 22 ^{o}C to 29 ^{o}C, especially in the upper floors and more so in the atrium zones than the office zones.

Figure 17 depicts the atrium proportion decreased to 1/4 of the office proportion. The natural ventilation of this dynamic simulation group performed similarly to the other atrium proportions and placements. Significantly, there was no thermal comfort in the whole medium-rise building during the cold season when the external temperature ranged from 10.9 ^{o}C to 17 ^{o}C. This poor performance can be attributed to the fact that the side window opening on the tower over the atrium was always opened, leading to dramatic air movements from outdoor to indoor zones, which, however, has a positive function during warm seasons.

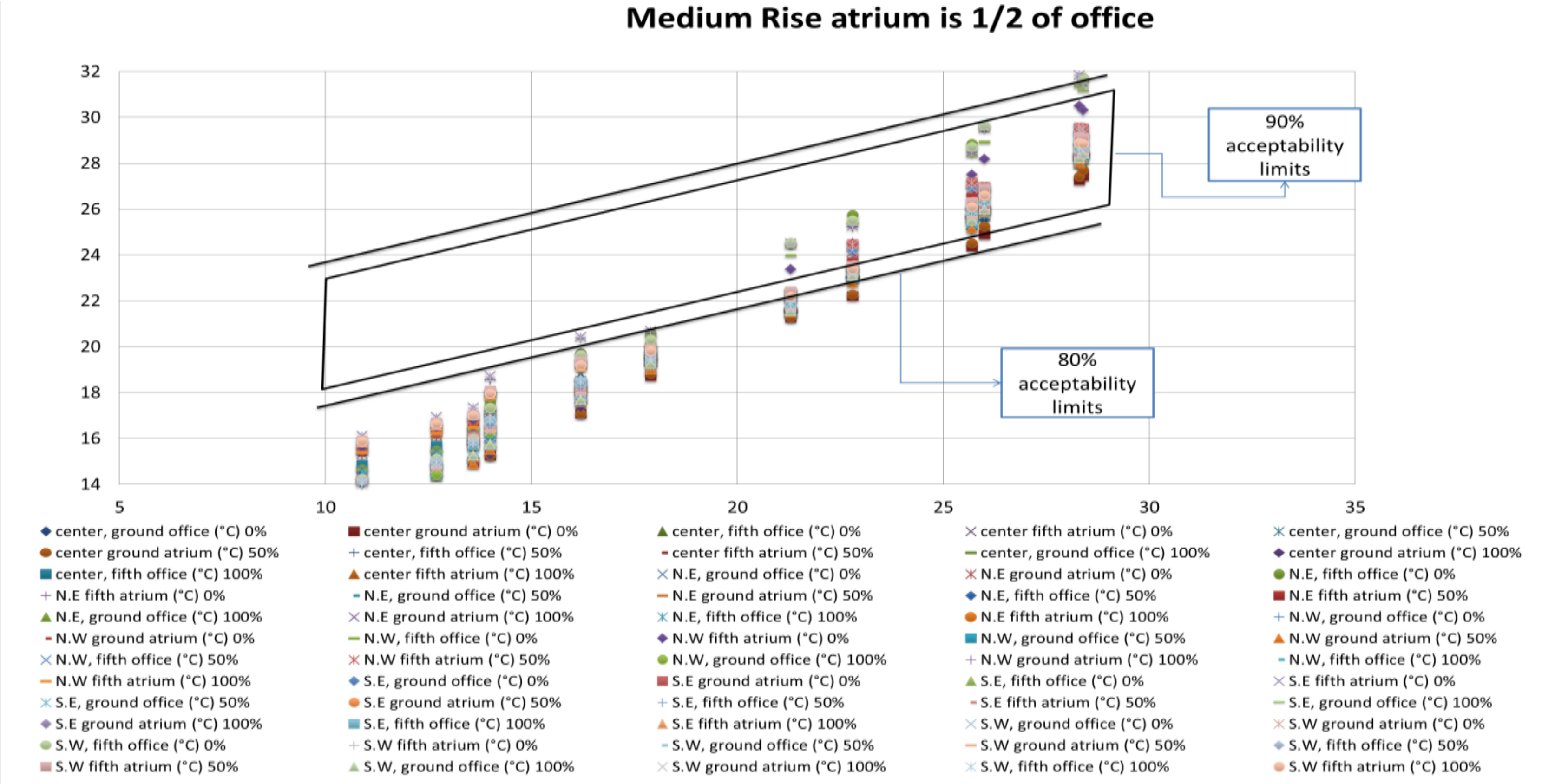


Figure 15: The adaptive model of a naturally conditioned Medium-Rise building with atrium proportion 1/2 of the office space (different atrium placements and window opening ratios as 0%, 50% & 100%.

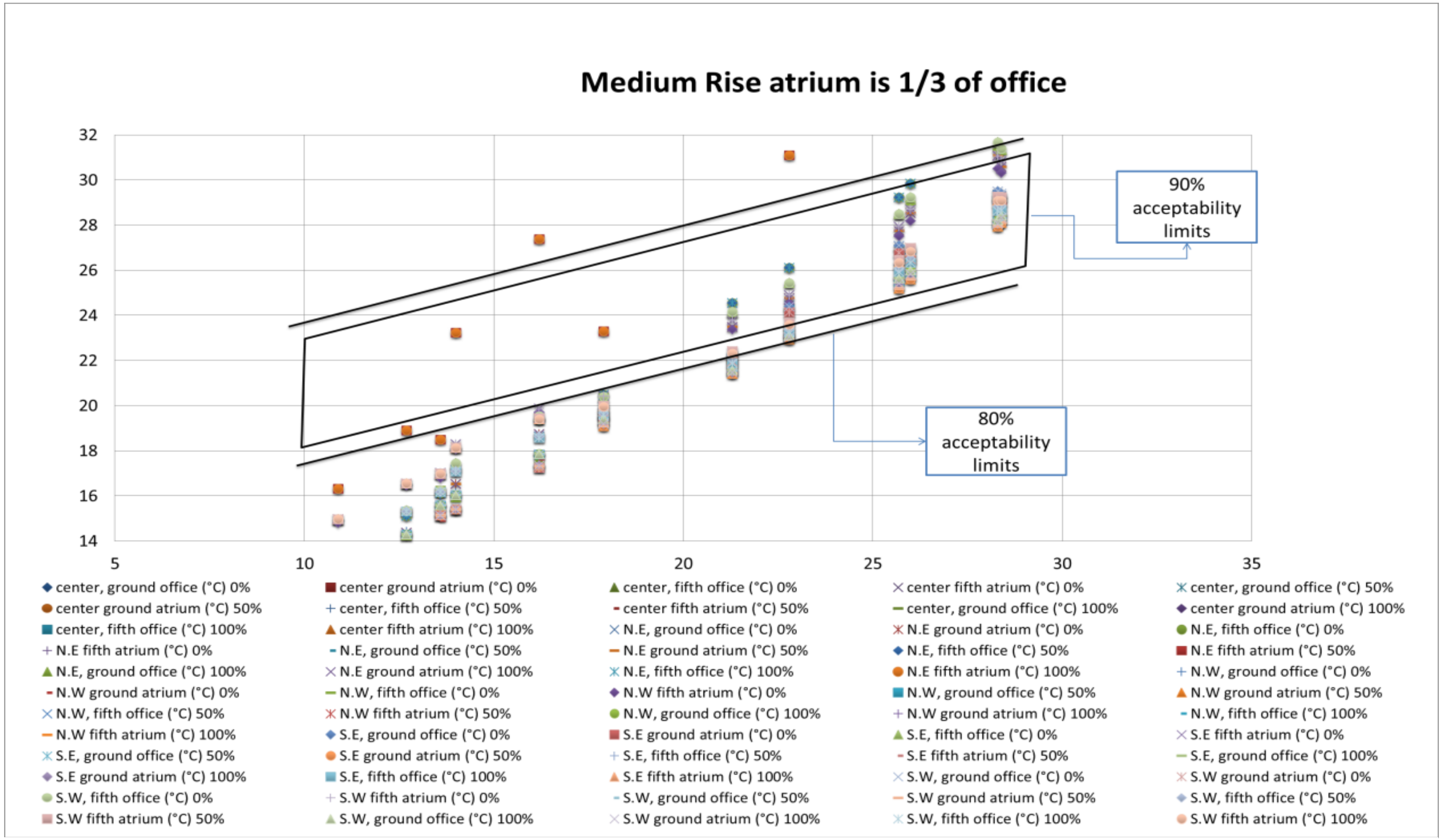


Figure 16: The adaptive model of a naturally conditioned Medium-Rise building with atrium proportion 1/2 of the office space (different atrium placements and window opening ratios as 0%, 50% & 100%.

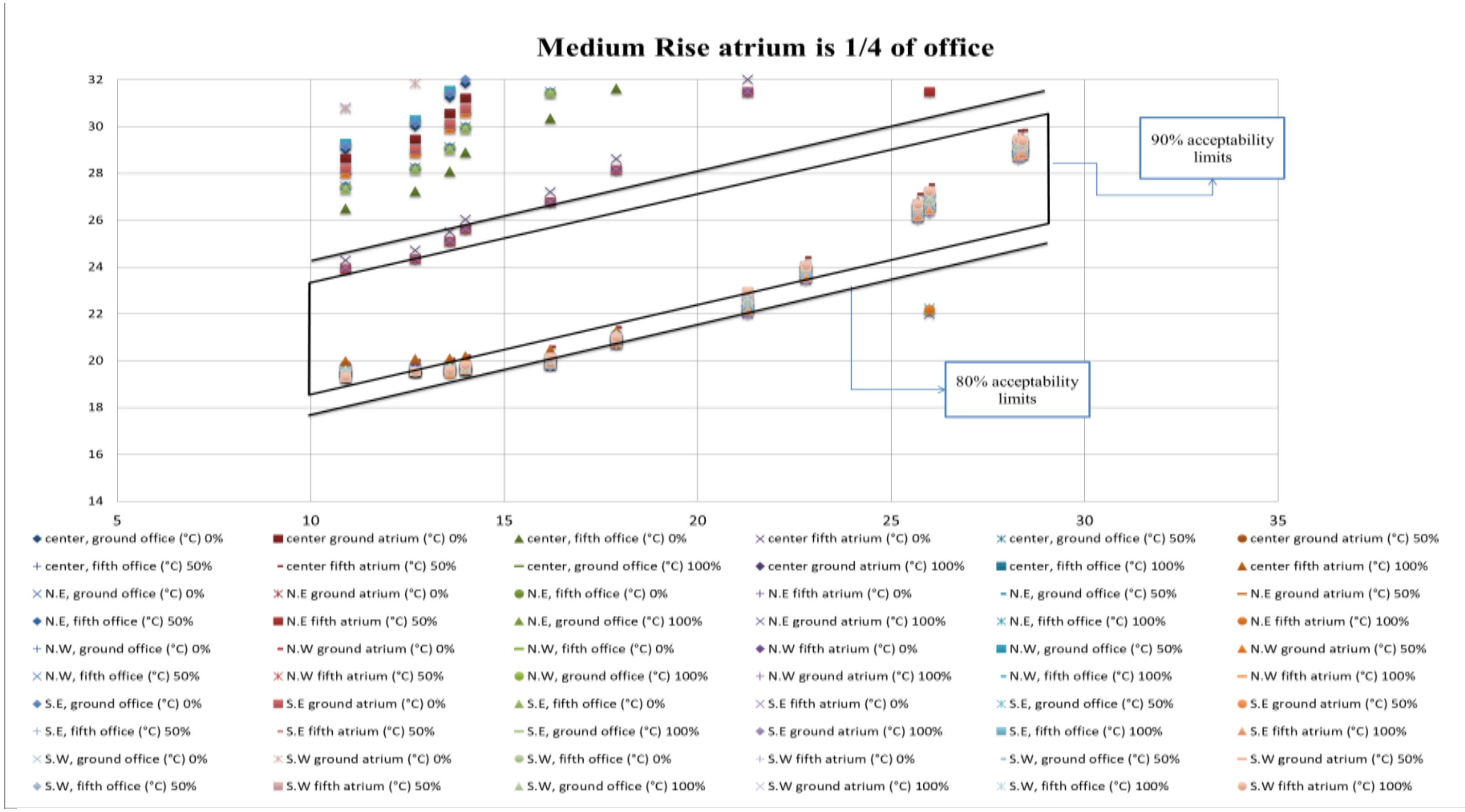


Figure 17: The adaptive model of a naturally conditioned Medium-Rise building with atrium proportion 1/4 of the office space (different atrium placements and window opening ratios as 0%, 50% & 100%.

5.2.1.3 High-Rise Atrium Buildings

Figure 18 illustrates the dynamic simulation models of a high-rise atrium building having a natural ventilation internal condition and atrium proportion 1/2 of the office proportion with the atrium placed in different orientations. In this dynamic simulation group, January to May had a higher discomfort condition for occupants than other months. Furthermore, when all windows on the external facade were closed except for the tower side windows (for natural ventilation), there was still no thermal comfort condition in all the building floors (zones). This discomfort condition also persistent when all external window opening ratios were increased to 50% with the south-east and center orientations in this simulation group. However, the center and south-west atrium orientations, while all external facade window openings had been completely opened, had more an acceptable thermal performance on all floors (buildings zones) during the year.

The high-rise atrium building simulations illustrated in Figure 19, with a natural ventilation condition with the atrium proportion 1/3 of the office proportion and the atrium placed in the center, north-east, north-west, south-east, and south-west orientations with 0%, 50%, and 100% window opening ratios, had a relatively consistent thermal performance throughout the year. The general finding of this group was that thermal comfort was achievable on all floors during springtime. However, this simulation group had maximum discomfort conditions in wintertime with different window opening ratios and atrium placements.

Figure 20 depicts the dynamic simulation group when the atrium proportion was decreased to 1/4 of the office proportion based on a natural ventilation internal condition which had a varying thermal performance during the year. For instance, when the atrium was placed in the center, north-west and south-east orientations, thermal comfort was observed during the springtime with 0% and 100% opening ratios for all external facade window (and the tower side windows always completely opened). The upper floors, especially the tenth floor, also provided users' thermal comfort in the wintertime when the external windows were closed in the north-east atrium placement. Notably, internal occupants' comfort performance dropped slightly based on how much the window opening ratio increased relative to the decrease in external temperature.

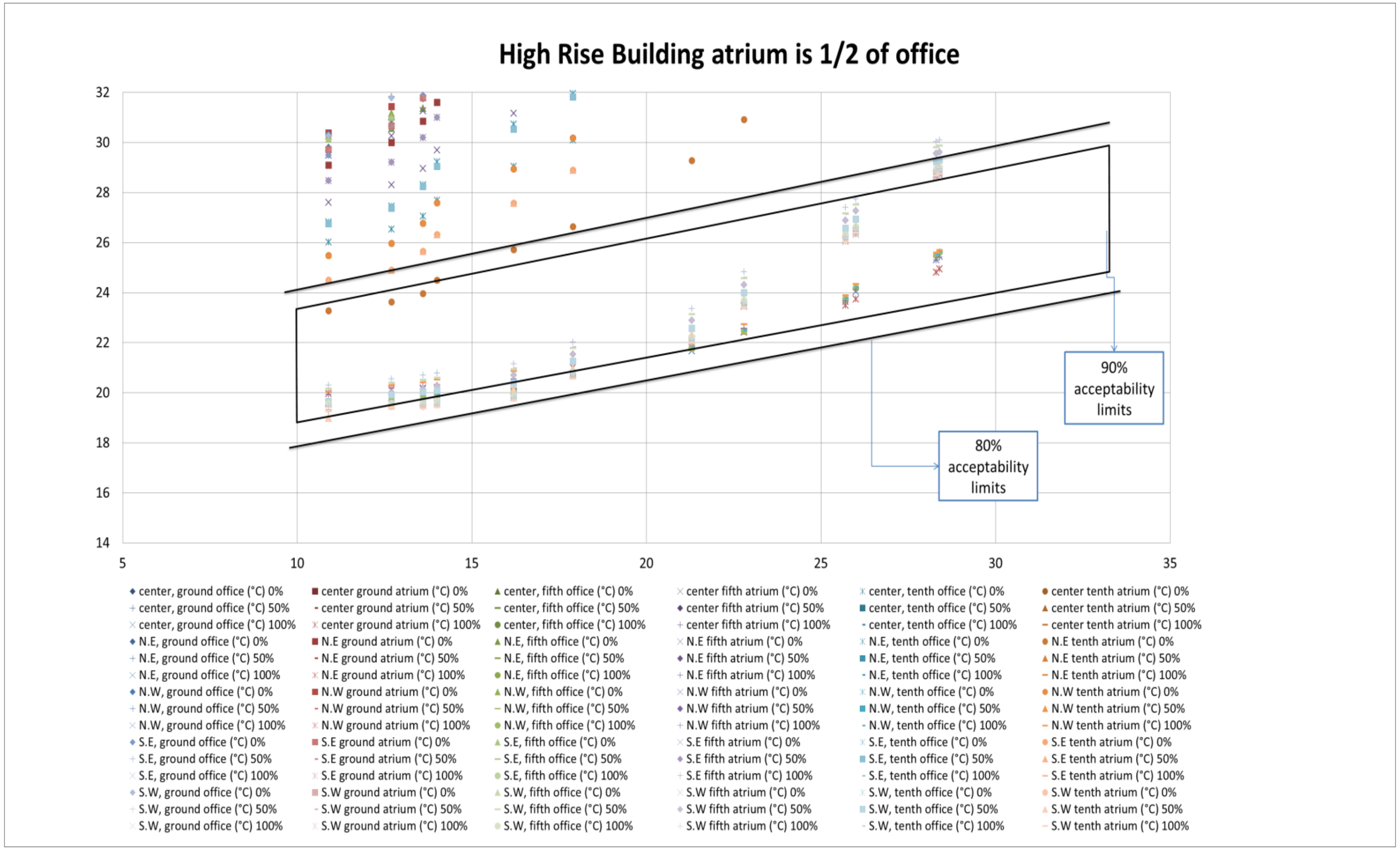


Figure 18: The adaptive model of a naturally conditioned High-Rise with atrium proportion 1/2 of the office space (different atrium placements and window opening ratios as 0%, 50% & 100%).

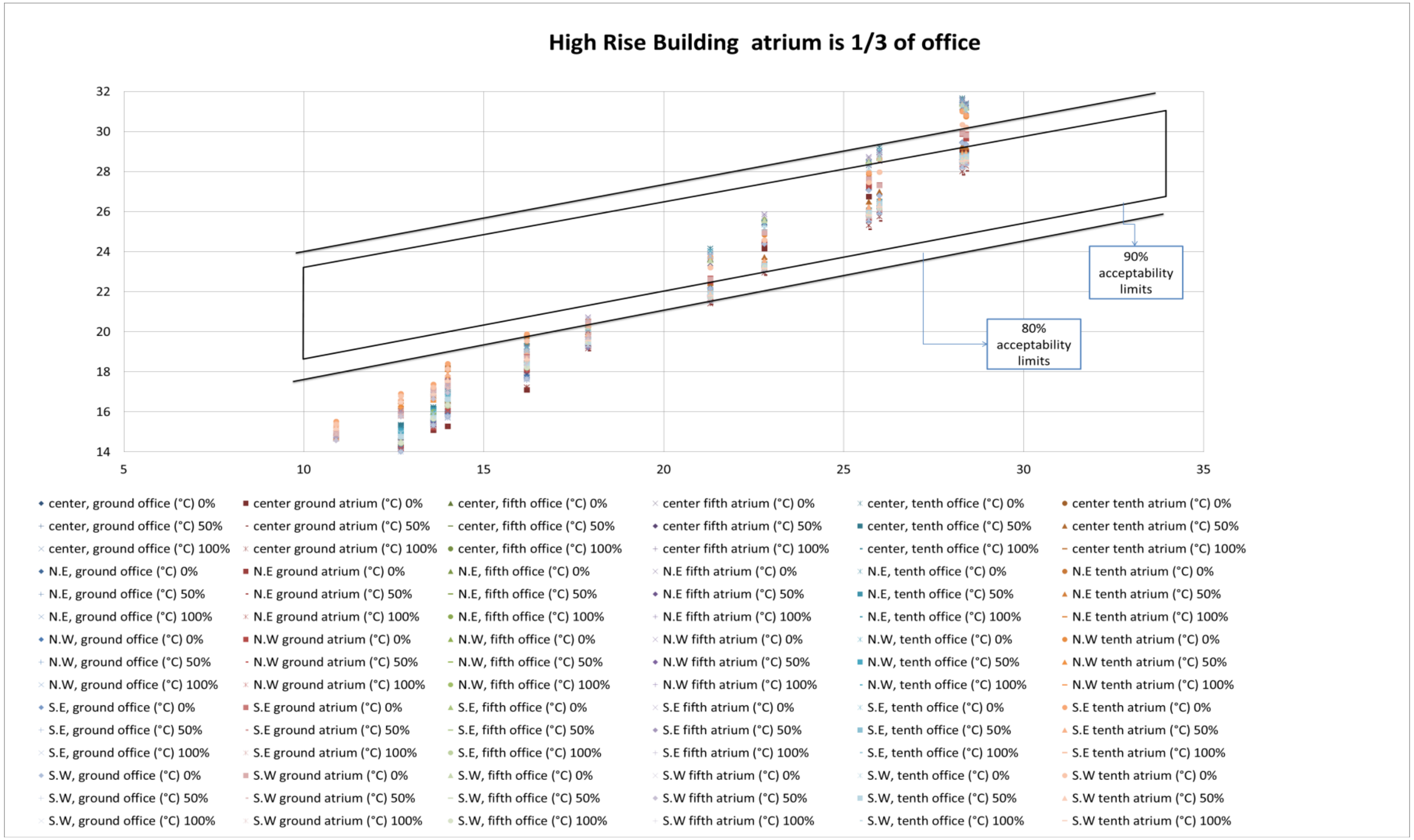


Figure 19: The adaptive model of a naturally conditioned High-Rise with atrium proportion 1/3 of the office space (different atrium placements and window opening ratios as 0%, 50% & 100%).

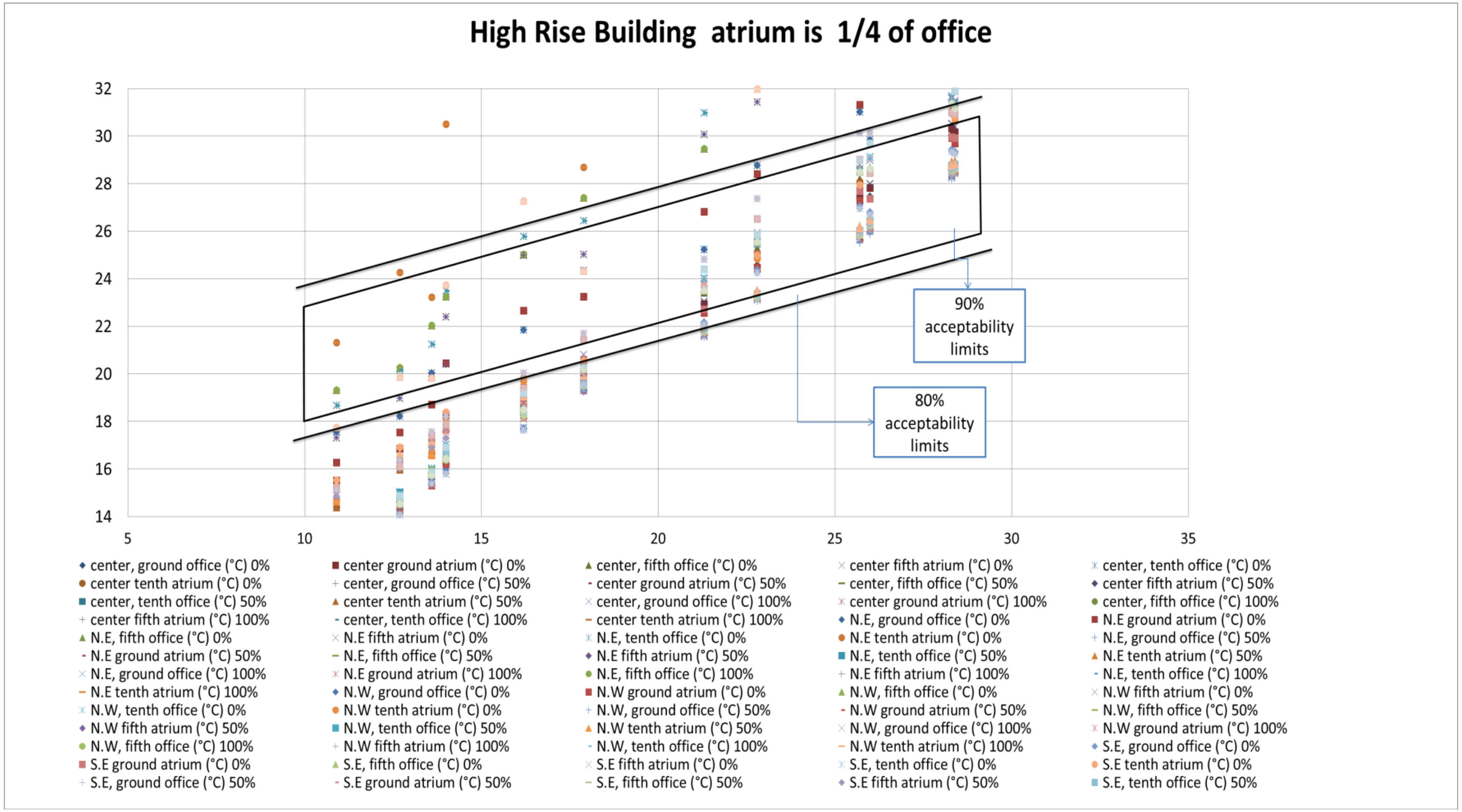


Figure 20: The adaptive model of a naturally conditioned High-Rise with atrium proportion 1/4 of the office space (different atrium placements and window opening ratios as 0%, 50% & 100%).

5.2.2 Active Conditioned Atrium Buildings

5.2.2.1 Single-Floor Atrium Buildings

In this group of simulations, the design parameters were kept the same as the previous single-floor model but with different window opening ratios and internal building conditions. The internal condition involved an air conditioning system with extended hours. Figure 21 depicts the thermal comfort condition as PMV (predicted mean vote) categories when the atrium proportion is 1/2 of the office proportion. For the entirety of the cold months from November to March, all of the different atrium placements in the building had internal comfort conditions for occupants, especially based on category C (-0.70 to 0.70) which also covers the other categories. The north-east and north-west atrium orientations had thermal comfort conditions based on category A just in the office zone throughout the year, while the atrium zone had this acceptable condition during cold seasons. Although the south-east and south-west atrium orientations had thermal comfort conditions based on category B in the office zone, they had a negative performance in the atrium zone during summertime similar to previous simulation groups. As illustrated in Figure 22, the single-floor office building with the atrium proportion 1/2 of the office proportion reported PPD (predicted percentage of dissatisfied) performances exceeding acceptable standards. The south-west atrium orientation had maximum percentages of occupants' dissatisfaction in the office and atrium zones throughout the year. However, while the south-east atrium orientation also performed similarly to the previous placement, the center atrium placement had a better PPD percentage than the other atrium placements with the same condition and design parameters.

Figure 23 illustrates the simulation group with the atrium proportion set at 1/3 of the office proportion in a single-floor building. The south-east atrium orientation had an acceptable thermal comfort in terms of PMV for all building zones during the year based on category B. Although the atrium zones on the last floor had a negative performance, especially from April to October. In contrast, the thermal comfort (PMV) of the south-west atrium orientation in the office zones was mainly based on category A, except for November and May when it was based on category B. However, the atrium zones did not provide thermal comfort from April to end of September, while January to May, November, and December were had thermal comfort based category B. In the north-west placement of this dynamic simulation group, the office zone mainly had internal comfort based on category A, with May and December having comfort according to category B. In the atrium zone, thermal comfort from October to May was based on category A and B indicating complete comfort, while from April to September did not have any comfort at all. The north-east atrium orientation had thermal comfort conditions from December to May based on category B and based on category A during other months. This atrium zone in this group had internal comfort from October to May based on category B, but from April to September was complete discomfort. When the atrium is located in the center of the building, thermal comfort was provided in the office zone during the year and October to May had comfort based on category C. As illustrated in Figure 24, the PPD thermal comfort parameter, the center atrium orientation had a better comfort condition than the other north-east, north-west, south-east, and south-west atrium placements.

As shown in Figure 25, when the atrium proportion changed to 1/4 of the office proportion in a single-floor building with a center atrium orientation, the office zone had thermal comfort based on category C during the year. However, the atrium zone had the worst internal condition from April to September with the other months providing thermal comfort based on category C (-0.70 to 0.70). The north-east atrium orientation in the office zone had thermal comfort from January to December according to category A. Furthermore, the atrium zone in this group had thermal comfort (PMV) from November to March based on category A and based on category C in April. The office zone in the north-west atrium placement had an acceptable internal comfort from January to December based on category B (-0.50 to 0.50) and other months based on category A (-0.20 to 0.20). The atrium zone during April to September had a negative internal comfort, although thermal comfort was observed from October to March based on category B. The office zones in the south-east and south-west atrium orientations had internal comfort conditions during the year based on category B, as well as in the atrium zones from October to March. As depicted in Figure 26, the PPD for the atrium proportion as 1/4 of the office proportion with a center atrium placement had better users' satisfaction (comfort) in the office zone based on category C of PPD. In addition, the south-east, south-west, north-west, and north-east atrium orientations had thermal comfort based on the PPD categories in the office zones.

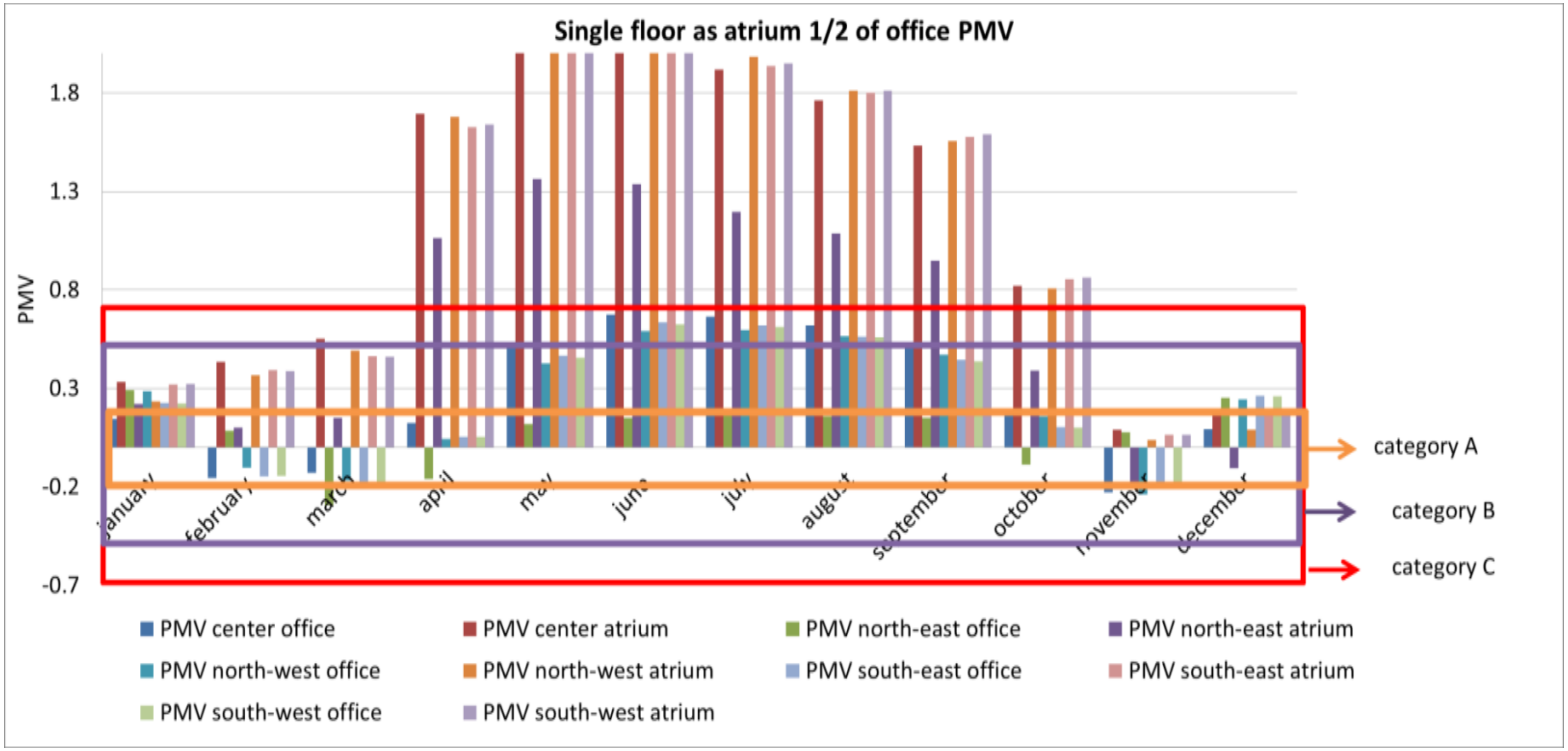


Figure 21: The PMV (predicted mean vote) for a mechanically conditioned Single-Floor building with atrium proportion 1/2 of the office space.

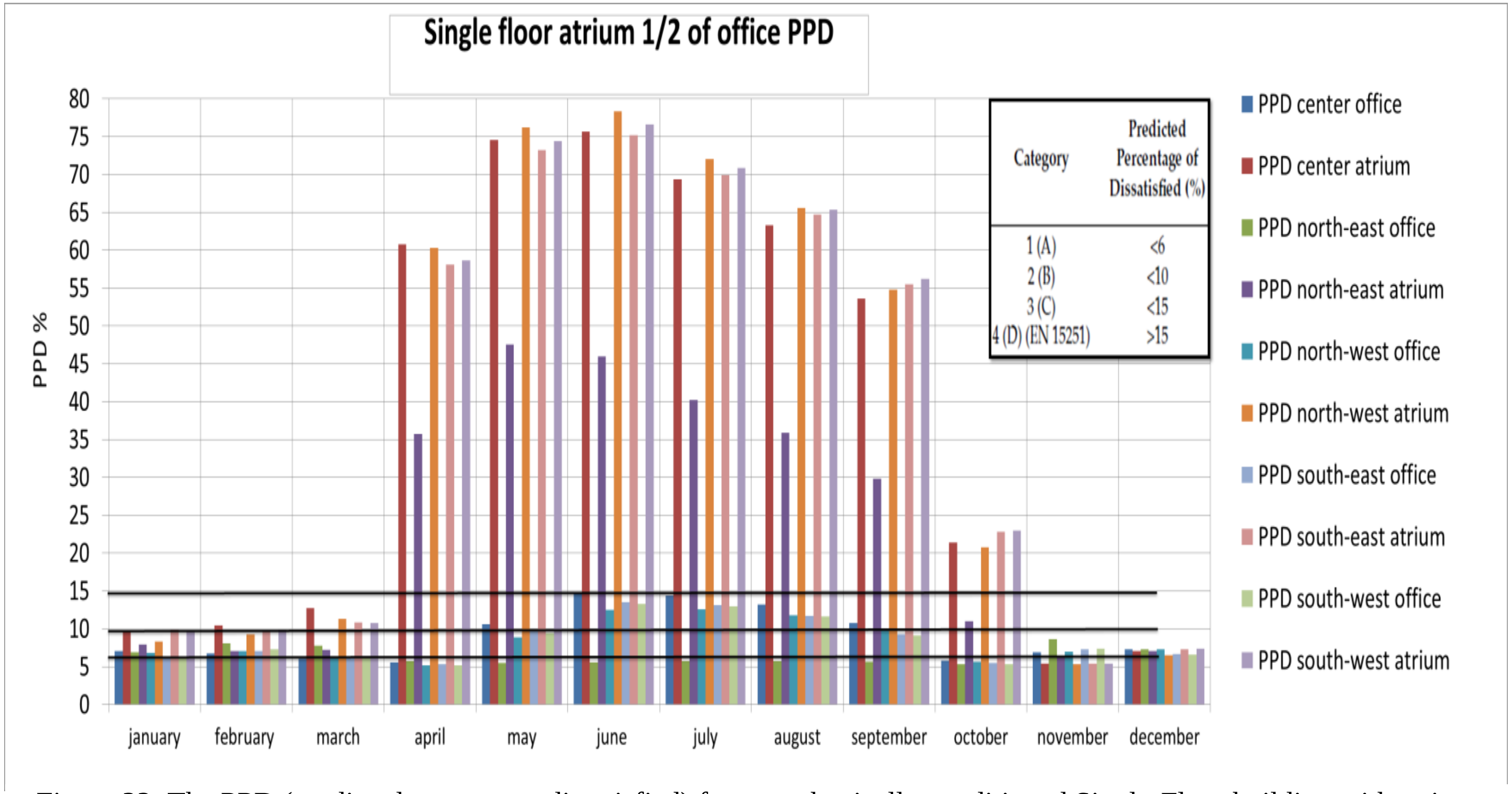


Figure 22: The PPD (predicted percentage dissatisfied) for a mechanically conditioned Single-Floor building with atrium proportion 1/2 of the office space.

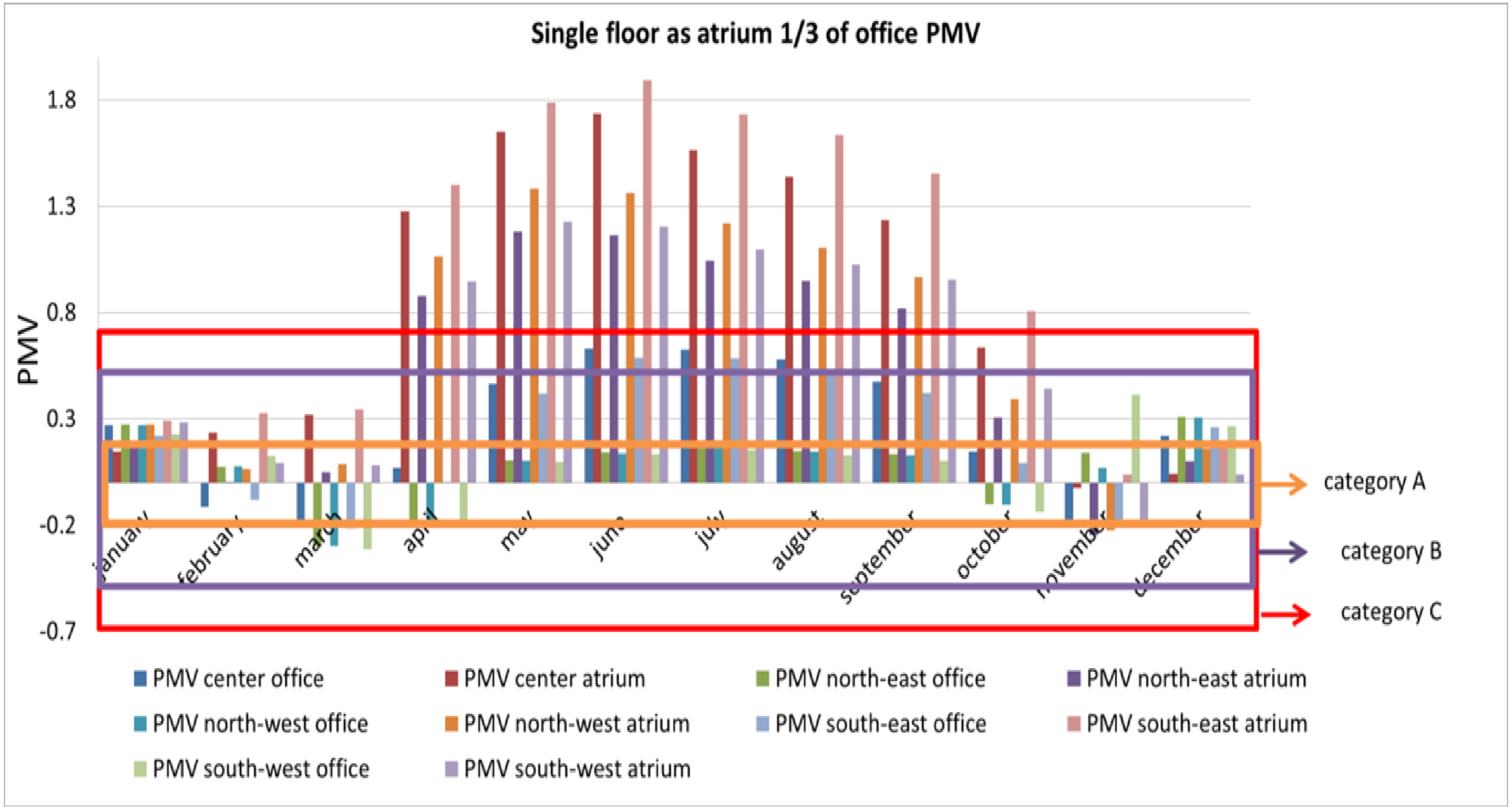


Figure 23: The PMV (predicted mean vote) for a mechanically conditioned Single-Floor building with atrium proportion 1/3 of the office space.

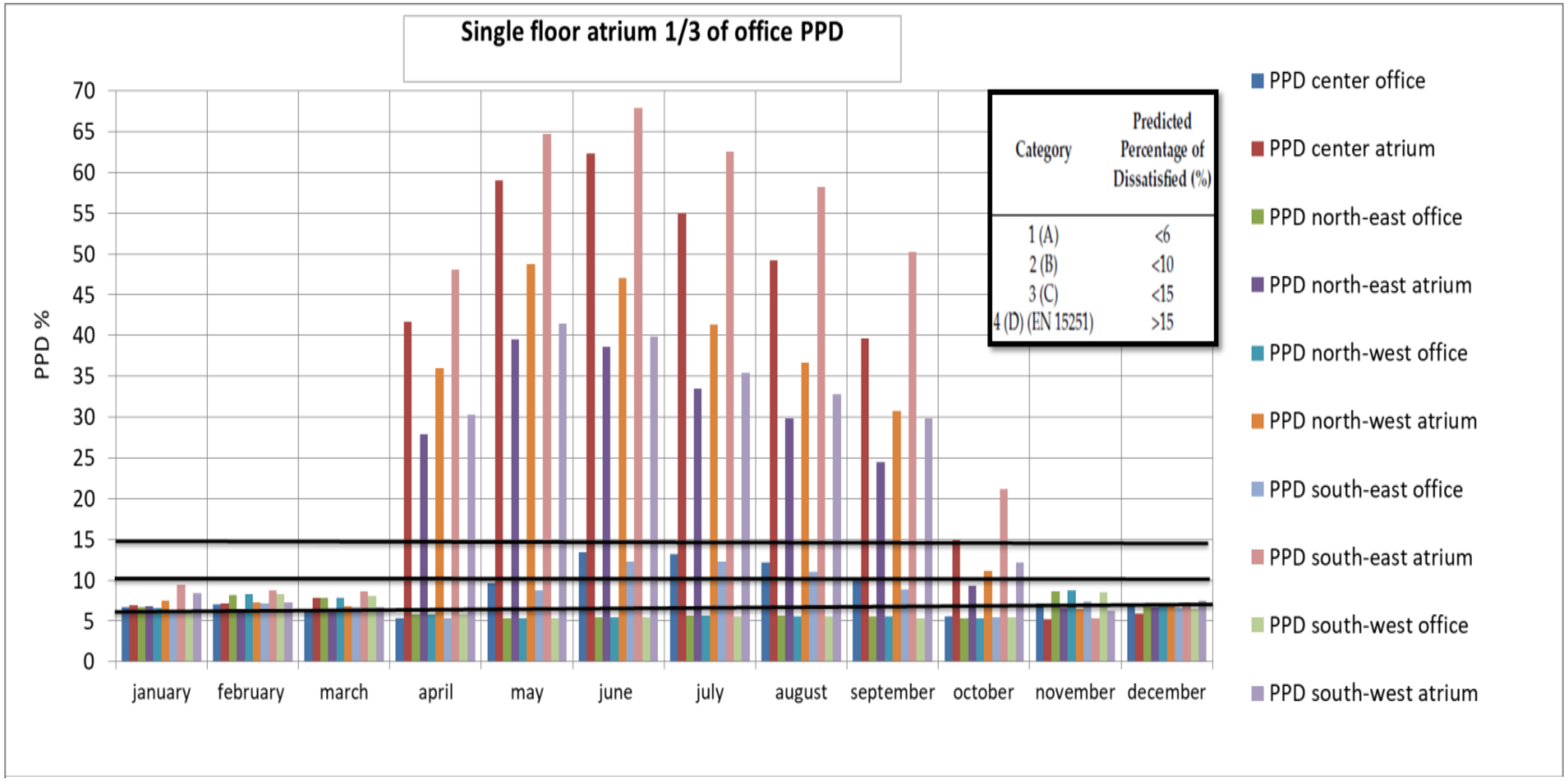


Figure 24: The PPD (predicted percentage dissatisfied) for a mechanically conditioned Single-Floor building with atrium proportion 1/3 of the office space.

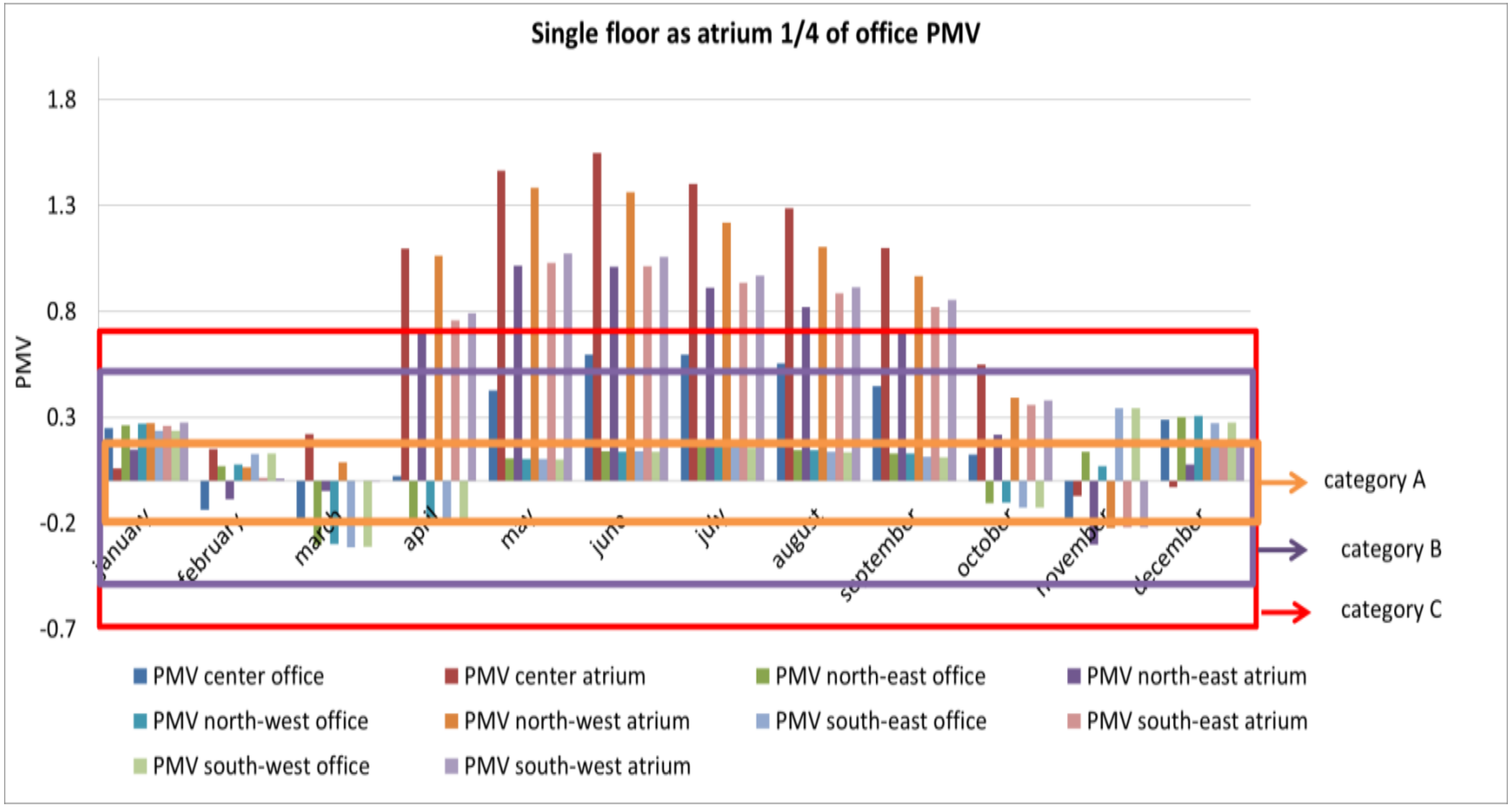


Figure 25: The PMV (predicted mean vote) for a mechanically conditioned Single-Floor building with atrium proportion 1/4 of the office space.

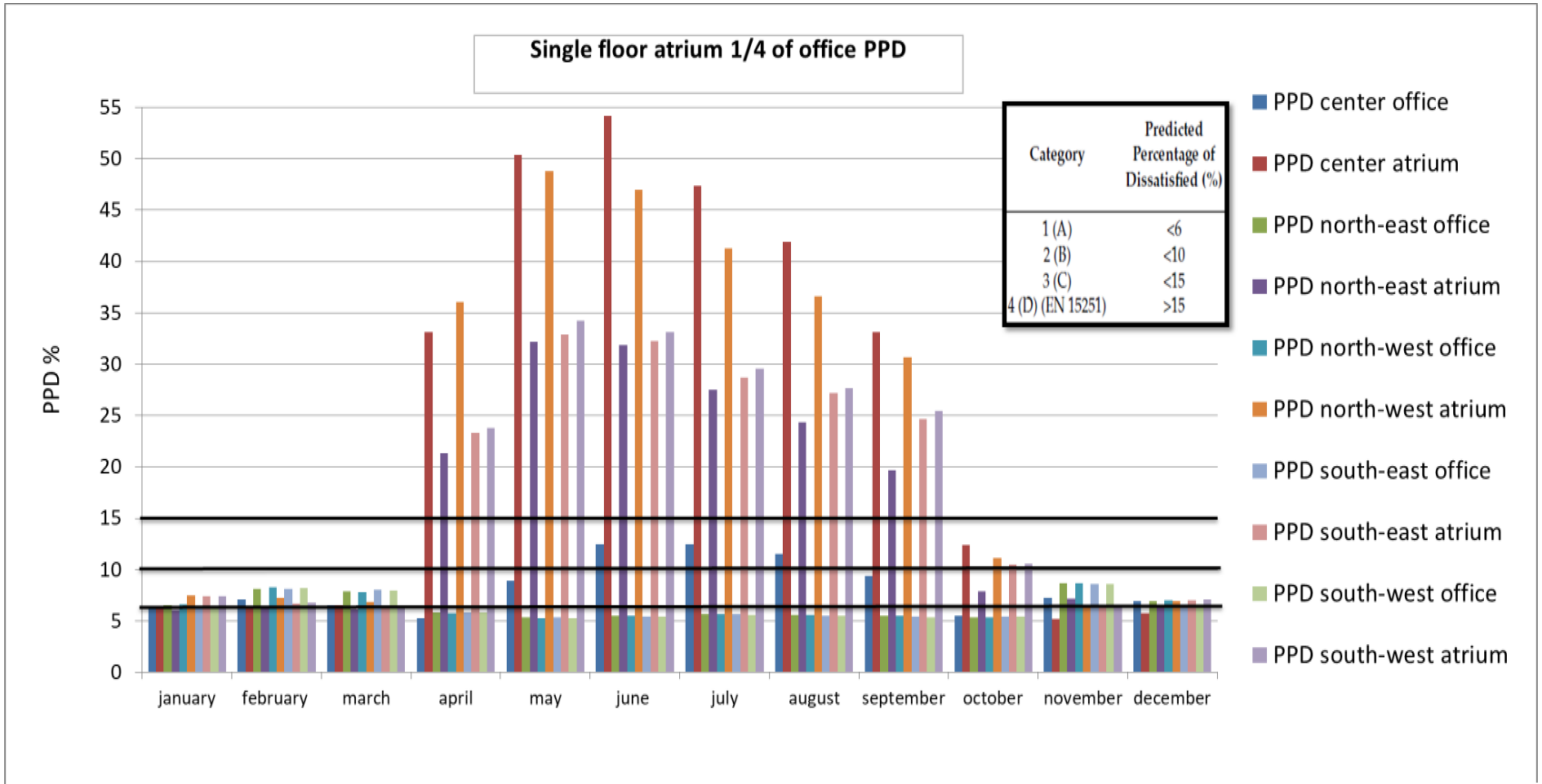


Figure 26: The PPD (predicted percentage dissatisfied) for a mechanically conditioned Single-Floor building with atrium proportion 1/4 of the office space.

5.2.2.2 Medium-Rise Atrium Buildings

In this dynamic thermal simulation group for the medium-rise atrium building, the internal condition was changed to a mechanical system using air conditioning. As illustrated in Figure 27, when the atrium proportion was set at 1/2 of the office proportion, the PMV (predicted mean vote) was acceptable for different atrium orientations (center, north-east, north-west, south-east, and south-west) from January to March, November, and December with thermal comfort based on category C (-0.70 to 0.70). However, the most negative condition existed in the atrium zone of the last floor (fifth floor) for the center, north-east, north-west, south-east, and south-west atrium orientations, especially from April to October. As depicted in Figure 28, the PPD (predicted percentage of dissatisfied) analysis results had a close performance to the PMV. In this dynamic simulation group with different atrium placements, thermal comfort was observed according to category C (C <15) from January to March, November, and December. Although the fifth-floor atrium zone in this simulation group still had the most discomfort condition compared to other building zones.

As can be seen in Figure 29, when the atrium proportion changed to 1/3 of the office proportion in a medium-rise atrium building, thermal comfort was observed from January to March, November, and December based on PMV. Significantly, the lower floors in this simulation group, especially the ground floor, had a better internal comfort performance with the atrium placed in the center and south-east. A PPD analysis of the same design parameters (atrium proportion 1/3 of the office proportion), showed a thermal comfort condition based on category B (B<10) from January to March, November, and December according to as can be seen in Figure 30.

As depicted in Figure 31, the PMV factor of the medium-rise building with the atrium proportion 1/4 of the office proportion was similar to the acceptable standards. Additionally, thermal comfort in this dynamic simulation group was based on category B (-0.50 to -0.50), from January to March April and category C from October to December (-0.70 to 0.70). Also, as illustrated in Figure 32, which analyzed the PPD parameter, January to March, November, and December also had thermal comfort based on category B (B<10), while October was based on category C (C<15). As with the other medium-rise atrium building simulations, the atrium zone of the last floor (fifth floor) had the worst users' internal comfort conditions compared to other building zones.

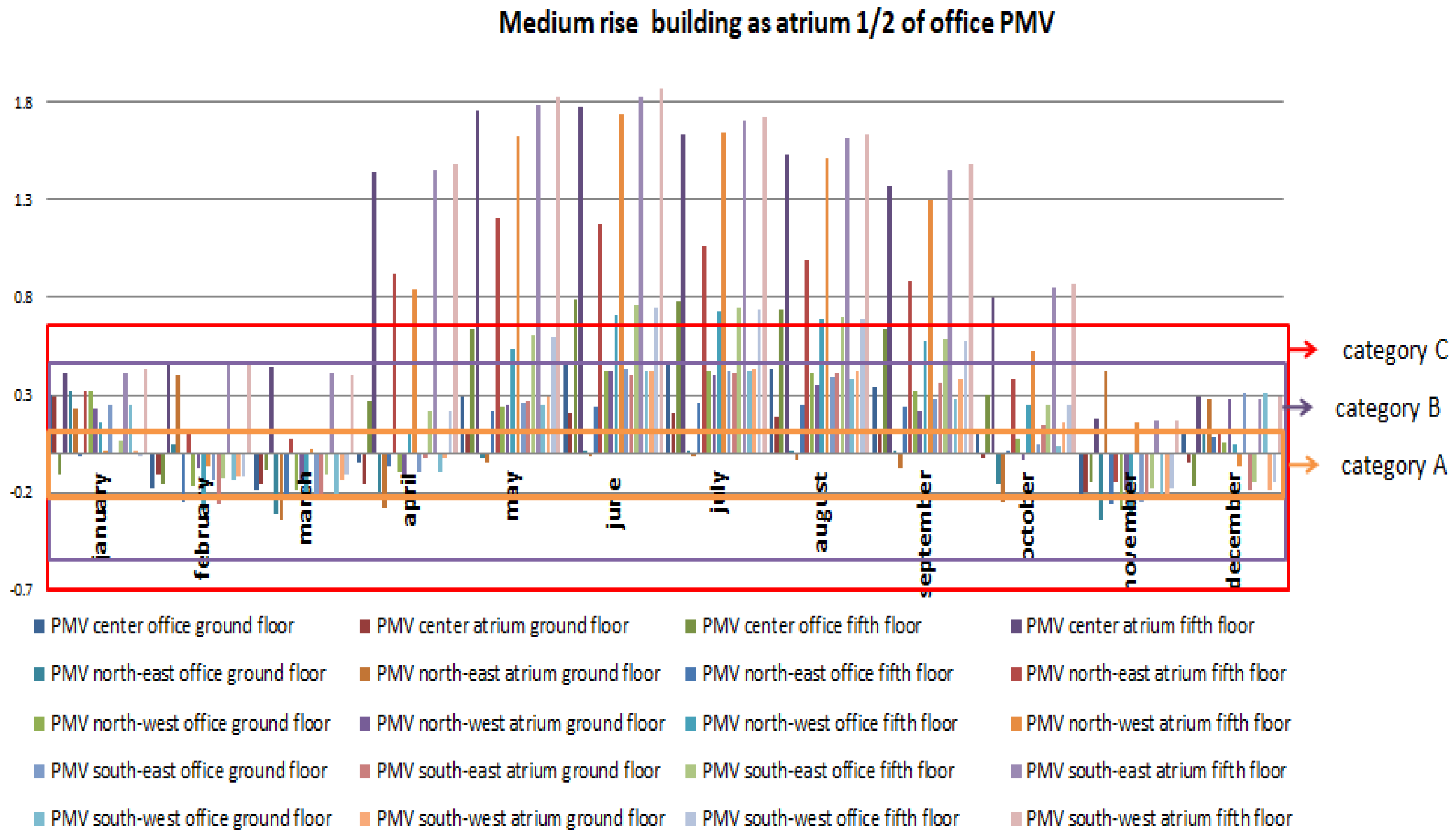


Figure 27: The PMV (predicted mean vote) for a mechanically conditioned Medium-Rise building with atrium proportion 1/2 of the office space.

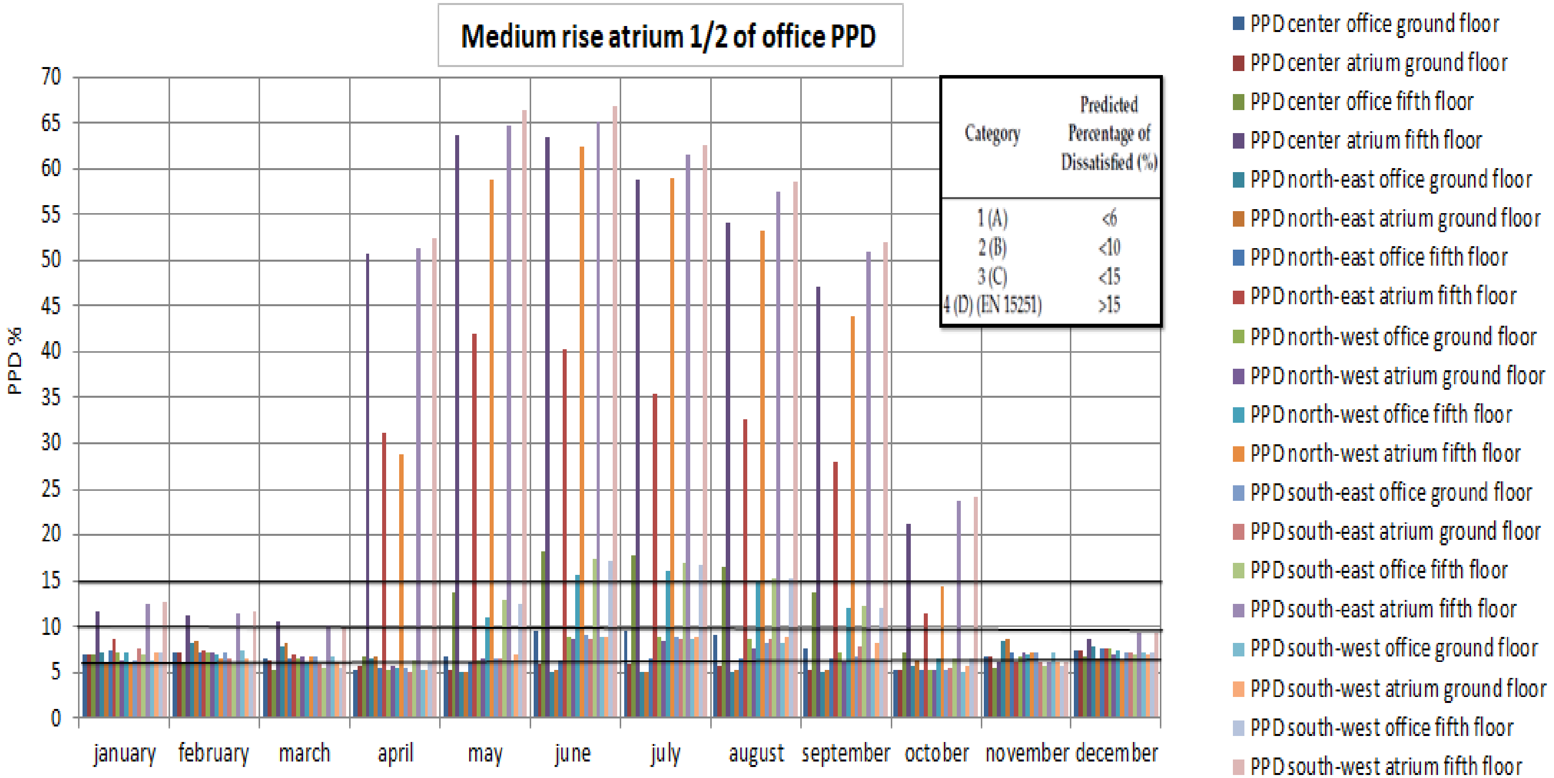


Figure 28: The PPD (predicted percentage dissatisfied) for a mechanically conditioned Medium-Rise building with atrium proportion 1/3 of the office space.

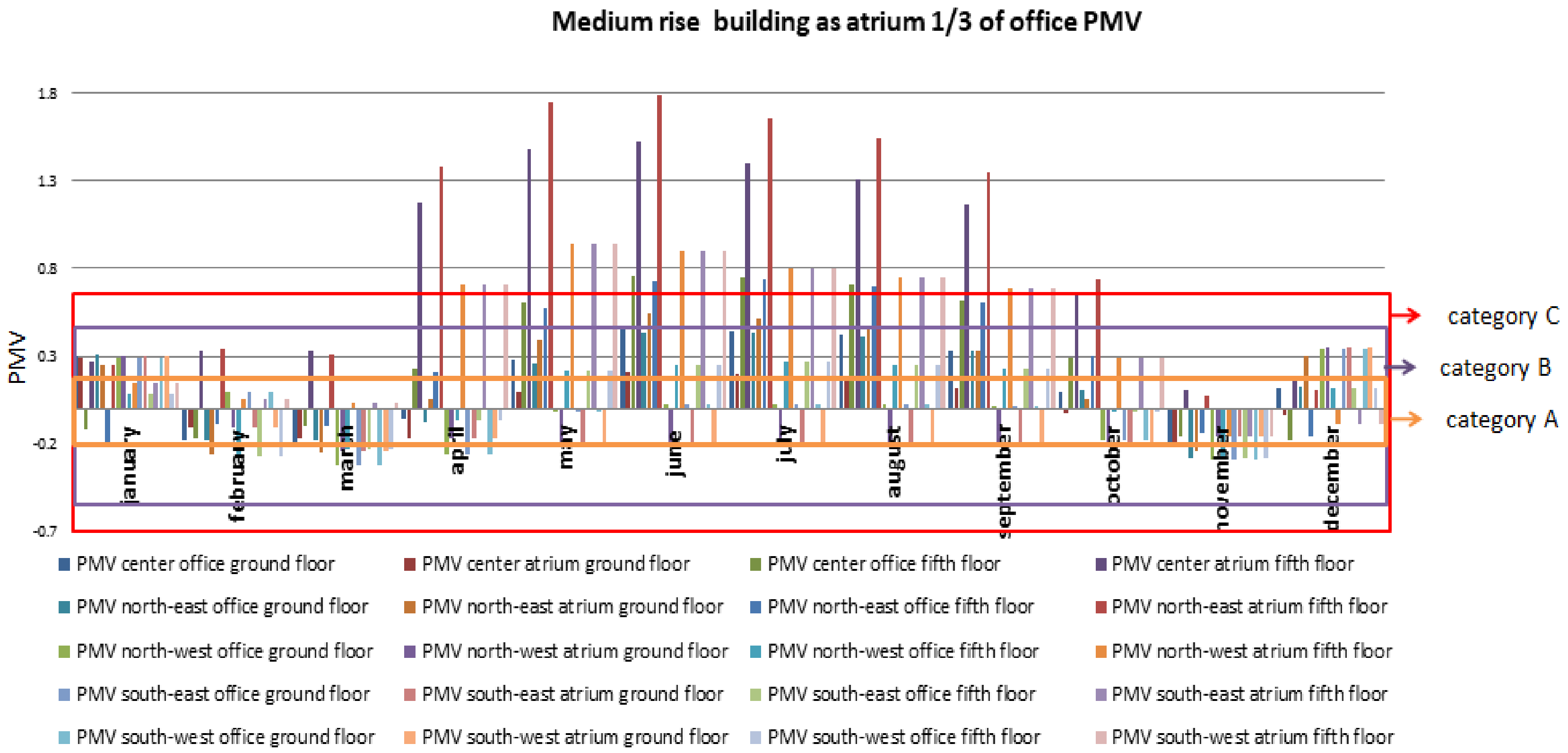


Figure 29: The PMV (predicted mean vote) for a mechanically conditioned Medium-Rise building with atrium proportion 1/3 of the office space.

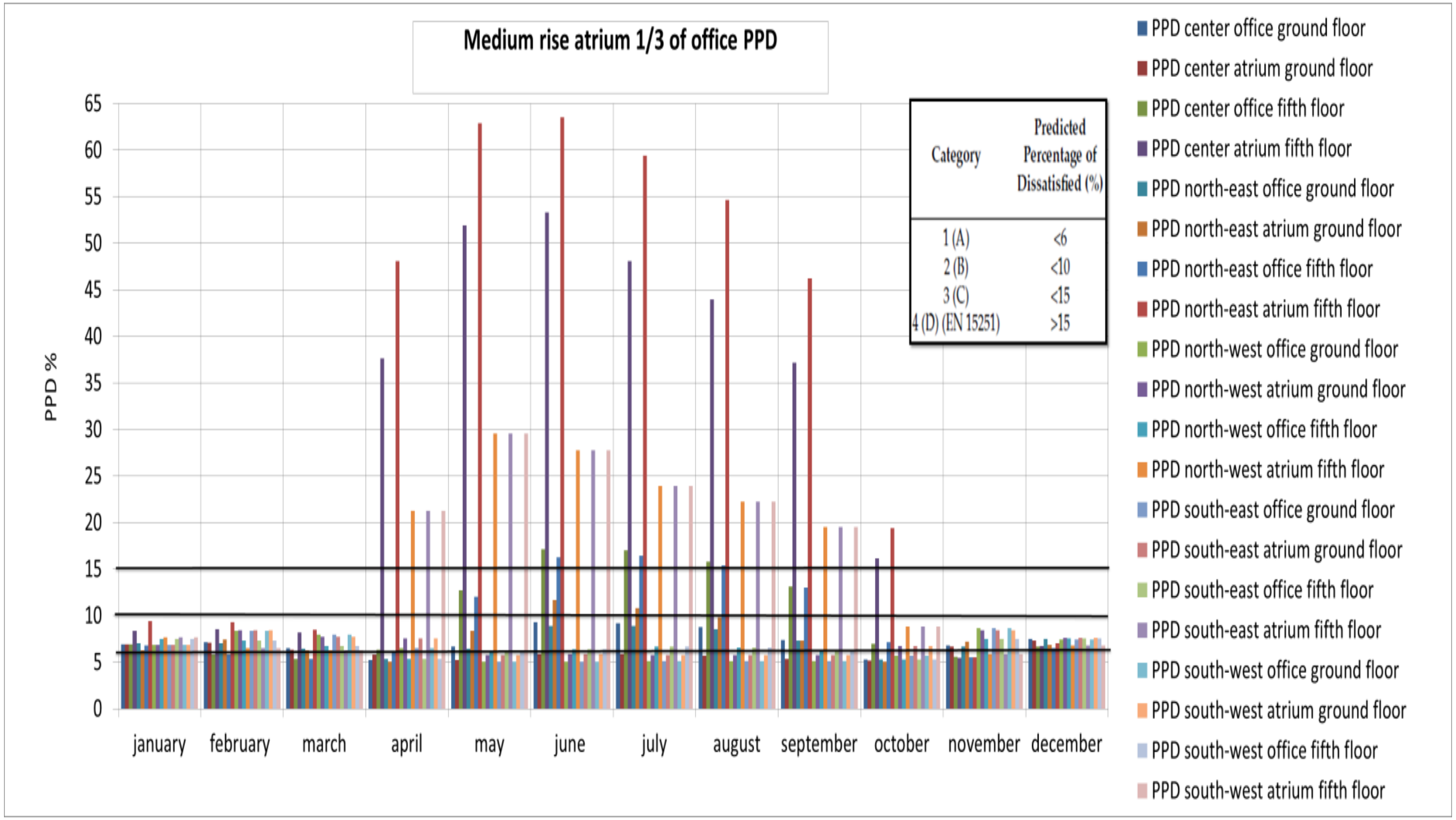


Figure 30: The PPD (predicted percentage dissatisfied) for a mechanically conditioned Medium-Rise building with atrium proportion 1/3 of the office space.

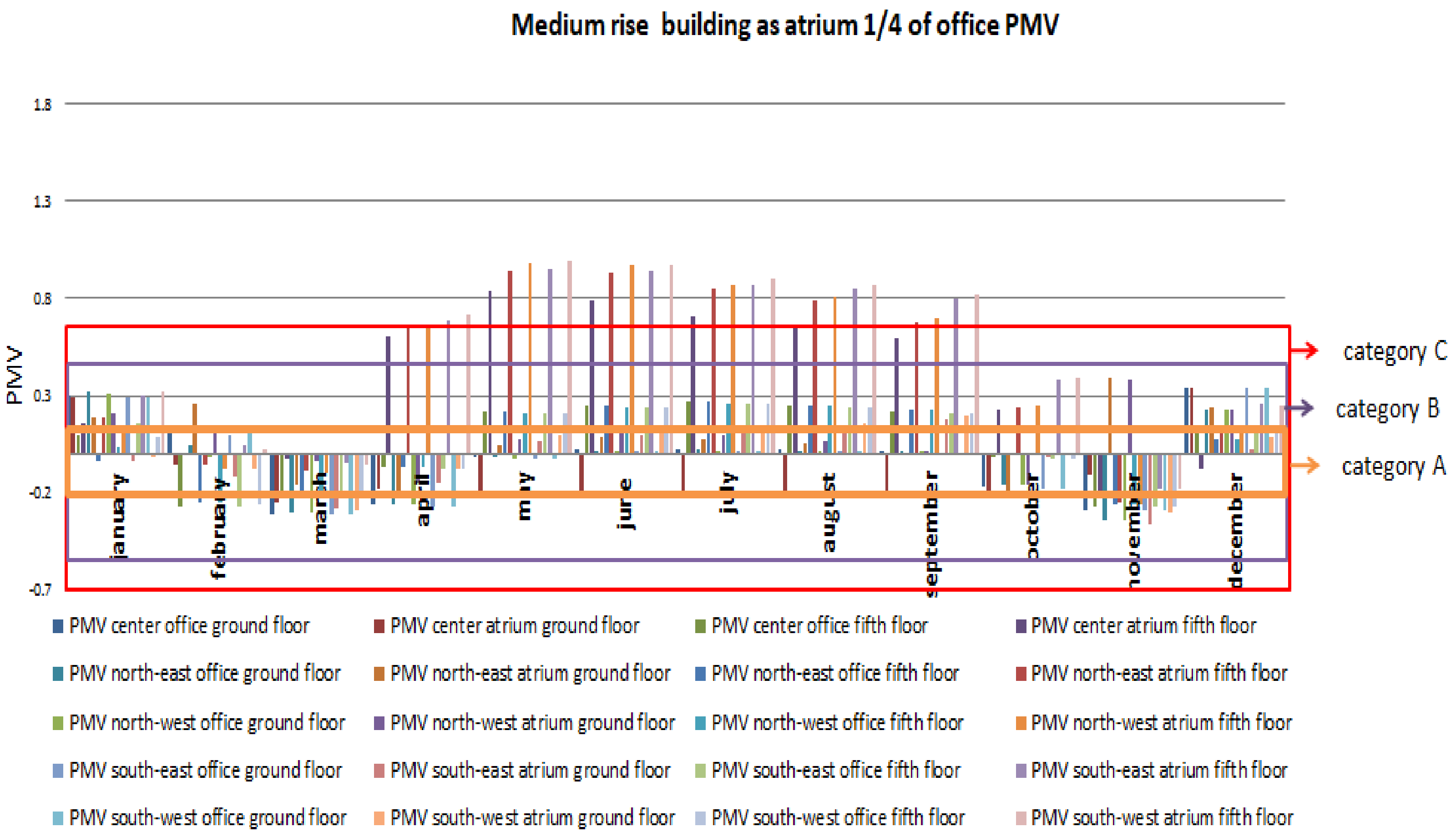


Figure 31: The PMV (predicted mean vote) for a mechanically conditioned Medium-Rise building with atrium proportion 1/4 of the office space.

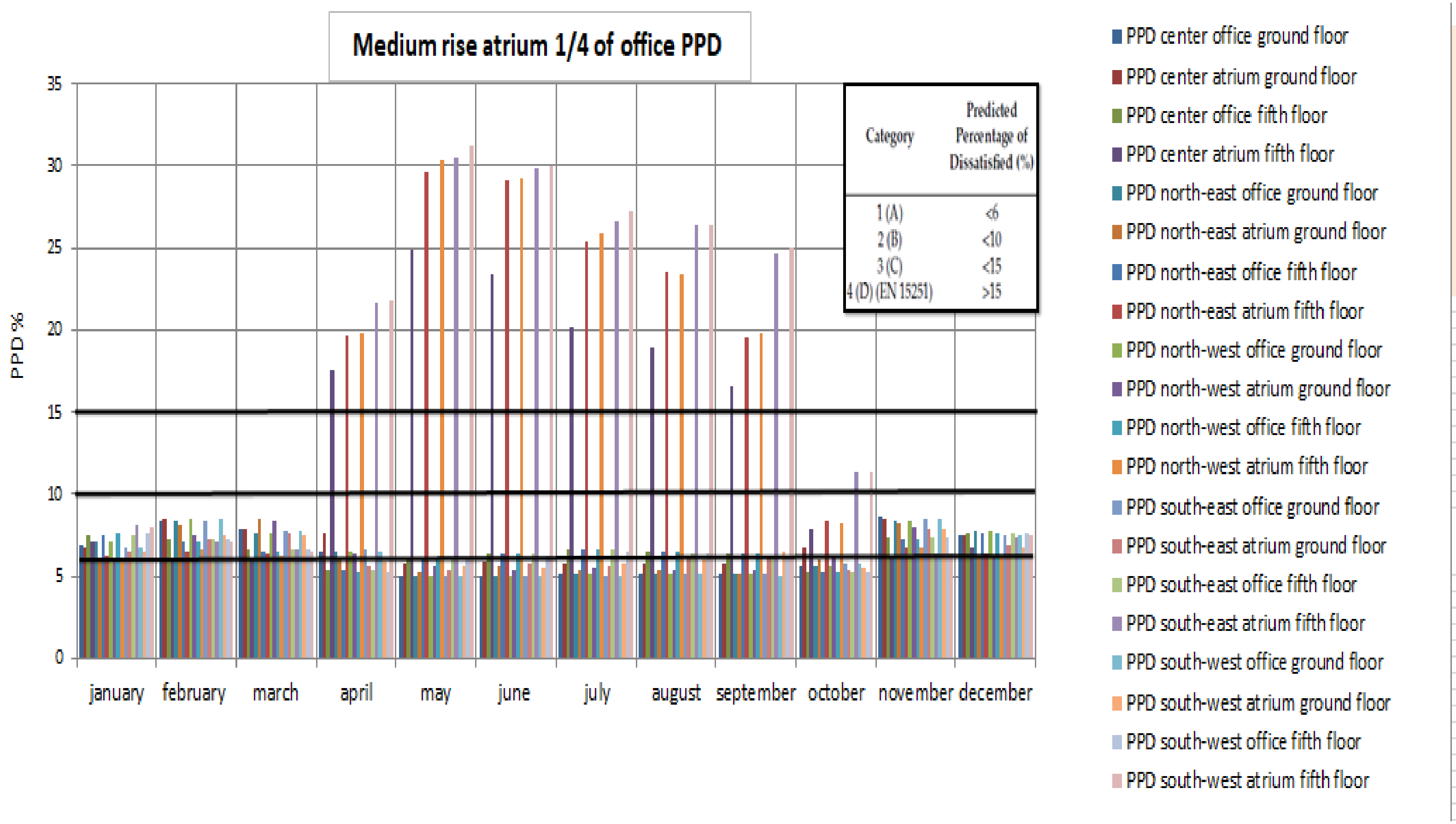


Figure 32: The PPD (predicted percentage dissatisfied) for a mechanically conditioned Medium-Rise building with atrium proportion 1/4 of the office space.

5.2.2.3 High-Rise Atrium Buildings

As illustrated in Figure 33, in terms of the PMV (predicted mean vote), the last atrium zone on the tenth floor of the high-rise atrium building with the atrium proportion 1/2 of the office proportion had the maximum dissatisfaction throughout the year and with different atrium orientations. However, in the north-east atrium orientation, the office zone of the last floor had a thermal comfort condition based on category B (-0.50 to 0.50), which is in contrast to the atrium zone condition of the same floor. As shown in Figure 34, the (predicted percentage of dissatisfied) PPD of this dynamic simulation group depicted thermal comfort conditions based on category c (C<15) during the year except for the atrium zone of the last floor. Furthermore, the north-east, north-west, south-east, and south-west atrium orientations of the high-rise atrium building provided occupants' thermal comfort from January to March, November, and December based on category B (B<10).

Figure 35 depicts the simulation high-rise atrium building with the atrium proportion changed to 1/3 of the office proportion. All building zones had maximum users' satisfaction throughout the year based on category C of PMV (-0.70 to 0.70) except the last atrium zone of the last floor. Furthermore, as shown in Figure 36, the PPD of this simulation group was based on category A (A<6) in January, November and December as category B (B<10), and from February to March as category C (B<15); all of which provided users' satisfaction (thermal comfort).

As illustrated in Figure 37, when the atrium proportion decreased to 1/4 of the office proportion there is maximum occupants' satisfaction from February to March, November, and December based on category B (-0.50 to 0.50) of PMV (predicted mean vote) in all atrium placements. Although the middle floors of the high-rise atrium building had the most negative internal condition in January. As shown in Figure 38, data analysis placed PPD (predicted percentage of dissatisfied) from January to March in category C (C<15) and November and December in category B (B<10), indicating minimum users’ dissatisfaction (thermal comfort achieved).

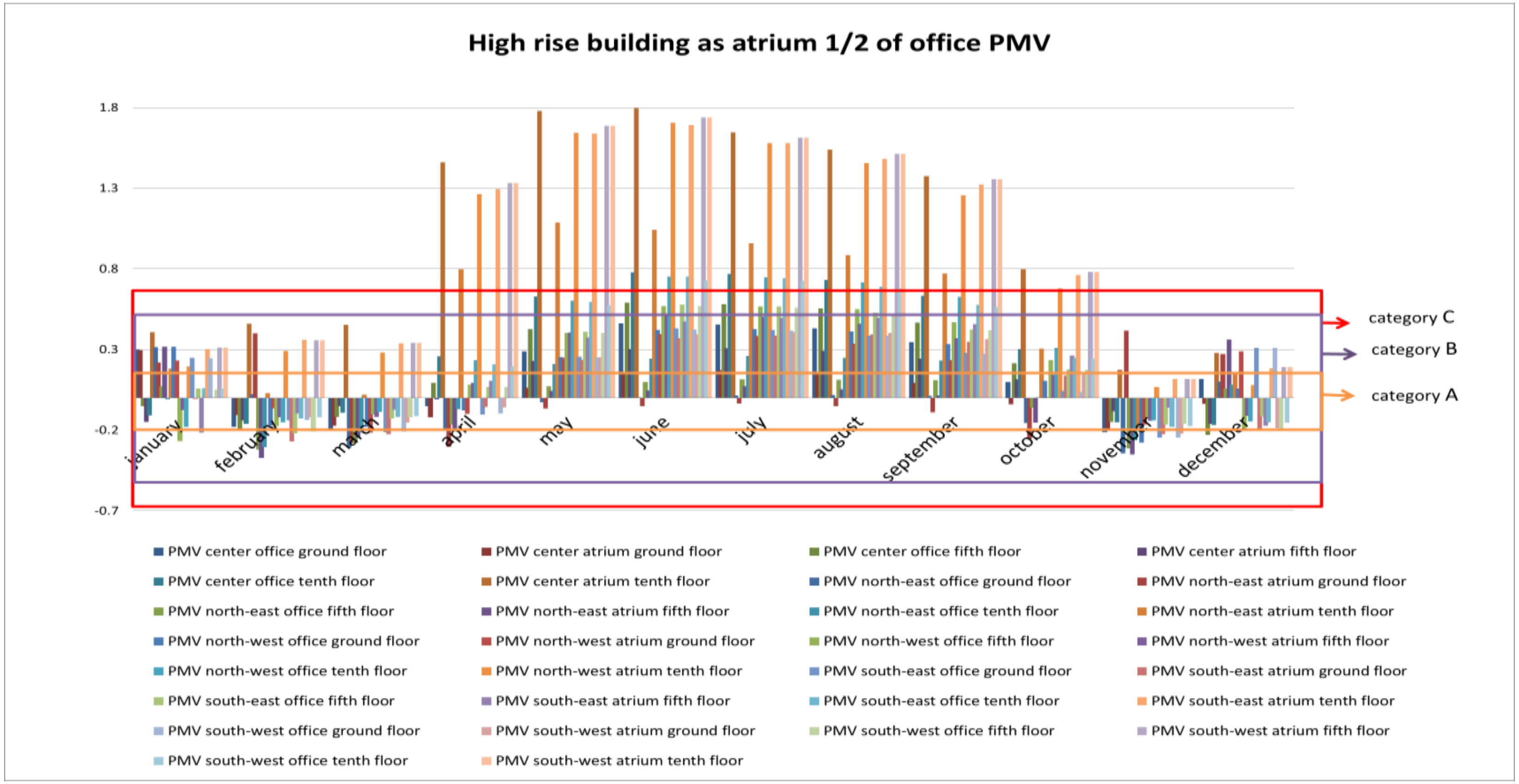


Figure 33: The PMV (predicted mean vote) for a mechanically conditioned High-Rise building with atrium proportion 1/2 of the office space.

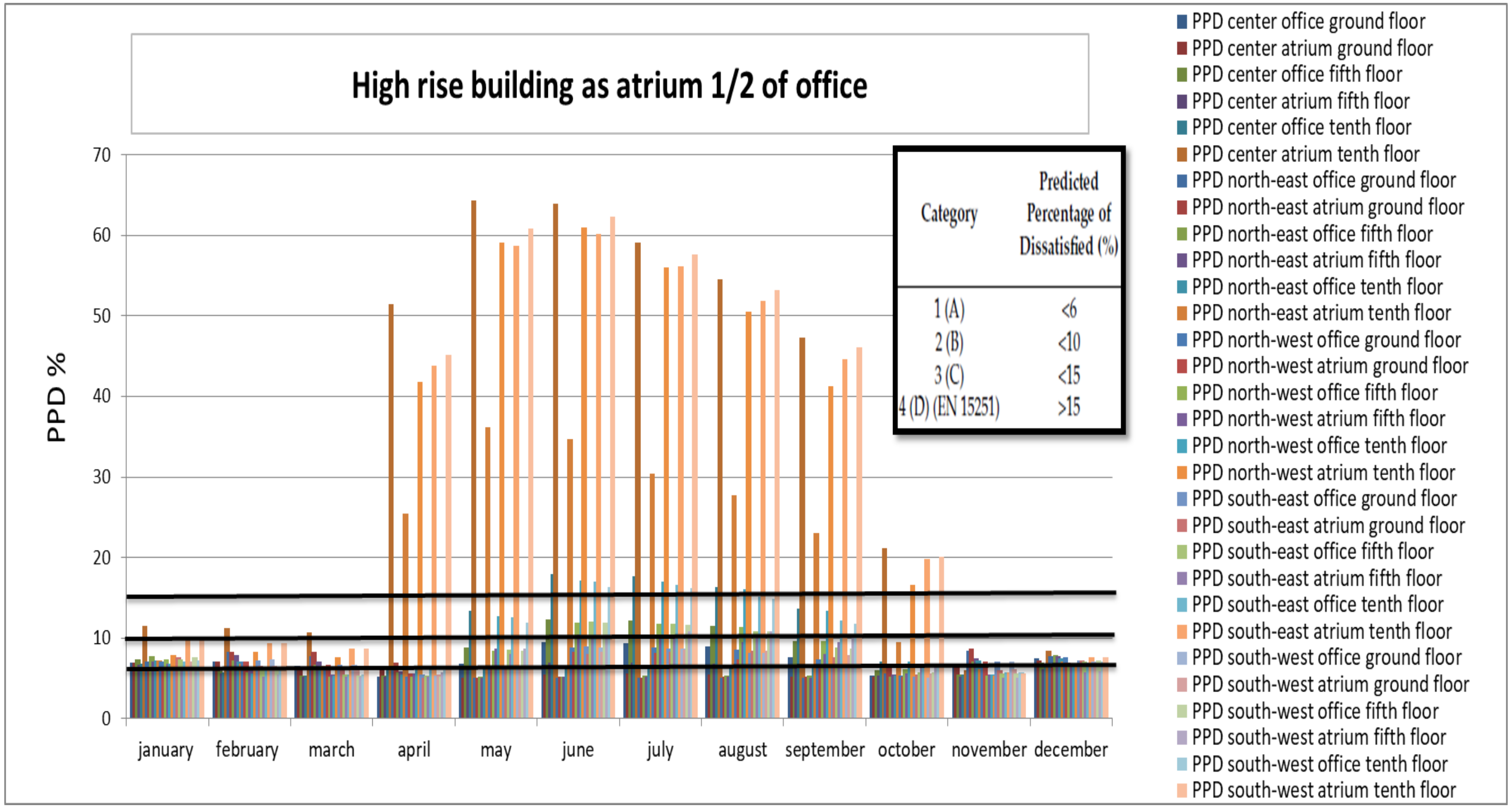


Figure 34: The PPD (predicted percentage dissatisfied) for av mechanically conditioned High-Rise building with atrium proportion 1/2 of the office space.

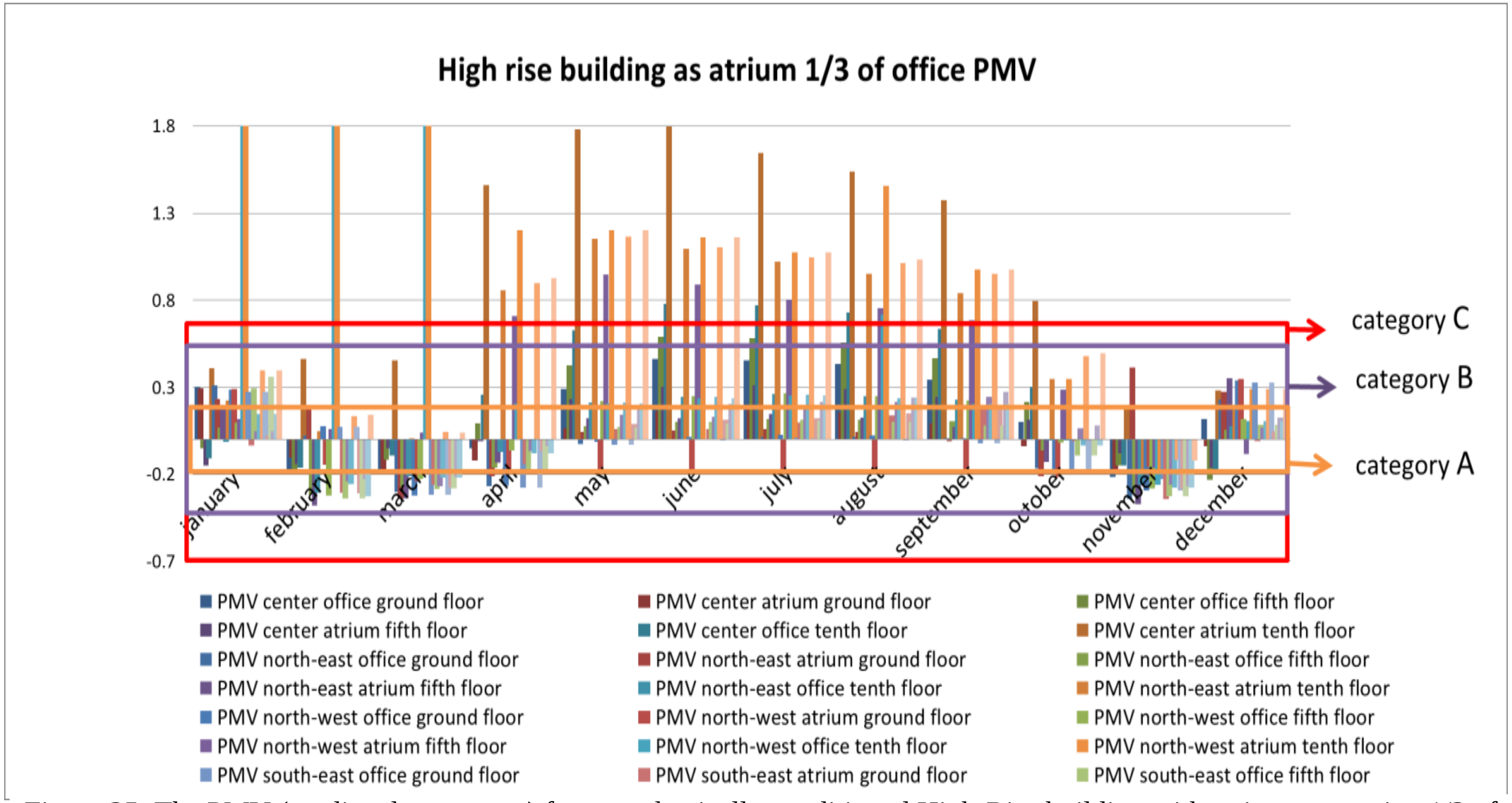


Figure 35: The PMV (predicted mean vote) for a mechanically conditioned High-Rise building with atrium proportion 1/3 of the office space.

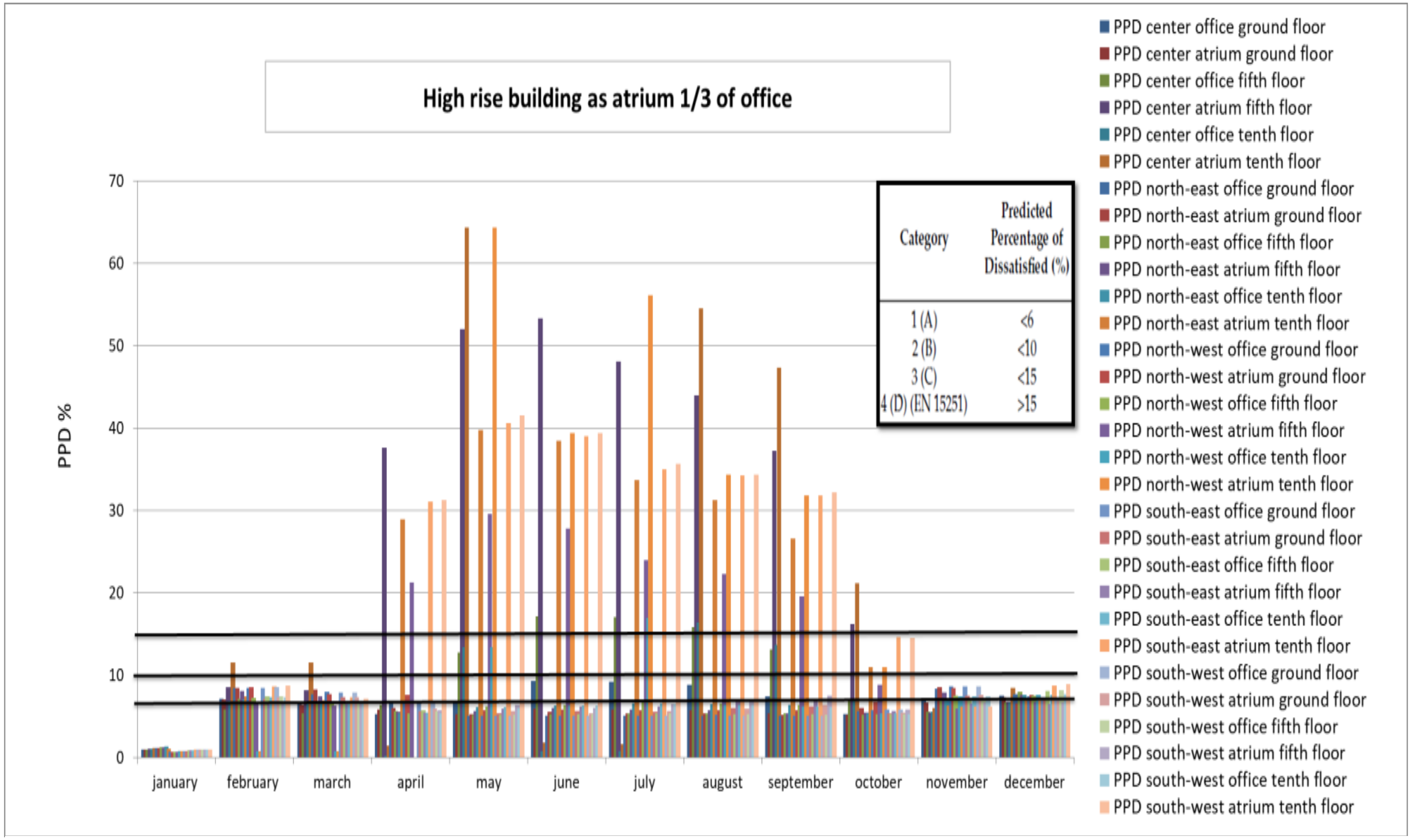


Figure 36: The PPD (predicted percentage dissatisfied) for av mechanically conditioned High-Rise building with atrium proportion 1/3 of the office space.

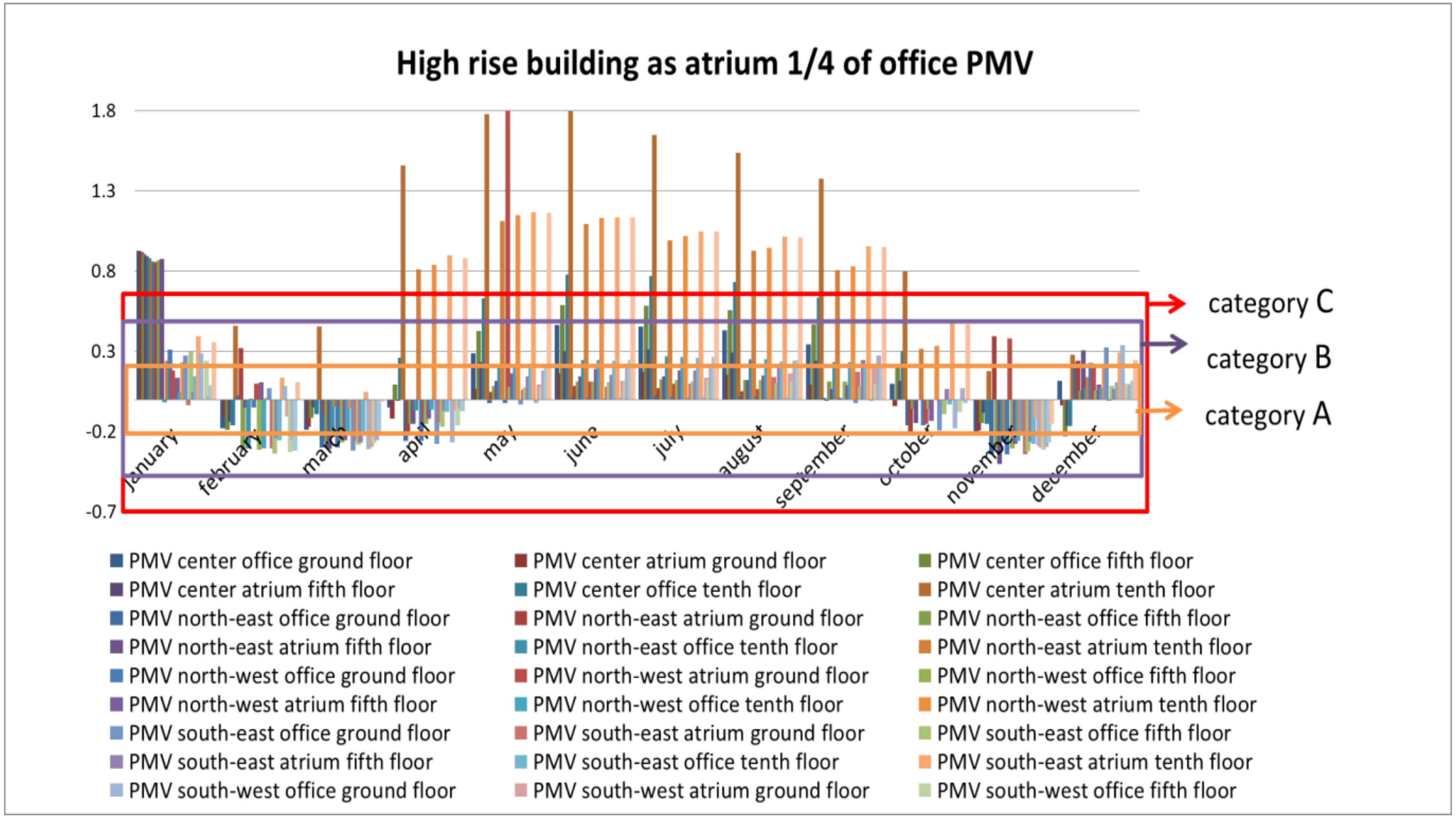


Figure 37: The PMV (predicted mean vote) for a mechanically conditioned High-Rise building with atrium proportion 1/4 of the office space.

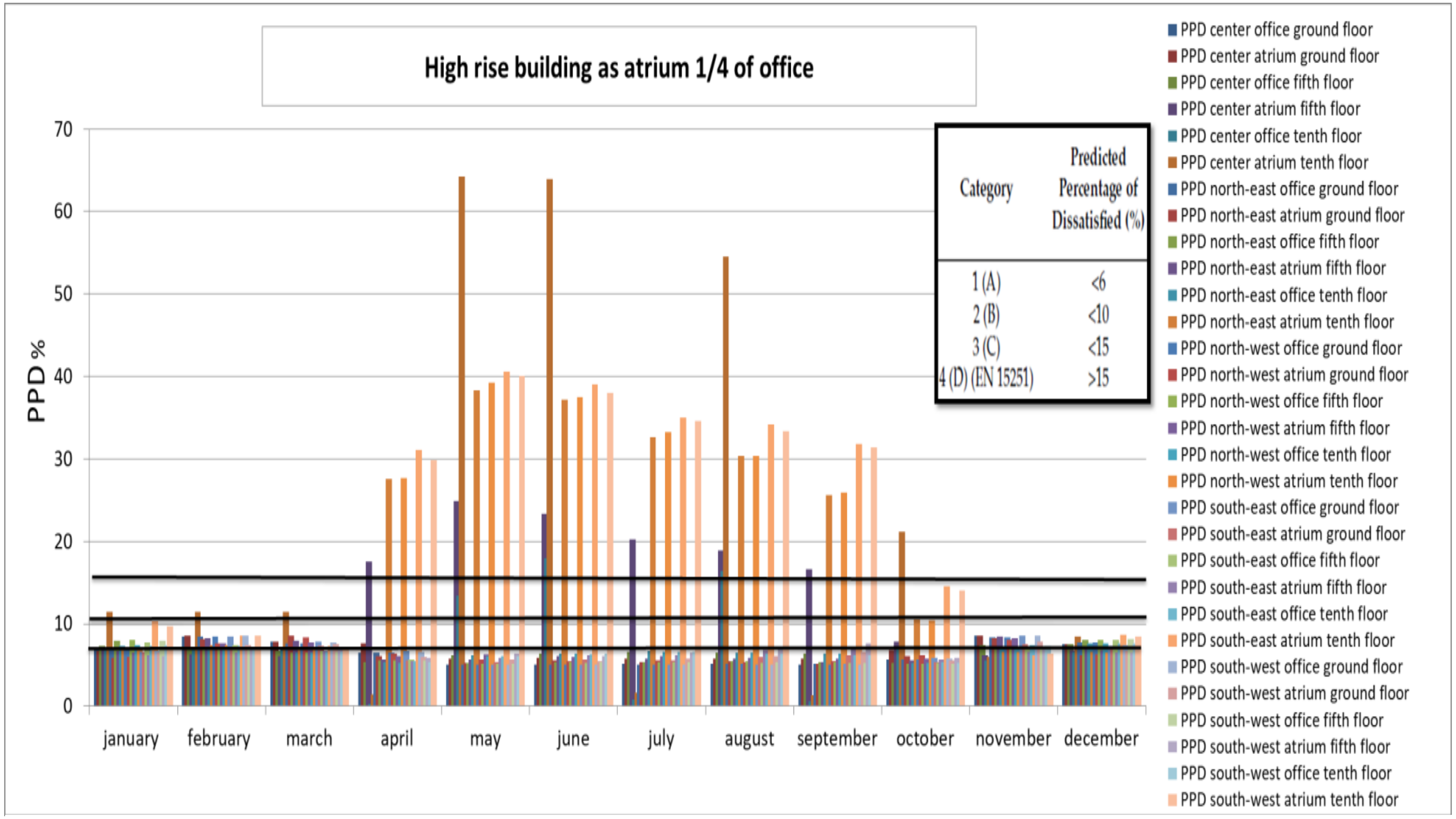


Figure 38: The PPD (predicted percentage dissatisfied) for av mechanically conditioned High-Rise building with atrium proportion 1/4 of the office space.

5.3 Discussion and Synthesis of the Atrium Buildings

5.3.1 Passive Conditioned Atrium Buildings

5.3.1.1 Single-Floor Atrium Buildings

The dynamic simulation of single-floor buildings all had internal thermal comfort based on the standards, as can be seen in Table 8. All dynamic simulation single-floor models with atrium proportions 1/2, 1/3, and 1/4 of the office proportion and the different atrium placements were analyzed and discussed on a monthly basis. In the single-floor atrium building, when the atrium proportion was half of the office proportion (1/2) and the building facade windows were completely closed except the tower over the atrium zone, thermal comfort was observed in the office zone throughout the winter period in the center, south-east, and north-west atrium orientations, and in the winter and spring periods for the north-east atrium orientation. This comfort condition occurred due to the dramatic decrease in air and temperature exchanges from the outdoor to the indoor environment. An investigation of the energy usage of this dynamic simulation group illustrated that the average energy factors during the year were: 27.32 ^{o}C mean radiant temperature (MRT), 1382.17W infiltration/ventilation gain, and 325.48 W building heat transfer of heat loss, all occurring just in the office zone.

When all the external windows were opened as 50%, the internal thermal comfort of the office zone was observed from May to July in the north-east atrium orientation, which had the following yearly averages: 23.94 ^{o}C mean radiant temperature (MRT), 556.78 W infiltration/ventilation gain, and 109.77 W building heat transfer of heat gain. However, when the atrium proportion decreased to 1/3 and 1/4 of the office proportion, the indoor occupants' comfort remained stable with a 50% window opening ratio for which the office zone of this atrium simulation group had the following energy performance yearly averages: 24.99 ^{o}C mean radiant temperature (MRT), 16218.24 W infiltration/ventilation loss, and 291.51 building heat transfer of heat loss (for the north-east atrium orientation with atrium proportion 1/3 of office proportion). Besides, the north-east atrium orientation with atrium proportion 1/4 of the office proportion and the same window opening ratio had the following yearly average energy performance: 24.57 ^{o}C mean radiant temperature (MRT), 0 W infiltration/ ventilation, and 816.44 W building heat transfer of heat loss. Accordingly, these two atrium placements and proportions (1/3 and 1/4) behave similarly in terms of thermal and energy considerations.

Table 8: The adaptive model analysis of a Single-Floor building (one floor atrium building, northeast: NE, northwest: NW, southeast: SE, southwest: SW, O: office zone, A: atrium zone).

<table>
<tr><th rowspan="2">Atrium Placement.</th><th rowspan="2">Atrium Proportion</th><th rowspan="2">Wind. Opening Ratios</th><th rowspan="2">Zone</th><th rowspan="2">Floor</th><th rowspan="2">Months</th><th colspan="2">Accepted Comfort Level</th></tr>
<tr><th>90%</th><th>80%</th></tr>
<tr><td rowspan="5">Center</td><td rowspan="16">1/2 (atrium proportion is 1/2 of the office proportion)</td><td>0%</td><td rowspan="4">O</td><td rowspan="16">Ground</td><td>May to June</td><td rowspan="2">*</td><td>*</td></tr>
<tr><td rowspan="2">50%</td><td>January to June</td><td></td></tr>
<tr><td>July</td><td></td><td>*</td></tr>
<tr><td rowspan="2">100%</td><td>January to March</td><td rowspan="3">*</td><td></td></tr>
<tr><td>A</td><td rowspan="3">January to April</td><td></td></tr>
<tr><td rowspan="7">NE</td><td rowspan="2">0%</td><td>O</td><td rowspan="3">*</td></tr>
<tr><td>A</td><td></td></tr>
<tr><td rowspan="2">50%</td><td>O</td><td>March to April</td><td></td></tr>
<tr><td>A</td><td>January to April</td><td colspan="2" rowspan="3">*</td></tr>
<tr><td rowspan="2">100%</td><td>O</td><td rowspan="2">March to April</td></tr>
<tr><td>A</td></tr>
<tr><td rowspan="5">NW</td><td rowspan="4">0%</td><td rowspan="2">O</td><td>January to February</td><td>*</td><td></td></tr>
<tr><td>March to April</td><td></td><td>*</td></tr>
<tr><td rowspan="2">A</td><td>January to April</td><td>*</td><td></td></tr>
<tr><td>May</td><td></td><td rowspan="2">*</td></tr>
<tr><td>50%</td><td>O</td><td>January to February</td><td></td></tr>
</table>

Table 8 (continued).

Atrium Placement.	Atrium Proportion	Wind. Opening Ratios	Zone	Floor	Months	Accepted Comfort Level	
						90%	80%
NW	1/2 (atrium proportion is 1/2 of the office proportion)	50%	O	Ground	March to April	*	
			A		February to July		*
		100%	O		March to April		
					June to August	*	
			A		February to April		*
					May to June	*	
SE		0%	O		January to February		
					March to April		*
		50%	A		January to April	*	
					April to May		*
			O		January to June	*	
		100%	O		January to July		*
			A		January to June		
					July to August		
SW		0%	O		January to April	*	
			A				
		50%	O		January to June		
			A		January to July		*
		100%	O		January to August	*	
		0%			January to April	*	
		50%	A		January to April		*
			O		January to June	*	
			A		January to July		*
		100%	O		January to August		
			A		Whole year		*
Center	1/3 (atrium proportion is 1/3 of the office proportion)	0%	O		January to April	*	
			A		January to May		*
NE			O		January to July		
		50%	A		May to July		
					January to June	*	
		100%	O		March to April		
Center		50%			January and May		*
			A		February to March		

Table 8 (continued).

Atrium Placement.	Atrium Proportion	Wind. Opening Ratios	Zone	Floor	Months	Accepted Comfort Level 90%	Accepted Comfort Level 80%
Center	1/3 (atrium proportion is 1/3 of the office proportion)	50%	O	Ground	January to March	*	
					April and June		*
		100%			January to March September to December	*	
					April		*
			A		January to July	*	
NE		0%	O		January to February		*
					March to April		
			A		January to May	*	
		50%	O		January to June		
					April to July		*
			A		January to July	*	
		100%	O				
			A		January to August		
NW			O		March to April		
			A		January to April		
SE			O		January to February		
		0%	A		April		*
SW			O		March to May and October	*	
			A		January		
		100%	O		January to March November to December	*	
					April to July		*
			A		January to March May to September	*	
Center	1/4 (atrium proportion is 1/4 of the office proportion)	0%	O		January to April	*	
			A		January to May		
		100%	O and A		January to August		
NE		0%	O		January to July		*
		50%			May to July		
			A		January to June	*	
		100%	O		March to April	*	
NW		0%	A		March to May November to December		
					January to March		
		100%	O		January to May		
		0%	A		December		*
SE			O		April to May October to November		
		100%	A		February to March	*	

Table 8 (continued).

Atrium Placement.	Atrium Proportion	Wind. Opening Ratios	Zone	Floor	Months	Accepted Comfort Level	
						90%	80%
SE	1/4 (atrium proportion is 1/4 of the office proportion)	100%	A	Ground	December to February	*	
SW			O		April to May October to November		*
			A		March		

Appendix A, Figures 39 to 47, illustrates the single-floor atrium building based on the following factors: mean radiant temperature, infiltration and ventilation gain, and building heat transfer. The single-floor atrium building with atrium proportion 1/2 of the office proportion, north-west placement, and 100% opening ratio for all windows had a maximum mean radiant temperature (MRT) of 66.86 ^{o}C in the atrium zone during July. In contrast, the office zone in the north-east atrium orientation with a 0% window opening ratio had a minimum mean radiant temperature (MRT) of 20.16 ^{o}C. In this dynamic simulation group (atrium proportion 1/2 of office proportion), infiltration ventilation, considered the maximum heat gain, occurred in the office zone of the north-east atrium orientation with 443.73 Watts throughout August. Also, the most significant heat loss based on infiltration ventilation occurred in the office zone of the north-east atrium placement with 76780.51 Watts during December. Furthermore, it was observed that when all of the external windows were closed (0% window opening), this atrium proportion group had the maximum mean radiant temperature (MRT) compared to other window opening ratios. Additionally, from June to September the south-west atrium placement and the north-west atrium placement with 0% window opening and the atrium proportion set at 1/2 and the north-west atrium placement with 50% windows opening during summertime all had the maximum average mean radiant temperature (MRT). The office zone in the north-west atrium placement with a 50% window opening ratio had the maximum heat loss in June with 3948 Watts according to building heat transfer, when compared to other placements and window opening types. The dynamic simulation group consisting of single-floor buildings with atrium proportion 1/3 of the office proportion, the atrium placed in the south-east and south-west orientations, and a 50% window opening ratio had a high average mean radiant temperature (MRT) from May to October. However, the south-west atrium orientation with 0% window opening had the minimum mean radiant temperature (MRT) in the office zone of 18.44 ^{o}C in December. Based on the infiltration ventilation gain factors, the highest amount of heat loss was recorded during the autumn and winter period when the atrium is placed in the center of the building with a 100% window opening ratio, which is the reason why the users' satisfaction has the lowest average. The highest amount of heat gain from infiltration ventilation occurred in the office zone of the north-west orientation despite the external windows being completely open. When the atrium proportion decreased to 1/4 of the office proportion, the atrium zone of the center orientation had the highest mean radiant temperature (MRT) of 61.76 ^{o}C in July, while the office zone of the south-east atrium orientation had the lowest MRT (mean radiant temperature) of 18.17 ^{o}C in December compared to other placements and window opening ratios. As a general achievement, the 1/4 atrium proportion had the highest mean radiant temperature (MRT) during the spring and summer periods. The north-east atrium placement had the maximum infiltration ventilation gain during August of 2180.97 Watts in the office zone, while the maximum ventilation heat loss of 48709.26 Watts was recorded in the office zone of the center atrium orientation in December. Based on building heat transfer, the office zone of the center atrium placement with a 100% window opening ratio experienced the maximum 48709.25 Watts heat gain in December, although the same zone and atrium placement with a 50% window opening ratio also experienced the maximum heat loss of s 2382.93Watts in June.

Figure 48 in Appendix A illustrates the energy performance of the north-west atrium placement in the dynamic simulation group with the atrium proportion 1/2 of the office proportion, a passive indoor condition (natural ventilation), all external windows opened by 50%, and applying 50% shading devices into each atrium external facade. The maximum average mean radiant temperature in the office zone occurred in July at 33.57 ^{o}C, while the minimum existed in January at 21.14 ^{o}C. In contrast, within the atrium zone, the MRT increased dramatically to 46.85 ^{o}C in July and with the minimum average recorded in this zone at 26.25 ^{o}C in January. In terms of infiltration ventilation performance, the office zone had its lowest average heat loss of 21676.3 Watts in January and the highest average of 25036.3 Watts in September. Additionally, the highest average heat loss in the atrium zone was 680.8 Watts in January, and the lowest was 311.1 Watts in October. The office zone of this simulation group also has it is highest average building heat transfer as 1327.8 Watts heat loss in June, and its minimum average as 493.8 Watts heat loss in January, while the atrium zone has its maximum and minimum building heat transfer (BHT) as 3910 Watts heat loss in June and 273.7 Watts heat loss in January, respectively.

5.3.1.2 Medium-Rise Atrium Buildings

The dynamic thermal simulation medium-rise atrium building when the internal condition was based on natural ventilation (naturally conditioned system) via the tower side opening and windows of the building. All dynamic simulation medium-rise models included the atrium proportion as 1/2, 1/3, and 1/4 of the office proportion and different atrium placements analyzed on a monthly basis, as shown in Table 9. The medium-rise atrium building, completely achieved users' indoor comfort throughout the spring and summer periods when all windows were opened in the south-east and south-west atrium orientations with the atrium proportion set as 1/2 and 1/3 of the office proportion. The average energy performance factors for all the atrium building office zones throughout the year are as follows: 23.33 ^{o}C mean radiant temperature (MRT), 957.26 W infiltration/ventilation loss, and 492.68 W building heat transfer of heat loss. However, in this group of dynamic simulations, when the atrium was placed in the center with the atrium proportion as 1/2, 1/3, and 1/4 of the office proportion, indoor thermal comfort was observed in the office zones during summertime which the energy performance behaved similarly to other models in this simulation group.

Table 9: The adaptive model analysis of a Medium-Rise building (five-floor atrium building, northeast: NE, northwest: NW, southeast: SE, southwest: SW, O: office zone, A: atrium zone).

Atrium Placement	Atrium Proportion	Wind. Opening Ratios	Zone	Floor	Months	Accepted Comfort Level 90%	Accepted Comfort Level 80%
Center	1/2 (atrium proportion is 1/2 of the office proportion)	0%	O	Ground	June to October	*	
			A		June to July		*
					August to September	*	
			O	Fifth	May		*
					June to September		
		50%		Ground	June to September	*	
			A		June to October		
					September		*
			O	Fifth	June to October	*	
					May		*
		100%		Ground	June to September	*	
					October		*
			A		June to September	*	
					October		*
NE		0%	O	Ground	June to October	*	
			A	Fifth	May to July		
			O				
		50%	O	Ground	June to October		
					May		*
			A		June to October	*	
			O	Fifth			
		100%	O and A	Ground	June to September		
Center		0%	O	Ground	June to October	*	
			A		June to July		*
					August to September	*	
			O	Fifth	May		*
					June to September		
		50%	A	Ground		*	
					June to October		
					September		*
		100%	O	Fifth	June to October	*	
					May		*
				Ground	June to September	*	
					October		*
			A		June to September	*	
					October		*

Table 9 (continued).

Atrium Placement	Atrium Proportion	Wind. Opening Ratios	Zone	Floor	Months	Accepted Comfort Level 90%	80%
NE	1/2 (atrium proportion is 1/2 of the office proportion)	0%	O	Fifth	June to October	*	
			A				
			O		May to July		
		50%		Ground	June to October		
					May		*
			A		June to October	*	
			O	Fifth			
		100%	O and A	Ground	June to September		
					October		*
			O	Fifth	June to September	*	
					October		*
NW		0%		Ground	July to October	*	
				Fifth	May to June		
		50%		Ground	June to September		
					October		*
			A		June to September	*	
					October		*
			O	Fifth	June to September	*	
					October		*
		0%			October		*
				Ground	July to October	*	
				Fifth	May to June	*	*
NE		50%		Ground	June to September		
		100%		Fifth	October		*
					June to September	*	
NW		100%	O	Ground	June to September	*	
			A		October		*
					June to September	*	
			O	Fifth	October		*
					June to September	*	
					October		*
SE		0%, 50%, and 100%		Ground	June to October	*	
			A				
			O	Fifth			
SW				Ground			
			A	Fifth			
			O				

Table 9 (continued).

Atrium Placement	Atrium Proportion	Wind. Opening Ratios	Zone	Floor	Months	Accepted Comfort Level	
						90%	80%
Center	1/3 (atrium proportion is 1/3 of the office proportion)	0%	A	Ground	June to October	*	
			O	Fifth	March to June		
		50% and 100%	O and A	Ground	June to September		
					October		*
			O	Fifth	June to September	*	
					October		*
NE and NW		0%		Ground	June to October	*	
			A	Ground	July to August		*
			O	Fifth	September to November May	*	
		50%		Ground	May to June		
					July to August		*
			A		May to June	*	
			O	Fifth			
					July to August		*
		100%		Ground	May to September	*	
			A		August to October		
					July		*
			O	Fifth	August to October	*	
					July		*
SE and SW		0%	O and A	Ground	June to September	*	
				Fifth	May to October		
		50% and 100%	O	Ground	June to September	*	
				Fifth	October		*
					June to September	*	
					October		*
Center	1/4 (atrium proportion is 1/4 of the office proportion)	0%		Ground	June to September	*	
			A				
			O	Fifth	May to June		
					September		*
Center		50%	O and A	Ground	June to August	*	
					October		*
			O	Fifth	July to August	*	
		100%	O and A	Ground			
					May		*

Table 9 (continued).

Atrium Placement	Atrium Proportion	Wind. Opening Ratios	Zone	Floor	Months	Accepted Comfort Level	
						90%	80%
NE	1/4 (atrium proportion is 1/4 of the office proportion)	0%	A	Fifth	June to August	*	
					October		*
			O		May to June	*	
		50% and 100%	O and A	Ground	May to September		
			O	Fifth	May		*
NW		0%	O and A	Ground	May to September	*	
			O	Fifth	May to June September to October		
		50% and 100%	O and A	Ground	June to September		
					May to October		*
			O	Fifth	June to September	*	
					May to October		*
SE		0%		Ground	May to September	*	
			A		October		*
			O	Fifth	May to June	*	
		50% and 100%	O and A	Ground	September		*
					June to September	*	
			O	Fifth	September		*
					June to September	*	
SW		0%		Ground	May to September		
			A		June to August		
			A	Ground	July to September		*
			O	Fifth	May September to November	*	
		50% and 100%	O and A	Ground	May to September		*

Appendix B, Figures 49 to 57, depicts the energy performance of the medium-rise dynamic simulation buildings based on the energy factors of this research. The medium-rise atrium building models with the atrium proportion 1/2 of the office proportion had the minimum gain of mean radiant temperature (MRT) with 15.36 °C in the ground atrium zone of the north-east orientation in December with a 50% opening ratio for all external windows. The maximum average mean radiant temperature (MRT) of about 38.08 ^{o}C occurred in the ground atrium and last floor (fifth floor) office zones based on passive performance. According to the infiltration ventilation gain in this group of simulation models, all passive dynamic models lose heat during cold months and gain heat during warm months. On the other hand, in the medium-rise building with the atrium proportion as 1/2 of the office proportion, there was a 1257.29 Watts heat loss in the ground office zone of the south-east atrium placement during August when all external windows were completely closed. Additionally, the last floor atrium zone of the north-west, south-east, and south-west atrium placements with the same atrium proportion all had a high average heat loss. The ground atrium zone of the center atrium orientation also had heat loss during the spring and summer periods. The medium-rise atrium as 1/3 of the office proportion in the last atrium zone of the north-east orientation with 100% opening (all windows opened completely of the building) had 29.98 ^{o}C in July. The ground atrium in the north-west atrium placement with 0% opening had 15.38 ^{o}C during December. Overall, the last atrium zone received the maximum amount of mean radiant temperature throughout summer in all atrium placements and window opening ratios. In the medium-rise atrium building when the atrium proportion changed to 1/4 of the office proportion in the last office zone of the center placement when all the windows were opened (100% windows opening) had a 1475.58 ^{o}C maximum mean radiant temperature (MRT) during February, while the ground atrium zone of the center atrium placement when all the external windows were closed completely (0% windows opening) had the 17.64 ^{o}C minimum mean radiant temperature (MRT) in April. The medium-rise with atrium proportion 1/4 of the office proportion when all external windows were opened completely had the minimum and maximum infiltration ventilation for heat gain and loss; for instance, the last atrium zone in the south-west atrium orientation had 2186.75 Watts (maximum) heat gain in August and the ground office in the center atrium orientation had 70271.01 Watts (minimum) heat loss in April. Furthermore, in this atrium proportion group (1/4), the last office zone of the south-east atrium orientation with 100% window opening had the highest amount of heat gain according to building heat transfer (BHT) with 57381.13 Watts during December and the maximum heat loss of 2209.29 Watts in the last office zone of the north-east atrium orientation with a 50% window opening ratio in November.

5.3.1.3 High-Rise Atrium Buildings

The dynamic thermal simulation model for a high-rise atrium building, when the internal condition was based on natural ventilation (naturally conditioned system) via the tower side opening and the windows of the building is depicted in Table 10, used to show the comfort zones of all models in this group. All dynamic simulation medium-rise models with the atrium proportion 1/2, 1/3, and 1/4 of the office proportion and different atrium placements analyzed and discussed on a monthly basis. In the high-rise atrium building, thermal comfort was observed, when all windows of the building were opened completely from May to July and November to December, in the office zones of north-east and north-west atrium orientation with the atrium proportion as 1/2 of the office proportion. The average energy performance values recorded for these areas are as follows: 27.1 ^{o}C mean radiant temperature (MRT), 41871.1 W infiltration/ventilation gain, and 695.56 W building heat transfer of heat loss during the year. When the window opening ratio decreased to 50%, the center atrium orientation with the atrium proportion set as 1/3 of the office proportion and the north-east and north-west atrium orientations with the atrium proportion as 1/4 of the office proportion have a greater thermal comfort than other simulation models. Furthermore, the general average energy performance of the office zones is: 22.92 ^{o}C mean radiant temperature (MRT), 4079.32 W infiltration/ventilation gain, and 37.82 W building heat transfer of heat loss during the year

Table 10: The adaptive model analysis of a High-Rise building (10-floor atrium building, northeast: NE, northwest: NW, southeast: SE, southwest: SW, O: office zone, A: atrium zone).

Atrium Placement	**Atrium Proportion**	**Wind. Opening Ratios**	**Zone**	**Floor**	**Months**	**Accepted Comfort Level**	
						90%	**80%**
Center	1/2 (atrium proportion is 1/2 of the office proportion)	100%	O	Ground	January to April		*
			A				
			O	Fifth	May to June		
				Tenth	Whole year	*	
NE		50%		Ground	January to October		
		100%	A		February to July		*
					January, August, September, and October	*	
			O				
SE	1/3 (atrium proportion is 1/3 of the office proportion)	0%	O and A	Ground	June to December		*
			O	Fifth and Tenth	June to September		
		50% and 100%	O and A	Ground, Fifth, and Tenth	July to December		
SW		0%	O	Fifth	June and July		
Center	1/4 (atrium proportion is 1/4 of the office proportion)	50% and 100%	O and A	Tenth	August and September		
		0%	O	Ground, Fifth, and Tenth	June to December	*	
				Ground			
				Fifth and Tenth	June to September		
		50% and 100%	O and A	Ground and Fifth	July to December		

Table 10 (continued).

Atrium Placement	**Atrium Proportion**	**Wind. Opening Ratios**	**Zone**	**Floor**	**Months**	**Accepted Comfort Level**	
						90%	**80%**
NE	1/2 (atrium proportion is 1/2 of the office proportion)	100%	O	Fifth and Tenth	November and December		*
NW			A	Ground	May and July	*	
			O	Fifth and Tenth			
				Ground	June to August		*
SW			O and A	Ground, Fifth, Tenth	Whole year		
		50%			November and December		
					January to September	*	
Center	1/3 (atrium proportion is 1/3 of the office proportion)	0%	O	Ground	June to December		
			A		May to December		
			O	Fifth	June to September		
				Tenth	May to September		
		50%		Ground	June to December		
			A		July to December		
			O	Tenth	June to November		
Center		100%	O and A	Ground, Fifth, and Tenth	July to December		
NE		0%, 50%, and 100%			June to December		*
NW		0%	O	Tenth		*	
		50%	O and A	Ground, Fifth, and Tenth			
		100%					
SE		0%		Ground	Whole year		*
				Fifth, and Tenth	June to September		
		50%		Ground, Fifth, and Tenth	July to December		
		100%			May to December	*	
SW		0%		Ground	June, November, and December		*
					July, August, and September	*	

Table 10 (continued).

<table>
<tr><th rowspan="2">Atrium Placement</th><th rowspan="2">Atrium Proportion</th><th rowspan="2">Wind. Opening Ratios</th><th rowspan="2">Zone</th><th rowspan="2">Floor</th><th rowspan="2">Months</th><th colspan="2">Accepted Comfort Level</th></tr>
<tr><th>90%</th><th>80%</th></tr>
<tr><td rowspan="15">NE</td><td rowspan="24">1/3 (atrium proportion is 1/3 of the office proportion)</td><td rowspan="7">0%</td><td rowspan="2">O</td><td rowspan="4">Ground</td><td>March to May</td><td>*</td><td></td></tr>
<tr><td>June to September</td><td></td><td>*</td></tr>
<tr><td rowspan="2">A</td><td>April to July</td><td>*</td><td></td></tr>
<tr><td>August</td><td></td><td>*</td></tr>
<tr><td rowspan="3">O</td><td>Fifth</td><td>January to May</td><td rowspan="2">*</td><td rowspan="2"></td></tr>
<tr><td rowspan="2">Tenth</td><td>February to May</td></tr>
<tr><td>January and June</td><td></td><td>*</td></tr>
<tr><td rowspan="3">50%</td><td rowspan="2">A</td><td rowspan="2">ground</td><td>August to December</td><td rowspan="6">*</td><td></td></tr>
<tr><td>July to December</td><td rowspan="2">*</td></tr>
<tr><td rowspan="2">O</td><td>Fifth and Tenth</td><td>July to November</td></tr>
<tr><td rowspan="5">100%</td><td rowspan="2">Ground</td><td>March to September</td><td rowspan="3"></td></tr>
<tr><td>A</td><td>July to November</td></tr>
<tr><td rowspan="5">O</td><td>Fifth</td><td>Jan. to May</td></tr>
<tr><td rowspan="2">Tenth</td><td>January, May, June, and August</td><td></td><td>*</td></tr>
<tr><td>February, March, and April</td><td>*</td><td></td></tr>
<tr><td rowspan="9">NW</td><td rowspan="6">0%</td><td rowspan="4">Ground</td><td>June</td><td></td><td>*</td></tr>
<tr><td>July to December</td><td>*</td><td></td></tr>
<tr><td rowspan="2">A</td><td>May to December</td><td></td><td>*</td></tr>
<tr><td>June to November</td><td rowspan="6">*</td><td rowspan="3"></td></tr>
<tr><td rowspan="5">O</td><td>Fifth</td><td>May to Aug.</td></tr>
<tr><td>Tenth</td><td>June to September</td></tr>
<tr><td>50%</td><td>Ground</td><td>July to December</td><td rowspan="3">*</td></tr>
<tr><td rowspan="2">100%</td><td rowspan="2">Fifth and Tenth</td><td>July to December</td></tr>
<tr><td>July to December</td></tr>
</table>

Illustrated in Appendix C, Figures 58 to 66, are the energy performance of high-rise atrium buildings based on passive performance. In this dynamic simulation group with the atrium proportion as 1/2 of the office proportion, the last atrium zone in the center atrium orientation with a 50% window opening ratio had the highest mean radiant temperature (MRT) of 75.86 °C in July, and the south-west atrium orientation with a

50% window opening ratio had the lowest mean radiant temperature (MRT) of 20 ^{o}C December. The ground office of the north-west atrium orientation when all windows were opened completely experienced a heat loss of 204445.13 Watts based on infiltration ventilation gain. Also, the north-west and south-west atrium placement had the most noticeable heat loss for this group during wintertime. In this dynamic simulation group (1/2 proportion) the last office zone in the center atrium orientation had the maximum heat losing (building heat transfer) of 5680.16 Watts with a 50% window opening ratio in July. Furthermore, the maximum heat gaining of 3590.41 Watts was reported for the same atrium placement and opening (center, 50%) in December. When the atrium proportion of the high-rise dynamic simulation models changed to 1/3 of the office proportion, the south-east atrium placement with 0% window opening had the maximum mean radiant temperature (MRT in last atrium floor) of 37.09 ^{o}C in July. The minimum number occurred in the ground atrium of the center orientation at 15.51 ^{o}C with a 50% window opening ratio in December. Additionally, the center atrium placement had the maximum amount of heat loss in the last atrium zone at 2457.32 Watts with a 50% window opening ratio in December. However, the 100% window opening ratio had a high amount of heat loss on the last floor based on infiltration and ventilation. The south-east atrium orientation with a 0% window opening ratio had the highest average heat loss of 1559.91 Watts in the ground office zone in July based on building heat transfer (BHT). Although the north-west atrium orientation had noticeable heat loss during warm months when all the external windows closed (0%). In the high-rise atrium building with atrium proportion 1/4 of the office proportion, the last atrium zone of the north-east atrium placement with 0% window opening had the 55.71 ^{o}C maximum mean radiant temperature (MRT) in July while the 15.86 ^{o}C minimum mean radiant temperature (MRT) was recorded in the ground atrium zone of the north-west atrium orientation in December. It was also observed that when all the windows were opened (100% window opening), the last office zone, especially in center atrium placement, had the highest heat loss during the spring and summer periods, although the north-east atrium orientation had a relatively stable balance between heat loss and gain during the year. The highest heat gain of this simulation group (1/4) was 969.81 Watts heat gain in the last floors of the center atrium orientation with a 100% window opening ratio and the main heat loss occurred in the ground office of the north-east atrium orientation during the warm months.

Appendix C, Figure 67, illustrates the high-rise atrium building with the atrium 1/2 of the office proportion, natural ventilation when all the external facade windows were closed (0% window opening) and the atrium located in the north-east orientation with the addition of a 30% shading device over each atrium external facade. The recorded energy performance is as follows: for the office zone, the highest mean radiant temperature (MRT) was 40.7 ^{o}C in the upper office zones in July while the lowest average mean radiant temperature (MRT) occurred in the lower office zones at 17.2 ^{o}C in February. Similarly, the ground atrium zone had the maximum mean radiant temperature of 42.1 ^{o}C in July and a minimum MRT of 16.2 ^{o}C in January. Furthermore, the infiltration ventilation gain occurred mainly on the middle floor of the office zones. The building heat transfer as heat loss occurred in the upper office zones with a maximum average of 580 watts in November and maximum heat gain of 1609 watts on the middle floor of the office zone in June. Similarly, the ground atrium zone had the maximum heat loss at 579.2 watts in November and a maximum heat gain of 377.8 watts in July.

As shown in Appendix C, Figure 68, the energy performance of the high-rise south-west atrium placement with atrium proportion 1/3 of the office proportion, natural ventilation with 100% windows opening, and a 30% shading device over each external atrium facade, had the maximum mean radiant temperature (MRT) of 32.5 ^{o}C in July and the minimum in January, all in the ground atrium zone. The office zones had a maximum mean radiant temperature (MRT) of 40.9 ^{o}C on the last floor in July and a minimum average mean radiant temperature of 17.1 ^{o}C in January on the ground floor. Furthermore, the highest average building heat transfer (BHT) occurred in the last floor office zone as 1458.7 watts heat loss in November, while the main heat gain (BHT) occurred on the lower office floor as 1800.5 watts in June. Remarkably, the atrium zone of the building heat transfer (BHT) was only gaining heat throughout the year.

Appendix C, Figure 69, depicts the high-rise atrium building in a north-east placement with the atrium proportion 1/4 of the office proportion, natural ventilation using all windows opened completely (100% window opening) and a 30% shading device over each atrium external facade, which had its highest average mean radiant temperature (MRT) in the office zone of the last floor at 33.2 ^{o}C in July and the lowest average in the ground office zone at 21.3 ^{o}C in January. Similarly, the atrium zone had a maximum mean radiant temperature (MRT) of 31.9 ^{o}C and a minimum MRT of 20.1 ^{o}C in January. Based on infiltration ventilation, the office zone in middle floors had the maximum heat loss at 30030 watts, and the minimum heat loss of 138.2 watts, while the ground atrium zone had the maximum infiltration ventilation loss at 138.2, all in January. Furthermore, the minimum heat loss in the ground atrium zone occurred at 17.9 watts in September. It should also be mentioned that this simulation experienced infiltration ventilation losses in all office zones. In this dynamic simulation model, the building heat transfer (BHT) of the office zones had its highest heat loss as 726 watts on the last floor with the maximum heat gain on the lower floors as 1356.7 watts in August. Additionally, the ground atrium zone has the highest average heat loss with 368.1 watts in January and the minimum heat loss at 77 watts in September.

5.3.2 Active Conditioned Atrium Buildings

5.3.2.1 Single-Floor Atrium Buildings

As an active internal condition (basic air conditioning), the single-floor atrium building can be assessed based on the predicted mean vote (PMV) and the predicted percentage of dissatisfied (PPD) throughout the year. The office zones of all the atrium building orientations provided internal thermal comfort based on categories standards. However, the atrium zones of all orientations have discomfort conditions during the summertime when the atrium proportion is 1/2 of the office proportion. In the dynamic simulation group of the single atrium proportion as 1/2 of the office proportion, the discomfort condition in the atrium zone can be explained by its energy performance, specifically the massive infiltration ventilation gain during the summertime. For instance, in this simulation group, the south-east atrium orientation had a higher infiltration ventilation gain in all building zones compared to other placements and the center atrium orientation had a high average building heat transfer, especially during warm months. Although, the maximum heat changes caused by air (infiltration/ventilation) occurred in the atrium zones during cold months.

The heat transfer and air temperature changes of the dynamic simulation models with a mechanical indoor condition occurred through the windows and material conduction because all window openings in the building and atrium are closed in active performance simulation models. Furthermore, according to the ISO 7730 (2005) and

EN 15251 (2007) standards, the percentages of the other thermal comfort classifications are shown in Tables 11 to 14 for the thermal comfort analysis of a mechanically conditioned single-floor atrium building, including: Dissatisfied (PD) Due to Draught (%), PD Due to Vertical Air Temperature Difference (%), PD Due to Cool or Warm Floor (%), and PD Due to Radiant Temperature Asymmetry (%), all illustrated in each zone during the year.

Table 11: Annual Percentage of Dissatisfied (PD) Due to Draught (%) for the Single-Floor atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

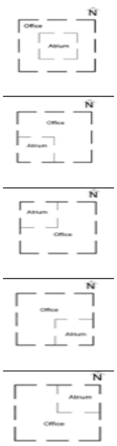
<table>
<tr><th colspan="5">Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system</th></tr>
<tr><th>Atrium orientation</th><th>Atrium proportion of office proportion</th><th>Building zones</th><th>Months</th><th>Percentage of Dissatisfied (PD) Due to Draught (%)</th></tr>
<tr><td rowspan="7">Center</td><td rowspan="24">atrium proportion is 1/2 of the office proportion
</td><td rowspan="3">Office</td><td>January to April</td><td>Category A</td></tr>
<tr><td>May to September</td><td>Category B</td></tr>
<tr><td>October to December</td><td rowspan="2">Category A</td></tr>
<tr><td rowspan="4">Atrium</td><td>January</td></tr>
<tr><td>February to March</td><td>Category B</td></tr>
<tr><td>October</td><td>Category C</td></tr>
<tr><td>November to December</td><td rowspan="2">Category A</td></tr>
<tr><td rowspan="3">North-east</td><td>Office</td><td>During a year</td></tr>
<tr><td rowspan="2">Atrium</td><td>October</td><td>Category B</td></tr>
<tr><td>November to December</td><td rowspan="2">Category A</td></tr>
<tr><td rowspan="7">North- west</td><td rowspan="3">Office</td><td>January to May</td></tr>
<tr><td>June to August</td><td>Category B</td></tr>
<tr><td>September to December</td><td rowspan="2">Category A</td></tr>
<tr><td rowspan="4">Atrium</td><td>January to February</td></tr>
<tr><td>March</td><td>Category B</td></tr>
<tr><td>October</td><td>Category C</td></tr>
<tr><td>November to December</td><td rowspan="2">Category A</td></tr>
<tr><td rowspan="3">South-east</td><td rowspan="3">Office</td><td>January to May</td></tr>
<tr><td>June to August</td><td>Category B</td></tr>
<tr><td>September to December</td><td rowspan="2">Category A</td></tr>
<tr><td rowspan="4">South-west</td><td rowspan="3">Office</td><td>January to May</td></tr>
<tr><td>June to August</td><td>Category B</td></tr>
<tr><td>September to December</td><td rowspan="2">Category A</td></tr>
<tr><td>Atrium</td><td>January to February</td></tr>
</table>

Table 11 (continued).

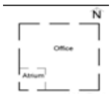
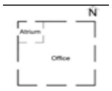
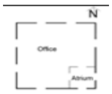
Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**Percentage of Dissatisfied (PD) Due to Draught (%)**
South- west	atrium proportion is 1/2 of the office proportion	Atrium	March	Category B
			October	Category C
			November to December	Category A
Center	atrium proportion is 1/3 of the office proportion     	Office	January to May	Category A
			June to August	Category B
			September to December	Category A
		Atrium	January to March	Category A
			October	Category B
			November to December	Category A
North- east		Office	During year	Category A
		Atrium	January to March	Category A
			April	Category C
			August to September	Category C
			October to December	Category A
North- west		Office	During year	Category A
		Atrium	January to March	Category A
			October	Category C
			November to December	Category A
South- east		Office	January to May	Category A
			June to August	Category B
			September to December	Category A
		Atrium	January to March	Category A
			October	Category C
			November to December	Category A
South- west		Office	During a year	Category A
		Atrium	January to March	Category A
			September	Category C
			October	Category B
			November to December	Category A
Center	atrium proportion is 1/4 of the office proportion	Office	January to May	Category A
			June to August	Category B
			September to December	Category A

Table 11 (continued).

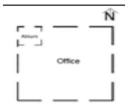
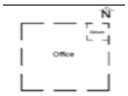
Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**Percentage of Dissatisfied (PD) Due to Draught (%)**
Center	atrium proportion is 1/4 of the office proportion     	Atrium	January to March	Category A
			October	Category B
			November to December	Category A
North-east		Office	During year	
		Atrium	January to March	
North-west		Office	During year	
		Atrium	January to March	
			October	Category C
			November to December	Category A
South-east		Office	During year	
		Atrium	January to March	
			April	Category C
			July to September &October	Category B
			November to December	Category A
South-west		Office	During year	
		Atrium	January to March	
			April & July to September	Category C
			October	Category B
			November to December	Category A

Table 12: Annual PD Due to Vertical Air Temperature Difference (%) for the Single-Floor atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system

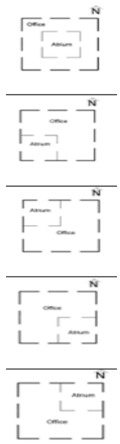
Atrium orientation	Atrium proportion of office proportion	Building zones	Months	PD Due to Vertical Air Temperature Difference (%)
Center	atrium proportion is 1/2 of the office proportion 	Office	January to April	Category C
		Office	October to December	
		Atrium	January & November to December	
North- east		Office	During year	
		Atrium	January to March & November & December	
North- west		Office	January to May	
			September to December	
		Atrium	January to February	
			November to December	
South- east		Office	January to May	
			September to December	
		Atrium	January to February	
			November to December	
South- west		Office	January to May	
			September to December	
		atrium	January to February	
			November to December	
Center	atrium proportion is 1/3 of the office proportion	Office	January to May	
			September to December	
		Atrium	January to March	
			November to December	
Nor th- east		Office	During year	

Table 12 (continued).

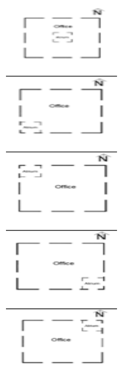
Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Vertical Air Temperature Difference (%)**
North- east	atrium proportion is 1/3 of the office proportion 	Atrium	January to March	Category C
			October to December	
		Office	During year	
North- west		Atrium	January to March	
			November to December	
South- east		Office	January to May	
			September to December	
		Atrium	January to March	
			November to December	
South- west		Office	During year	
		Atrium	January to March	
			November to December	
Center	atrium proportion is 1/4 of the office proportion 	Office	January to May	
			September to December	
		Atrium	January to March	
			November to December	
North- east		Office	During year	
		Atrium	January to March	
			October to December	
North- west		Office	During year	
		Atrium	January to March	
			November to December	

Table 13: Annual PD Due to Cool or Warm Floor (%) for the Single-Floor atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

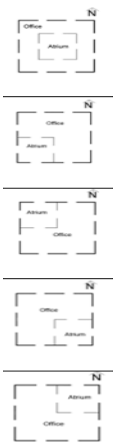
Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Cool or Warm Floor (%)**
Center	atrium proportion is 1/2 of the office proportion	Office	January to April	Category A
			October to December	
			May to September	Category C
		Atrium	January, November & December	Category A
			February to March	Category C
North- east		Office	During year	Category A
		Atrium	January to March	
			November to December	
			October	Category C
North- west		Office	January to May	Category A
			September to December	
			June to August	Category C
		Atrium	January to February	Category A
			November to December	
			March	Category C
South- east		Office	January to May	Category A
			September to December	
			June to August	Category C
		Atrium	January to February	Category A
			November to December	
			March	Category C
South- west		Office	January to May	Category A

Table 13 (continued).

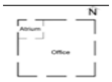
Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Cool or Warm Floor (%)**
South- west	atrium proportion is 1/2 of the office proportion	Office	September to December	Category A
			May to August	Category C
		Atrium	January to February	Category A
			November to December	
			March	Category C
Center	atrium proportion is 1/3 of the office proportion     	Office	January to May	Category A (fragile and sensitive persons)
			September to December	
			June to August	Category C
		Atrium	January to March	Category A
			November to December	
			October	Category C
North- east		Office	During year	Category A
		Atrium	January to March	
			October to December	
South- east		Office	January to May	
			September to December	
			June to August	Category C
		Atrium	January to March	Category A
			November to December	
South- west		Office	During year	
		Atrium	January to March	
			November to December	
Center	atrium proportion is 1/4 of the office proportion	Office	January to May	

Table 13 (continued).

Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system

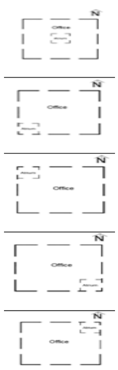
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Cool or Warm Floor (%)**
Center	atrium proportion is 1/4 of the office proportion	Office	September to December	Category A
			June to August	
		Atrium	June to March	
			November to December	
			October	Category C
North- east		Office	During year	Category A
		Atrium	January to March	
			October to December	
North- west		Office	During year	
		Atrium	January to March	
			November to December	
South- east		Office	During year	
		Atrium	January to March	
			November to December	
			October	Category C
South- west		Office	During year	Category A
		Atrium	January to March	
			November to December	

Table 14: Annual PD Due to Radiant Temperature Asymmetry Draught (%) for the Single-Floor atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

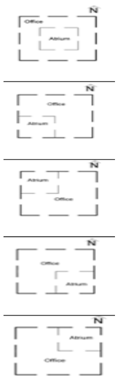
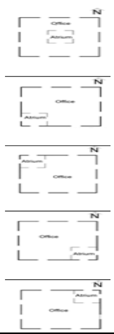
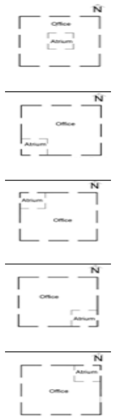
Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Radiant Temperature Asymmetry (%)**
Center	atrium proportion is 1/2 of the office proportion 	Office	January to April	Category C
			October to December	
		Atrium	January to December	
North- east		Office	During year	
		Atrium	January to March	
			November to December	
North- west		Office	January to April	
			September to December	
		Atrium	January to February	
			November to December	
South- east		Office	January to February	
			October to December	
		Atrium	January to February	
			November to December	
South- west		Office	January to May	
			September to December	
		Atrium	January to February	
			November to December	
Center	atrium proportion is 1/3 of the office proportion 	Office	January to May	
			September to December	
		Atrium	January to March	
			November to December	
North- east		Office	During year	

Table 14 (continued).

Thermal Comfort Classification of Dynamic Simulation Model for single-floor atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Radiant Temperature Asymmetry (%)**
North-east	atrium proportion is 1/3 of the office proportion 	Atrium	January to March	Category C
			October to December	
North- west		Office	During year	
		Atrium	January to March	
			November to December	
South- east		Office	January to March	
			September to December	
		Atrium	January to March	
			November to December	
South- west		Office	During year	
		Atrium	January to March	
			November to December	
Center	atrium proportion is 1/4 of the office proportion 	Office	January to May	
			September to December	
		Atrium	January to March	
			November to December	
North- east		Office	During year	
		Atrium	January to March	
			October to December	
North- west		Office	During year	
		Atrium	January to March	
			November to December	
South- east		Office	During year	
		Atrium	January to March and November to December	

Figures 70 to 72 in Appendix D illustrate the energy performance of all single-floor atrium buildings based on a mechanical indoor condition. In this simulation group with the atrium proportion 1/2 of the office proportion, the mean radiant temperature (MRT) had a smaller average and somewhat more similar performance compared to the other atrium placement simulation scenarios throughout the year. The center atrium orientation in this group had a higher heat gain than other simulation models with 1864.47 Watts in December based on building heat transfer (BHT). However, when the atrium proportion decreased to 1/3 of the office proportion, the average heat loss or gain according to the infiltration and ventilation gain was balanced during the year for different atrium placements.

The south-west atrium placement when the atrium was 1/2 of the office proportion with a mechanically conditioned (basic air conditioning) indoor system and a 50% shading device, had its highest mean radiant temperatures (MRT) at 63.3 ^{o}C in the office zone in July and 77.3 ^{o}C in the atrium zone, and its minimum MRT at 41 ^{o}C in the office zone in January and 47.2 ^{o}C in the atrium zone in January. The energy analysis of this simulation group also illustrated that in terms of infiltration ventilation, the office zone had a 6674.4 watts loss and the atrium zone a 2435.6 watts loss, both in January, as the lowest averages during a year. However, the office zone has 7758.4 watts and the atrium zone 2946 watts, both in July, also as the highest average throughout the year. Additionally, this simulation group with a 50% shading device over each atrium facade the building heat transfer (BHT) of the office zone had a 1552.13 watts maximum heat loss in June and a 589.5 watts minimum heat loss in December, while the atrium zone has a 302.3 watts maximum heat loss in April and a 415.9 watts maximum heat gain in November.

For the energy performance of the south-east atrium placement with the atrium 1/3 of the office proportion, natural ventilation, a 100% window opening ratio, and a 50% shading device over each atrium external facade, the office zone had a 33.3 ^{o}C maximum average mean radiant temperature (MRT) and 51.8 ^{o}C MRT for the atrium zone, both occurring in July. However, the minimum mean radiant temperature (MRT) existed in the office zone at 16 ^{o}C and the atrium zone at 23.6 ^{o}C, both in January. Accordingly, the maximum building heat transfer for the office zone in this group was 1685 watts heat loss in July and the minimum was 641.1 watts heat loss in December. In addition, the atrium zone building heat transfer (BHT) had a maximum of 1373.6 watts heat gain in December and a 2705.3 watts maximum heat loss in July.

5.3.2.2 Medium-Rise Atrium Buildings

According to the mechanical indoor condition (basic air conditioning) of the medium-rise atrium building, while occupants' thermal comfort is achievable, it fluctuates during the year. Using the predicted mean vote (PMV) and the predicted percentage of dissatisfied (PPD) throughout the year, the lower floors of this group based in the different atrium orientations had a higher average user thermal comfort in different seasons, but the atrium zones with the same design parameters had the lowest average indoor thermal comfort compared to other models.

Based on the ISO 7730 (200) and EN 15251 (2007) standards, the percentages of the other thermal comfort classifications are shown in Tables 15 to 18 for the thermal comfort analysis of a mechanically conditioned medium-rise atrium building with different atrium placements and proportions, including the Dissatisfied (PD) Due to Draught (%), PD Due to Vertical Air Temperature Difference (%), PD Due to Cool or Warm Floor (%), and PD Due to Radiant Temperature Asymmetry (%)illustrated for each zone during the year.

Table 15: Annual Percentage of Dissatisfied (PD) Due to Draught (%) for the Medium-Rise atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

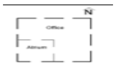
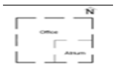
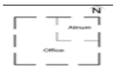
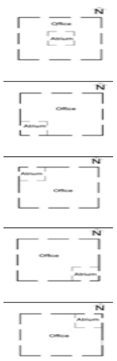
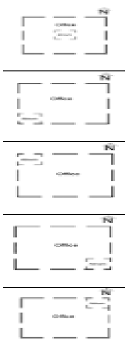
Thermal Comfort Classification of Dynamic Simulation Model for medium-rise atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**Percentage of Dissatisfied (PD) Due to Draught (%)**
Center	atrium proportion is 1/2 of the office proportion     	Office	January to April	Category A
			October to December	
			May to September	Category B
North-east			During year	Category A
		Ground Atrium		
North-west		Ground Office	During year	
		Ground Atrium	During year	
		Upper Office	January to April & October to December	Category B
South-east		Ground Office & Atrium	During year	Category A
		Upper Office	January to April &October to December	
			May to September	Category B
South-west		Ground Office & Atrium	During year	Category A
		Upper Office	January to April &October to December	
			May to September	Category B

Table 15 (continued).

<table>
<tr><th colspan="5">Thermal Comfort Classification of Dynamic Simulation Model for medium-rise atrium building as indoor Conditioned system</th></tr>
<tr><th>Atrium orientation</th><th>Atrium proportion of office proportion</th><th>Building zones</th><th>Months</th><th>Percentage of Dissatisfied (PD) Due to Draught (%)</th></tr>
<tr><td rowspan="3">Center</td><td rowspan="11">atrium proportion is 1/3 of the office proportion
</td><td>Ground Office & Atrium</td><td>During year</td><td rowspan="2">Category A</td></tr>
<tr><td rowspan="2">Upper Office</td><td>January to April &October to December</td></tr>
<tr><td>May to September</td><td>Category B</td></tr>
<tr><td rowspan="5">North- east</td><td>Ground Office</td><td>During year</td><td rowspan="2">Category A</td></tr>
<tr><td rowspan="2">Ground Atrium</td><td>January to May & August to December</td></tr>
<tr><td>June to July</td><td>Category B</td></tr>
<tr><td rowspan="2">Upper Office</td><td>January to April &October to December</td><td rowspan="10">Category A</td></tr>
<tr><td>May to September</td></tr>
<tr><td>North-west</td><td rowspan="3">Ground Office, Atrium & Upper Office</td><td rowspan="8">During year</td></tr>
<tr><td>South-east</td></tr>
<tr><td>South-west</td></tr>
<tr><td>Center</td><td rowspan="5">atrium proportion is 1/4 of the office proportion
</td><td rowspan="5">Ground Office & Atrium,

Upper Office</td></tr>
<tr><td>North-east</td></tr>
<tr><td>North-west</td></tr>
<tr><td>South-east</td></tr>
<tr><td>South-west</td></tr>
</table>

Table 16: Annual PD Due to Vertical Air Temperature Difference (%) for the Medium-Rise atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

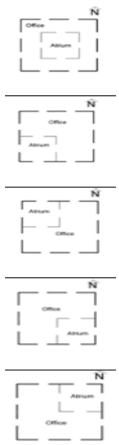
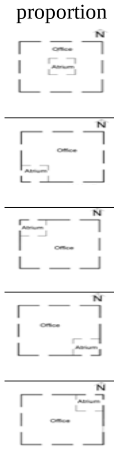
<table>
<tr><th colspan="5">Thermal Comfort Classification of Dynamic Simulation Model for medium-rise atrium building as indoor Conditioned system</th></tr>
<tr><th>Atrium orientation</th><th>Atrium proportion of office proportion</th><th>Building zones</th><th>Months</th><th>PD Due to Vertical Air Temperature Difference (%)</th></tr>
<tr><td rowspan="2">Center</td><td rowspan="9">atrium proportion is 1/2 of the office proportion
</td><td>Ground Office & Atrium</td><td>During year</td><td rowspan="10">Category C</td></tr>
<tr><td>Upper Office</td><td>January to April &October to December</td></tr>
<tr><td>North- east</td><td>Ground Office, Atrium & Upper Office</td><td rowspan="2">During year</td></tr>
<tr><td rowspan="2">North- west</td><td>Ground Office & Atrium</td></tr>
<tr><td>Upper Office</td><td>January to April &October to December</td></tr>
<tr><td rowspan="2">South- east</td><td>Ground Office & Atrium</td><td>During year</td></tr>
<tr><td>Upper Office</td><td>January to April &October to December</td></tr>
<tr><td rowspan="2">South- west</td><td>Ground Office & Atrium</td><td>During year</td></tr>
<tr><td>Upper Office</td><td>January to April &October to December</td></tr>
<tr><td>Center</td><td>atrium proportion is 1/3 of the office proportion
</td><td>Ground Office & Atrium</td><td>During year</td></tr>
</table>

Table 16 (continued).

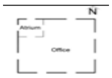
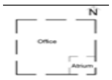
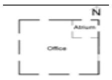
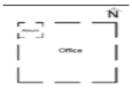
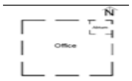
Thermal Comfort Classification of Dynamic Simulation Model for medium-rise atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Vertical Air Temperature Difference (%)**
Center	atrium proportion is 1/3 of the office proportion     	Upper Office	January to April &October to December	Category C
North- east		Ground Office	January to April &September to December	
		Ground Atrium	January to May &August to December	
		Upper Office	January to March & September to December	
North-west		Ground Office, Atrium & Upper Office	During year	
South-east				
South-west				
Center	atrium proportion is 1/4 of the office proportion     			
North-east				
North-west				
South-east				
South-west				

Table 17: Annual PD Due to Cool or Warm Floor (%) for the Medium-Rise atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

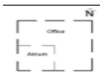
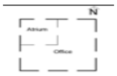
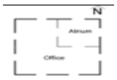
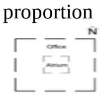
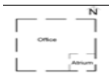
Thermal Comfort Classification of Dynamic Simulation Model for medium-rise atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Cool or Warm Floor (%)**
Center	atrium proportion is 1/2 of the office proportion     	Ground Office & Atrium	During year	Category C
		Upper Office	January to April & October to December	
North- east		Ground Office & Atrium Upper Office	During year	
North- west		Ground Office & Atrium	During year	
		Upper Office	January to April & October to December	
South- east		Ground Office & Atrium	During year	
		Upper Office	January to March & October to December	
South- west		Ground Office & Atrium	During year	
		Upper Office	January to April & October to December	
Center	atrium proportion is 1/3 of the office proportion     	Ground Office & Atrium	During year	Category A
		Upper Office	June to April &October to December	
			May to September	Category C
North-east		Ground Office & Atrium	During year	Category A
		Upper Office	June to April &October to December	

Table 17 (continued).

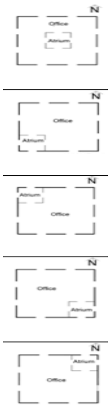
Thermal Comfort Classification of Dynamic Simulation Model for medium-rise atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Cool or Warm Floor (%)**
North-east	atrium proportion is 1/3 of the office proportion 	Upper Office	May to September	Category C
North- west		Ground Office & Atrium Upper Office	During year	Category A
South- east				
South- west				
Center	atrium proportion is 1/4 of the office proportion 			
North-east				
North- west				
South- east				
South- west				

Table 18: Annual PD Due to Radiant Temperature Asymmetry (%) for the Medium-Rise atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

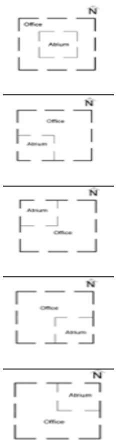
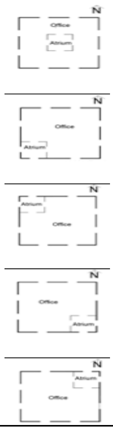
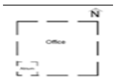
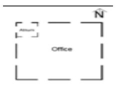
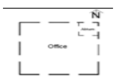
<table>
<tr><th colspan="5">Thermal Comfort Classification of Dynamic Simulation Model for medium-rise atrium building as indoor Conditioned system</th></tr>
<tr><th>Atrium orientation</th><th>Atrium proportion of office proportion</th><th>Building zones</th><th>Months</th><th>PD Due to Radiant Temperature Asymmetry (%)</th></tr>
<tr><td rowspan="2">Center</td><td rowspan="10">atrium proportion is 1/2 of the office proportion

</td><td>Ground Office & Atrium</td><td>During year</td><td rowspan="11">Category C</td></tr>
<tr><td>Upper Office</td><td>January to April & October to December</td></tr>
<tr><td rowspan="2">North- east</td><td>Ground Office & Atrium</td><td>During year</td></tr>
<tr><td>Upper Office</td><td>January to April & October to December</td></tr>
<tr><td rowspan="2">North- west</td><td>Ground Office & Atrium</td><td>During year</td></tr>
<tr><td>Upper Office</td><td>January to April & October to December</td></tr>
<tr><td rowspan="2">South- east</td><td>Ground Office & Atrium</td><td>During year</td></tr>
<tr><td>Upper Office</td><td>January to April & October to December</td></tr>
<tr><td rowspan="2">South- west</td><td>Ground Office & Atrium</td><td>During year</td></tr>
<tr><td>Upper Office</td><td>January to April & October to December</td></tr>
<tr><td>Center</td><td>atrium proportion is 1/3 of the office proportion

</td><td>Ground Office & Atrium</td><td>During year</td></tr>
</table>

Table 18 (continued).

Thermal Comfort Classification of Dynamic Simulation Model for medium-rise atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Radiant Temperature Asymmetry (%)**
Center	atrium proportion is 1/3 of the office proportion 	Upper Office	January to April & October to December	Category C
North- east		Ground Office & Atrium	During year	
		Upper Office	January to March & October to December	
North- west		Ground Office & Atrium Upper Office	During year	
South- east				
South- west				
Center	atrium proportion is 1/4 of the office proportion 			
North- east				
North- west				
South- east				
South- west				

Illustrated in Appendix E, Figures 73 to 75, is the medium-rise atrium building based on the mechanical condition while the atrium proportion is 1/2 of the office proportion. The maximum average mean radiant temperature (MRT) was 91.58 ^{o}C in the ground atrium zone of the north-east atrium placement in January. It was found that the mixed-mode (mechanical) internal condition in this atrium proportion group had a higher mean radiant temperature (MRT) in all placements from December to March than the passive internal condition. The center atrium orientation in this group had the highest level of heat gain due to infiltration ventilation gain in the ground office at 518.63 Watts during August. Furthermore, these indoor condition simulation models (atrium proportion as 1/2 of the office proportion) all had high levels of heat loss from November to April, especially during the winter period. On the other hand, the highest level of heat gain was 2704.75 Watts in the ground atrium of the north-east atrium orientation. Generally, the highest level of heat gain occurred in the ground atrium zones of the north-east, north-west, and south-west atrium orientations based on building heat transfer (BHT). When the atrium proportion changed to 1/3 of the office proportion with the north-east atrium orientation, the last floor had a higher average mean radiant temperature (MRT) than other atrium placement simulation models. The ground floor office zone and the last floor office zone both had about close averages of about 4605.28 Watts heat loss during the year due to infiltration and ventilation. The ground atrium zone of the north-east atrium orientation had the same heat loss from May to September, while the ground atrium zone of the north-east atrium orientation had the maximum level of heat loss during springtime and the ground office zone of the north-west atrium orientation had the maximum level of heat gain throughout the spring period. In the dynamic medium-rise simulation models, when the atrium proportion decreased to 1/4 of the office proportion, the mean radiant temperature (MRT) fluctuated between 23 ^{o}C and 25 ^{o}C during the year in all the building zones. The ground atrium zone of the north-east and north-west atrium orientations experienced heat loss due to infiltration ventilation during wintertime.

Overall, the building heat transfer (BHT) of this simulation group was balanced between heat loss and gain throughout the year.

5.3.2.3 High-Rise Atrium Buildings

The ISO 7730 (2005) and EN 15251 (2007) standards as percentages of the other thermal comfort classifications are shown in Tables 19 to 22 as the thermal comfort analysis of a mechanically conditioned high-rise atrium building, including the Dissatisfied (PD) Due to Draught (%), PD Due to Vertical Air Temperature Difference (%), PD Due to Cool or Warm Floor (%), and PD Due to Radiant Temperature Asymmetry (%) all illustrated for each zone during the year.

Table 19: Annual Percentage of Dissatisfied (PD) Due to Draught (%) for the High-Rise atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

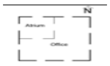
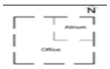
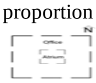
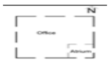
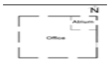
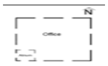
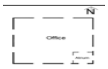
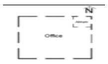
Thermal Comfort Classification of Dynamic Simulation Model for high-rise atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**Percentage of Dissatisfied (PD) Due to Draught (%)**
Center	atrium proportion is 1/2 of the office proportion 	Offices & Ground Atrium	During year	Category A & B
North-east				
North-west				Category A, B & C
South-east				
South-west				
Center	atrium proportion is 1/3 of the office proportion 			
North-east				Category B
North-west				Category A , B & C
South-east				Category A & B
South-west				
Center	atrium proportion is 1/4 of the office proportion 			Category A
North-east				
North-west				
South-east				
South-west				

Table 20: Annual Percentage of PD Due to Vertical Air Temperature Difference (%) for the High-Rise atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

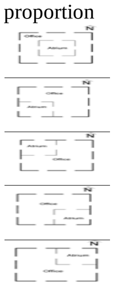
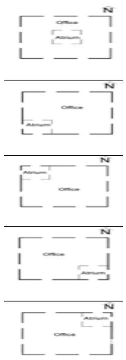
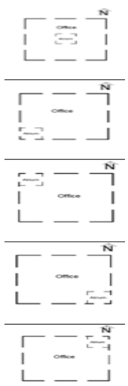
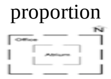
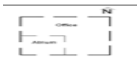
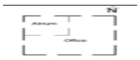
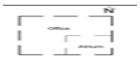
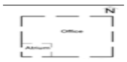
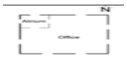
Thermal Comfort Classification of Dynamic Simulation Model for high-rise atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Vertical Air Temperature Difference (%)**
Center	atrium proportion is 1/2 of the office proportion 	Lower Office zones	During year	Category C
		Ground Atrium	May to September	
North- east		Lower Office zones	During year	
Center	atrium proportion is 1/3 of the office proportion 	Offices zone & Ground Atrium	January	Category A
North- east				
Nort h- west				
South- east				
South - west				
Nort h- east			During year	Category C
Sou th- east				
South - west				
Center	atrium proportion is 1/4 of the office proportion 			
North- east		Ground Office & Atrium		

Table 21: Annual Percentage of PD Due to Cool or Warm Floor (%) for the High-Rise atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

<table>
<tr><th colspan="5">Thermal Comfort Classification of Dynamic Simulation Model for high-rise atrium building as indoor Conditioned system</th></tr>
<tr><th>Atrium orientation</th><th>Atrium proportion of office proportion</th><th>Building zones</th><th>Months</th><th>PD Due to Cool or Warm Floor (%)</th></tr>
<tr><td>North-east</td><td rowspan="5">atrium proportion is 1/2 of the office proportion




</td><td rowspan="8">Offices zone & Ground Atrium</td><td>During year</td><td>Category A</td></tr>
<tr><td>Center</td><td>June to August</td><td>Category C</td></tr>
<tr><td>North-west</td><td rowspan="8">During year</td><td rowspan="13">Category A</td></tr>
<tr><td>South-east</td></tr>
<tr><td>South-west</td></tr>
<tr><td>South-east</td><td rowspan="5">atrium proportion is 1/3 of the office proportion

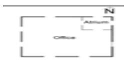
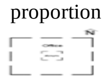
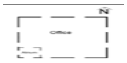
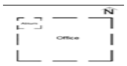
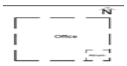
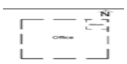
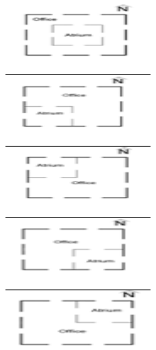
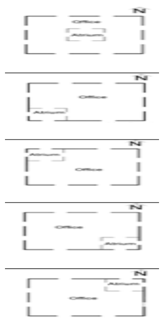
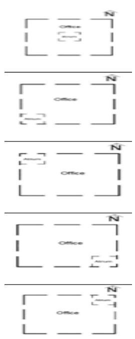
</td></tr>
<tr><td>South-west</td></tr>
<tr><td>North-east</td></tr>
<tr><td>Center</td><td rowspan="2">Lower zones</td></tr>
<tr><td>North-west</td></tr>
<tr><td>Center</td><td rowspan="5">atrium proportion is 1/4 of the office proportion




</td><td rowspan="5">Offices zone & Ground Atrium</td><td rowspan="5">During year</td></tr>
<tr><td>North-east</td></tr>
<tr><td>North-west</td></tr>
<tr><td>South-east</td></tr>
<tr><td>South-west</td></tr>
</table>

Table 22: Annual Percentage of PD Due to Radiant Temperature Asymmetry (%) for the High-Rise atrium building with a mechanically conditioned indoor system (Category A: fragile and sensitive persons, category B: users of the new building as a normal level, category C: moderate level for existing buildings).

Thermal Comfort Classification of Dynamic Simulation Model for high-rise atrium building as indoor Conditioned system				
Atrium orientation	**Atrium proportion of office proportion**	**Building zones**	**Months**	**PD Due to Radiant Temperature Asymmetry (%)**
North-east	atrium proportion is 1/2 of the office proportion 	Offices zone & Ground Atrium	During year	Category C
Center		Lower zones		
North-west				
South-east				
South-west				
South-east	atrium proportion is 1/3 of the office proportion 	Offices zone & Ground Atrium		
South-west				
North-east				
Center		Lower zones		
North - west				
South-east	atrium proportion is 1/4 of the office proportion 	Offices zone & Ground Atrium		
South-west				
Nort h- east				
North-west				
Center		Lower Up to Middle Floor zones		

As shown in Appendix F, Figures 76 to 78, the high-rise atrium building with the atrium proportion 1/2 of the office proportion and a south-west atrium orientation had the highest level of mean radiant temperature (MRT) compared to other simulation models. In terms of the infiltration and ventilation gains, the ground office of the south-west atrium orientation had a 529.88 Watts heat gain, a higher level than other simulation models. This group of simulation models experienced a balance between heat gain and loss according to the building heat transfer (BHT), although the ground office zone of the north-east atrium orientation experienced heat loss during wintertime and last atrium floor (10th floor) of south-west atrium orientation experienced heat gain during the year. When the atrium proportion changed to 1/3 of the office proportion, all floors received a high mean radiant temperature (MRT). The ground atrium of the north-east atrium orientation had a 507.62 Watts heat gain in August. Furthermore, the ground office of the same placement had a 971.51 Watts heat gain in December. In the high-rise atrium building with the atrium proportion as 1/4 of office proportion, the mean radiant temperature (MRT) for all the simulation models performed similarly during the year. In terms of infiltration ventilation gain, the ground office of the north-west atrium orientation had the maximum heat gain of 2181.7 Watts in August compared to other models and the maximum heat loss of 3751.08 Watts for this group in December. For the building heat transfer (BHT) of this atrium proportion group (1/4), the last floor had a high level of heat gain with 969.81 Watts in December, while the ground office zone of the north-east atrium placement had the highest level of heat loss during warm seasons.

5.3.3 Hybrid Conditioned Atrium Buildings

As a result of investigating the passive and active atrium performance in the different design and internal condition scenarios, a hybrid model is proposed for the hot and humid climate based on occupants' thermal satisfaction in the indoor accommodated zones depicted for each month in the concluding section. All these scenarios were analyzed for both natural ventilation and basic air conditioning indoor conditions and can be seen in Tables 23, 24, and 25 for the single-floor atrium building, Tables 26, 27, and 28 for the medium-rise atrium building, and Tables 29, 30, and 31 for the high-rise atrium building with the atrium as 1/2, 1/3, and 1/4 of the office proportion. Afterward, a combination of passive and active performance for indoor atrium building zones is presented in the form of a hybrid condition for indoor spaces. Notably, when basic air conditioning was applied to the building zones, there was thermal comfort in the single-floor office zone throughout the year, but when the volume increased to medium-rise and high-rise atrium buildings, a discomfort condition appeared in the atrium zone throughout the warm period. On the other hand, for natural ventilation (passive performance), when all the external facade windows were closed, users' thermal comfort is achievable during the cold months. Furthermore, for the warm periods, some proposed model scenarios can achieve thermal comfort based on the adaptive model through passive performance using a 50% shading device over each external window opening in the single-floor atrium building.

Table 23: The hybrid condition Single-Floor atrium building with atrium 1/2 of the office proportion which has thermal comfort throughout each month in the year (Good: all periods are thermal comfort, average: all periods are approximately thermal comfort, bad: in some periods are not thermal comfort).

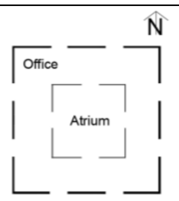
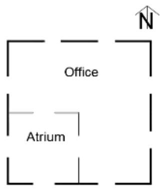
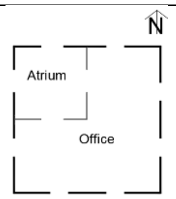
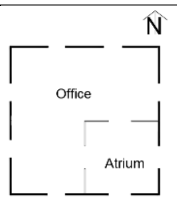
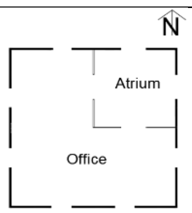
Plan View	**Internal Conditioned**	**Thermal Performance**	**Warm/ Cold Period**	**Windows Opening Ratio**	**Average acceptable performance (good, average, bad)**
	Passive	Adaptive model	Warm period	100%	Good
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	Average
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	Good
	Passive	Adaptive model	Cold period	0%	
	Passive	Adaptive model	Warm period	50%, 100%	
	Active	PMV & PPD	Cold period	0%	

Table 24: The hybrid condition Single-Floor atrium building with atrium 1/3 of the office proportion which has thermal comfort throughout each month in a year (Good: all periods are thermal comfort, average: all periods are approximately thermal comfort, bad: in some periods are not thermal comfort).

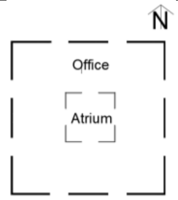
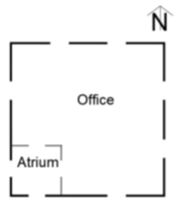
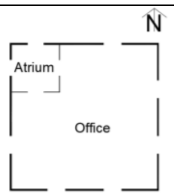
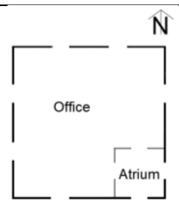
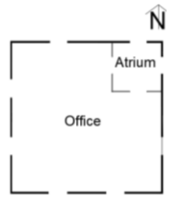
Plan View	**Internal Conditioned**	**Thermal Performance**	**Warm/ Cold Period**	**Windows Opening Ratio**	**Average acceptable performance (good, average, bad)**
	Passive	Adaptive model	Warm period	-	Bad
	Passive	Adaptive model	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	Average
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	-	Bad
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	-	
	Passive	Adaptive model	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	Good
	Active	PMV & PPD	Cold period	0%	

Table 25: The hybrid conditioned Single-Floor atrium building as atrium 1.4 of office proportion which has thermal comfort throughout each month in a year (Good: all periods are thermal comfort, average: all periods are approximately thermal comfort, bad: in some periods are not thermal comfort).

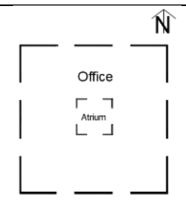
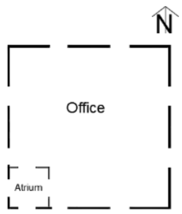
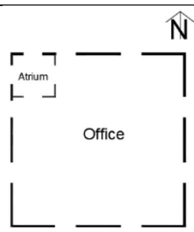
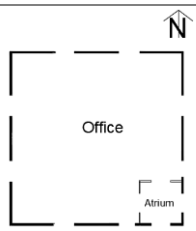
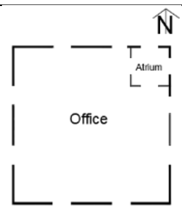
<table>
<tr><th>Plan View</th><th>Internal Conditioned</th><th>Thermal Performance</th><th>Warm/ Cold Period</th><th>Windows Opening Ratio</th><th>Average acceptable performance (good, average, bad)</th></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td><td rowspan="2">Good</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>-</td><td rowspan="6">Bad</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>-</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>-</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td><td rowspan="2">Average</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
</table>

Table 26: The hybrid conditioned Medium-Rise atrium building as atrium 1.2 of office proportion which has thermal comfort throughout each month in a year (Good: all periods are thermal comfort, average: all periods are approximately thermal comfort, bad: in some periods are not thermal comfort).

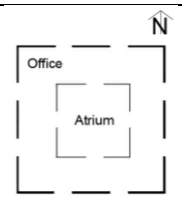
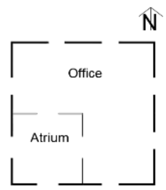
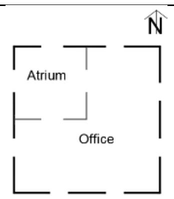
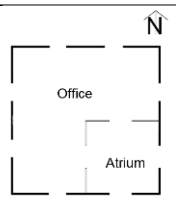
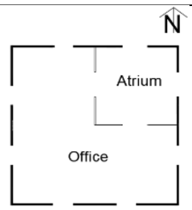
<table>
<tr><th>Plan View</th><th>Internal Conditioned</th><th>Thermal Performance</th><th>Warm/ Cold Period</th><th>Windows Opening Ratio</th><th>Average acceptable performance (good, average, bad)</th></tr>
<tr><td rowspan="2"></td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>-</td><td rowspan="2">Bad</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2"></td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td><td rowspan="2">Average</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2"></td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td><td rowspan="2">Bad</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>-</td></tr>
<tr><td rowspan="2"></td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td><td rowspan="4">Good</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2"></td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
</table>

Table 27: The hybrid conditioned Medium-Rise atrium building as atrium 1.3 of office proportion which has thermal comfort throughout each month in a year (Good: all periods are thermal comfort, average: all periods are approximately thermal comfort, bad: in some periods are not thermal comfort).

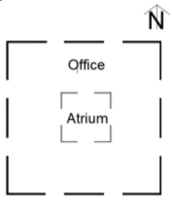
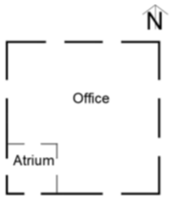
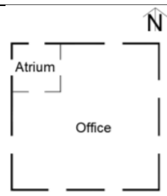
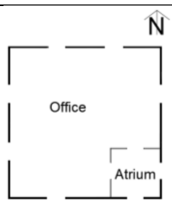
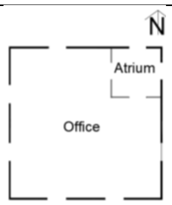
Plan View	Internal Conditioned	Thermal Performance	Warm/ Cold Period	Windows Opening Ratio	Average acceptable performance (good, average, bad)
	Passive	Adaptive model	Warm period	100%	Good
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	Average
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	50%	Good
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	
	Active	PMV & PPD	Cold period	0%	

Table 28: The hybrid conditioned Medium-Rise atrium building as atrium 1.4 of office proportion which has thermal comfort throughout each month in a year (Good: all periods are thermal comfort, average: all periods are approximately thermal comfort, bad: in some periods are not thermal comfort).

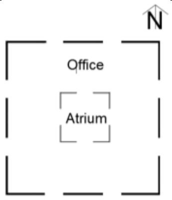
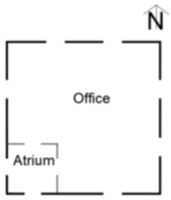
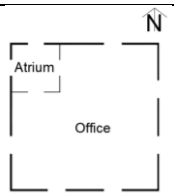
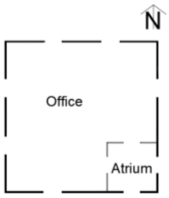
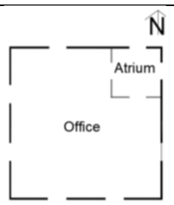
<table>
<tr><th>Plan View</th><th>Internal Conditioned</th><th>Thermal Performance</th><th>Warm/ Cold Period</th><th>Windows Opening Ratio</th><th>Average acceptable performance (good, average, bad)</th></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td><td rowspan="2">Good</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td><td rowspan="4">Average</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>50%</td><td rowspan="4">Good</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
</table>

Table 29: The hybrid conditioned High-Rise atrium building as atrium 1.2 of office proportion which has thermal comfort throughout each month in a year (Good: all periods are thermal comfort, average: all periods are approximately thermal comfort, bad: in some periods are not thermal comfort).

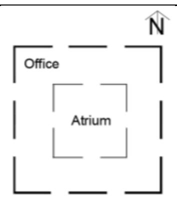
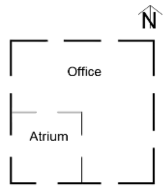
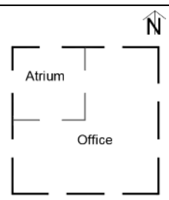
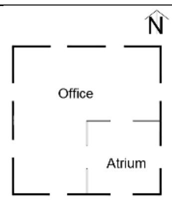
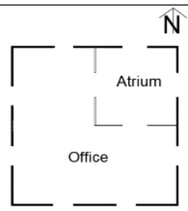
Plan View	**Internal Conditioned**	**Thermal Performance**	**Warm/ Cold Period**	**Windows Opening Ratio**	**Average acceptable performance (good, average, bad)**
	Passive	Adaptive model	Warm period	100%	Good
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	Average
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	Good
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	50%, 100%	
	Active	PMV & PPD	Cold period	0%	

Table 30: The hybrid conditioned High-Rise atrium building as atrium 1.3 of office proportion which has thermal comfort throughout each month in a year (Good: all periods are thermal comfort, average: all periods are approximately thermal comfort, bad: in some periods are not thermal comfort).

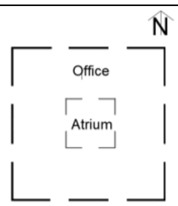
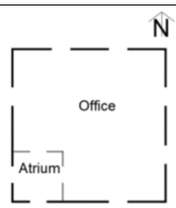
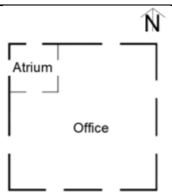
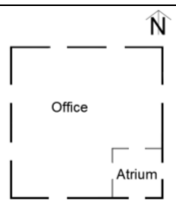
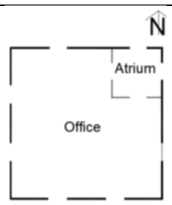
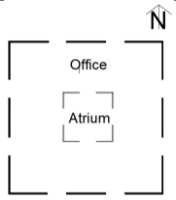
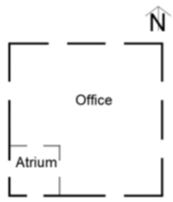
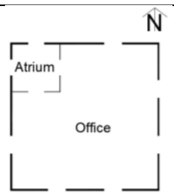
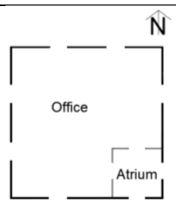
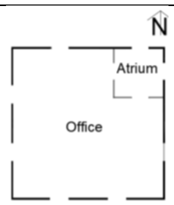
<table>
<tr><th>Plan View</th><th>Internal Conditioned</th><th>Thermal Performance</th><th>Warm/ Cold Period</th><th>Windows Opening Ratio</th><th>Average acceptable performance (good, average, bad)</th></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>50%, 100%</td><td rowspan="2">Good</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>100%</td><td rowspan="2">Average</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>50%, 100%</td><td rowspan="2">Bad</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>-</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>50%, 100%</td><td rowspan="4">Good</td></tr>
<tr><td>Passive</td><td>Adaptive model</td><td>Cold period</td><td>0%</td></tr>
<tr><td rowspan="2">
</td><td>Passive</td><td>Adaptive model</td><td>Warm period</td><td>50%, 100%</td></tr>
<tr><td>Active</td><td>PMV & PPD</td><td>Cold period</td><td>0%</td></tr>
</table>

Table 31: The hybrid conditioned High-Rise atrium building as atrium 1.4 of office proportion which has thermal comfort throughout each month in a year (Good: all periods are thermal comfort, average: all periods are approximately thermal comfort, bad: in some periods are not thermal comfort).

Plan View	**Internal Conditioned**	**Thermal Performance**	**Warm/ Cold Period**	**Windows Opening Ratio**	**Average acceptable performance (good, average, bad)**
	Passive	Adaptive model	Warm period	50%, 100%	Good
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	100%	Average
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	50%, 100%	
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	50%, 100%	Good
	Active	PMV & PPD	Cold period	0%	
	Passive	Adaptive model	Warm period	50%, 100%	
	Active	PMV & PPD	Cold period	0%	

In the single-floor atrium building dynamic simulation model which has thermal comfort with the atrium placed in the center of the building and 1/2 of the office proportion using basic indoor air-conditioning, the office zone had an average 21.64 ^{o}C mean radiant temperature, 1846.63 Watts infiltration ventilation loss, 1441.44 Watts building heat loss from January to March, while the atrium zone had average 26.33 ^{o}C mean radiant temperature, 775.54 Watts infiltration ventilation loss, and 1503.48 Watts building heat gain in the atrium zone. Furthermore, the north-east atrium placement using natural ventilation with a 100% opening ratio for all windows with the same atrium proportion has 26.66 ^{o}C mean radiant temperature, 2435 Watts infiltration ventilation loss, and 694.13Watts building heat gain in the office zone from May to September, and 34.17 ^{o}C mean radiant temperature, 3622Watts infiltration ventilation gain, and 644.3 Watts building heat gain in the atrium zone for same months, all indicating users' comfort.

Another recommended single-floor atrium building with the atrium 1/2 of the office proportion provided thermal comfort from October to December with the active internal condition (basic air-conditioning). In this model, the office zone had a 24 ^{o}C mean radiant temperature, 938.79 Watts infiltration ventilation loss, and 359.49 Watts building heat loss. The atrium zone of this simulation group had a 27.59 ^{o}C mean radiant temperature, 407.16 Watts infiltration ventilation loss, and 457.28 Watts building heat loss within the same period. In the single-floor atrium building when the atrium proportion decreased to 1/3 of the office proportion, thermal comfort was observed in the center atrium placement with the indoor mechanical condition (basic air conditioning) from January to April and November to December in the office zone with a 22.37 ^{o}C mean radiant temperature, 1765 Watts infiltration ventilation loss, and 503.69 Watts building heat gain, and a 26.15 ^{o}C mean radiant temperature, 263.17

Watts infiltration ventilation loss, and 477.93 Watts building heat gain in the atrium zone. When the atrium proportion changed to 1/4 of the office proportion, the center atrium also had the maximum average user satisfaction in indoor zones when using a mechanical condition (basic air-conditioning), providing thermal comfort from January to July with its energy performance as follows: 24.83 ^{o}C mean radiant temperature, 1167.85 Watts infiltration ventilation loss, and 412.9 Watts building heat loss in the office zone.

In the medium-rise atrium building dynamic simulation, the center atrium placement had a better thermal performance than other dynamic simulation models. The active atrium building with the center placement and a basic air conditioning system with the atrium 1/2 of the office proportion from had an average 22.69 ^{o}C mean radiant temperature, 1546.57 Watts infiltration ventilation loss, and 526.58 Watts building heat loss in all office zones from January to March and November to December. Furthermore, the ground atrium zone had a 23.4 ^{o}C mean radiant temperature, 1650.2 Watts infiltration ventilation loss, and 315.25 Watts building heat gain. Furthermore, the north-east atrium placement with the active indoor condition and the same atrium proportion (1/2 of the office proportion) also provided thermal comfort with the following energy performance: 28.81 ^{o}C mean radiant temperature, 9662.64 Watts infiltration ventilation loss, and 438.91 Watts building heat gain in all office zones, and 28.80 ^{o}C mean radiant temperature, 3793.79 Watts infiltration ventilation loss, and 158.85 Watts building heat gain in the ground floor atrium zone from April to October. In this atrium proportion group (atrium 1/2 of the office proportion), the south-east atrium placement has thermal comfort from June to September using natural ventilation when all the windows were opened completely (100%) with its average energy performance as 28.81 ^{o}C mean radiant temperature, 9662.64 Watts infiltration ventilation loss, and 438.91 Watts building heat loss in the office zone, and 28.80 °C mean radiant temperature, 3793.79 Watts infiltration ventilation gain, and 158.85 Watts building heat loss in the atrium zone. When the atrium proportion decreased to 1/3 of the office proportion, the north-east atrium placement using basic air conditioning provided thermal comfort from January to May, and October to December with the following energy performance averages: 35.45 °C mean radiant temperature, 4569.93 Watts infiltration ventilation loss, and 1897.35 Watts building heat loss in all office zones, and 33.78 °C mean radiant temperature, 559.53 Watts infiltration ventilation loss, and 444.22 Watts building heat loss in the ground atrium zone. Additionally, in this group (medium-rise atrium building), when the atrium proportion changed to 1/4 of the office proportion, thermal comfort was observed from June to September in the south-west placement using natural ventilation with a 50% window opening ratio with the following average energy performance: 28.46 °C mean radiant temperature, 12617.20 Watts infiltration ventilation loss, and 641.06 Watts building heat loss in all office zones. Furthermore, in this dynamic simulation group, the atrium zone had an average of 28.56 °C mean radiant temperature, 1200.13 Watts infiltration ventilation loss, and 20.68 Watts building heat gain in the ground atrium zone.

In the high-rise dynamic atrium simulation, the center placement has the maximum average thermal comfort. For instance, from November to March, using basic air conditioning, the indoor system provided acceptable thermal comfort with the following average energy performance: 22.75 °C mean radiant temperature, 1508.9 Watts infiltration ventilation loss, and 553.17 Watts building heat loss in all office zones, and 22.73 °C mean radiant temperature, 555.7 Watts infiltration ventilation loss, and 186.8 Watts building heat loss averages in the ground atrium zone. Notably, in this atrium group of high-rise buildings (atrium 1/2 of the office proportion), the center atrium placement using natural ventilation when all windows were 100% opened has thermal comfort from April to September with the following average energy performance: 25.75 ^{o}C mean radiant temperature, 75.3 Watts infiltration ventilation gain, and 430.12 Watts building heat loss in the ground atrium zone.

In the high-rise atrium building with the atrium 1/3 of the office proportion, the north-east atrium placement with an active internal condition (basic indoor air conditioning) had thermal comfort from October to March with the average energy performance of 23.83 ^{o}C mean radiant temperature, 1425.79 Watts infiltration ventilation loss, and 469.09 Watts building heat loss in all office zones, and 23.08 ^{o}C mean radiant temperature, 475.95 Watts infiltration ventilation loss, 233.31 Watts building heat loss averages in the ground atrium zone. When the atrium is located in the center placement with natural ventilation and all windows opened (100%), thermal comfort conditions were observed from April to September with the following average energy performance: 24.25 ^{o}C mean radiant temperature, 1415.63 Watts infiltration ventilation loss, and 292.94 Watts building heat gain in all office zones, while the ground atrium zone had 23.03 ^{o}C mean radiant temperature, 41.24 Watts infiltration ventilation loss, and 255.35 Watts building heat loss averages.

When the atrium proportion decreased to 1/4 of the office proportion in the same dynamic simulation scenario with a north-east atrium placement using basic air conditioning, the maximum average of users' comfort was observed from October to March with the following average energy performance: 25.19 ^{o}C mean radiant temperature, 580.2 Watts infiltration ventilation loss, and 333.46 Watts building heat loss in all office zones, and 24.03 ^{o}C mean radiant temperature, 235.2 Watts infiltration ventilation loss, and 393.76 Watts building heat loss ground atrium zone. The south-east atrium placement with the same proportion (1/4) using a passive performance with a 100% window opening ratio had an average 22.04 ^{o}C mean radiant temperature, 2665.17 Watts infiltration ventilation loss, and 253.83 Watts building heat loss all office zones. Furthermore, the ground atrium zone averaged 23.2 ^{o}C mean radiant temperature, 291.64 Watts infiltration ventilation loss, and 130.37 Watts building heat gain.

5.4 Final Comment

In brief, the method which is used for providing users' thermal comfort as the combination of the internal condition systems and building parameters in designing the optimum atrium model based on thermal performance. It can also be developed and applied to other climatic conditions to determine the most suitable atrium building model based on the maximum average user comfort while simultaneously accounting for energy performance. As a follow-up, the findings can be used to develop specific standards for the atrium in different building scales based on the microclimate.

5.5 Chapter Summary

In this chapter, all the model design alternatives have been illustrated for hot and humid climatic conditions. The stages and steps of the model were then distinguished based on the different categories of indoor condition systems and design parameters. The atrium models were categorized as either passive, active, or hybrid indoor conditions. In the next section, all the above distinguished model stages were analyzed and assessed to obtain the results of this research. The passive and active atrium building analyses and discussion were then presented for the single, medium, and high-rise atrium buildings. All evaluations and findings were based on thermal performance during the year using a monthly analysis of each zone in the models illustrated in individual figures, tables, and information texts. The optimum atrium model was then depicted based on the methods and design factors of this thesis in the findings and discussion section in denoting the hybrid internal condition. The chapter concludes with a clear presentation of the findings, including practical information on the atrium building. From a scientific perspective, the method of design parameter selection and the arrangement of the factors necessary for reaching the objective of this thesis have been performed, presenting comprehensive information regarding each scenario with individual details.

Chapter 6

CONCLUSION

Thermal performance in the atrium building is directly affected by the atrium placement, proportion, window openings ratio, and building volume. Furthermore, considering these factors can help predict the indoor thermal condition system during a year. Accordingly, the five main atrium orientations in the total building plan, that is: center, north-east, north-west, south-east, and south-west, have different individual thermal behaviors understood to include s indoor thermal comfort and energy performance in the hot and humid climate. Also, selecting the proper atrium design model can decrease the building energy demand and at the same time increase the users' satisfaction.

It is noteworthy that considering the architectural parameters in the atrium building (atrium placement and window opening ratios) can increase the users' comfort dramatically and improve energy efficiency performance throughout the year in Gazimagusa, North Cyprus. Also, applying other parameters like shading devices or blind systems can have more advantages, although it is essential to assess the net action of the atrium building behavior itself in this climate in moving towards sustainability. Furthermore, it can be mentioned that the shading device mainly affects the passive performance of the atrium building. The use of shading devices up to 50% in the single-floor and 30% in the medium-rise and high-rise dynamic simulation model over each atrium facade can cause users' comfort and influence energy performance in the atrium zone. However, the shading device up to the above percentages did not have remarkable effects on the thermal performance of the medium-rise atrium building model.

Generally, the 0% window opening ratio was significantly dissatisfying for the users' thermal comfort based on the hot and humid climate. This means that in this microclimate, it is vital to have air movement, although the 100% window opening ratio could act as a good solution for the atrium areas in the buildings. Moreover, less than 50% window opening ratio with different atrium orientations in the office building performed better in regards to increasing the indoor quality by improving the indoor temperature and relative humidity.

6.1 Hybrid Conditioned Atrium Buildings

The hybrid internal condition can be a suitable model for atrium buildings in a hot and humid climate with the application of natural ventilation and basic air conditioning. It can be mention that as hybrid internal conditioned in single, medium, and high-rise atrium building simulations, when the atrium volume was 1/3 and 1/4 of the office volume had a better performance throughout the year when the atrium placement was in the center, north-west, and south-west.

6.1.1 Single-Floor Atrium Buildings

The north-east atrium orientation in the single-floor office building simulation model had sufficient energy performance and suitable thermal comfort for users throughout the year in comparison to other dynamic simulation models. Additionally, the window opening ratio had a direct relationship with the indoor relative humidity: the more the window was open, the more dramatic increase in the relative humidity. Overall, the atrium was both suitable and effective in terms of indoor thermal comfort as indicated by actual temperatures and the MRT (mean radiant temperature).

The south-east single-floor atrium orientation in the simulation office models had a more suitable office space temperature than other simulation models despite the approximately 51% office indoor relative humidity in the cold season. In the summertime, the south-east single-floor atrium orientation in the simulation office models had better thermal comfort levels than other atrium orientation models in terms of temperature. Furthermore, in single-floor atrium building with a 1/2 atrium proportion, the north-east atrium orientation of the simulation models with minimum window opening ratios had a thermal comfort condition throughout the cold season based on comfort methods.

According to the energy performance parameters of building heat gain, loss, and mean radiant temperature, the dynamic simulation models of the north-west atrium orientation in the office building as the same proportion (1/2 atrium of office) with 0% windows opening ratio had the worst yearly average energy performance with identical heat loss and gain values of 103.4 W, and also mean radiant temperatures of about 34.4 °C in the office and 36.7 °C in the atrium zone. However, the south-east single-floor atrium orientation and north-east atrium orientation in the office building with a 0% window opening ratio had a negative energy performance behavior.

As an example, the passive performance of the north-east and south-east atrium orientations with atrium proportion as half of the office proportion in the single-floor office building had better internal comfort features than other simulation models, while also having the minimum average values. It can be concluded that up to the 50%

window opening ratios had the highest user comfort condition results throughout the year. The window opening ratio may be useful for generating thermal comfort by regulating air movement and decreasing humidity. The north-west atrium orientation in the simulation building with the 25% window opening ratios had thermal comfort conditions during the cold season. The office building simulation models with the north-east atrium orientation as the same proportion and window opening ratio had thermal comfort in the office zone in January, February, March, and April (cold season). These comfort conditions continued in the atrium zone with all previous parameters except for the 100% window opening ratio.

All of the dynamic thermal atrium building simulations with a single-floor depicted that when internal ventilation is based on a naturally conditioned system, there were overheating issues in the internal tower zones even though the side windows of the tower had been opened. Additionally, the single-floor building simulation with atrium volume 1/3 of office volume still had an overheating problem, especially during summer. It is noteworthy that the ratio of tower side windows over the atrium zone had a direct effect on indoor zones despite whether or not the facade windows of buildings have been opened or closed. The natural ventilation condition in the single-floor atrium building with the atrium volume 1/2 of the office volume had a better function than other models in this group.

In the single-floor atrium building simulation models, in contrast with other groups, the natural ventilation internal condition had a close acceptable indoor thermal comfort. Furthermore, the dynamic thermal simulation models with atrium proportion 1/3 of office proportion when the atrium is located in the center and also with atrium proportion 1/2 of office proportion with the center, north-east, north-west, and south-east atrium placements when all the facades external windows were completely closed had thermal comfort in the cold months. However, an atrium proportion 1/2 of the office proportion with the center, north-east, north-west, and south-east atrium placements with all external facade windows set at 50% and 100% window opening ratios had thermal comfort throughout springtime.

According to the ISO 7730 (2005) and EN 15251 (2007) standards which use the Percentages of the other thermal comfort classifications: PD Due to Draught (%), PD Due to Vertical Air Temperature Difference (%), PD Due to Cool or Warm Floor (%), and PD Due to Radiant Temperature Asymmetry (%) to illustrate each zone during the year, it can be concluded that in the single-floor atrium building dynamic simulation group with different atrium placements and proportions when the indoor environment is mechanically conditioned (basic air conditioning), occupants mainly experience discomfort in the atrium zone during warm periods. However, thermal comfort based on the other PPD parameters can often be reached throughout cold periods. For instance, in this simulation group, occupants' dissatisfaction in terms of the Percentage of Dissatisfied (PD) Due to Draught mainly occurred in the atrium zone during summertime in contrast with the same parameters in winter and autumn time. Additionally, the office zone has a higher average of users' comfort in this simulation group throughout the year based on the Percentage of Dissatisfied (PD) Due to Draught. Remarkably, the PD Due to Radiant Temperature Asymmetry in this simulation dynamic group achieved thermal comfort relying just on category C (<10) during different months even with the atrium proportions and placements changed accordingly. In contrast, PD Due to Cool or Warm Floor and PD Due to Vertical Air Temperature Difference all illustrated that indoor thermal comfort occurred based on category A (Cool or Warm Floor < 10, and PD Due to Vertical Air Temperature

Difference <3) and C (Cool or Warm Floor < 15, and PD Due to Vertical Air Temperature Difference <10). When the atrium building internal condition changed to a mechanical condition, the atrium proportion 1/3 of the office proportion in the single-floor with a center orientation had the maximum occupants' satisfaction (internal thermal comfort) throughout a year.

6.1.2 Medium-Rise Atrium Buildings

The natural ventilation performance of the internal conditions in the medium-rise building was better when the atrium proportion was less than the office proportion. For instance, an atrium volume 1/4 of the office volume had stronger air movement; consequently, thermal comfort exists in the whole of the building during springtime, especially on the lower floors. However, the natural ventilation performance with different atrium proportions, depicting that atrium orientation had a direct effect on the internal thermal condition. Additionally, an air-conditioned internal building condition illustrated that the center atrium placement had a minimum amount of PPD (predicted percentage of dissatisfied) compared to other atrium orientations. Also, the center atrium type had the maximum thermal comfort based on the standard categories throughout a year for occupants. However, when the atrium building internal condition changed to a mechanical condition, the atrium proportion 1/4 of office proportion in the medium-rise atrium building with a north-east orientation had the maximum occupants' satisfaction (internal thermal comfort) throughout a year.

The dynamic thermal simulation medium-rise atrium building with atrium proportion 1/2 of the office proportion did not have any thermal comfort throughout cold months despite different atrium placements and windows opening ratios. However, in this simulation group, users' comfort was more achievable during the warm months. When the atrium proportion decreased to 1/3 of the office proportion with the same naturally conditioned system, the center, and south-east atrium placement at 50% and 100% window opening ratios had a better thermal comfort especially throughout the warm months. However, in the same simulation group and with the same internal condition, when the atrium proportion changed to 1/4 of the office proportion, occupants' comfort was provided throughout summertime when the window opening ratio was increased accordingly.

In the medium-rise atrium building dynamic simulation group with the mechanical indoor system (basic air conditioning), the PD Due to Vertical Air Temperature Difference for different atrium parameters and proportions were based on category C (<10) throughout the year. As a remarkable example, when the atrium was placed in the north-east of the building and the atrium proportion was 1/3 of the office proportion, the minimum level of users' satisfaction occurred during different months in all of the zones of the building in comparison with other simulation scenarios in this group. Also, it can be mentioned that the medium-rise atrium building simulation was mainly acceptable as category A and C based on the aforementioned thermal comfort categories. For example, for the medium-rise atrium building with the atrium 1/4 of the office proportion, according to the PD Due to Cool or Warm Floor, all dynamic models with different atrium placements such as center, north-east, north-west, south-east, and south-west, have comfort in category A (<10) during a year. Furthermore, the PD Due to Radiant Temperature Asymmetry when the atrium was 1/2 and 1/4 of the office proportion in all placements behaved similarly during different seasons.

6.1.3 High-Rise Atrium Buildings

In the high-rise atrium building with natural internal ventilation, when the atrium proportion is 1/4 of office proportion, the north-east atrium placement had most occupants' thermal comfort. Furthermore, when the internal condition changed to the mechanical system, the high-rise building with an atrium proportion 1/3 of the office proportion with center placements had the most users' comfort throughout the year. Besides, high-rise atrium building simulations with the atrium volume 1/4 of office volume and based on natural ventilation also had more acceptable indoor users' comfort than other proportions.

In the dynamic thermal simulation high-rise atrium building, the upper floors generally had a better thermal performance when all window opening ratios were set as 100%, especially in the south-west atrium placement during warm periods. In contrast, 0% and 50% window opening ratios with center placement had a negative performance in all the building zones. In this simulation group, when the atrium proportion was half of the office proportion, closing all external facade windows harmed different atrium placements during different seasons. In the high-rise building with a naturally ventilated condition and atrium proportion 1/3 of the office proportion, different atrium placements had a suitable thermal comfort during cold months. When the atrium proportion decreased to 1/4 of the office proportion, there was a remarkable fluctuation of analysis data. Additionally, the north-east, north-west, and south-east atrium placements at 50% and 100% window opening ratios in the middle floors of this high-rise group had maximum internal user comfort based on a passive strategy. Thus, the north-east atrium placement when all windows were completely opened on the middle floors had thermal comfort throughout the warm months.

In the high-rise building simulation with atrium volume 1/3 of the office volume, when the internal environment was mechanically conditioned, the occupants had less predicted percentage of dissatisfaction than other dynamic thermal simulation models of high-rise buildings in this group when the atrium was placed in the center of the building. Importantly, while the atrium zone of the last floor in the high-rise building (tenth floor) had a discomfort condition, the 1/4 atrium volume of office volume had a better internal condition based on active performance than other high-rise atrium building dynamic thermal simulation models.

The high-rise atrium dynamic simulation models with a mechanical indoor condition (basic air conditioning) according to the Percentage of Dissatisfied (PD) Due to Draught, PD Due to Vertical Air Temperature Difference, PD Due to Cool or Warm Floor, and PD Due to Radiant Temperature Asymmetry, mainly reached thermal comfort during a year in the lower floors. For instance, based on the Percentage of Dissatisfied (PD) Due to Draught, and PD Due to Cool or Warm Floor, the atrium 1/4 of the office proportion with all different atrium placements provided comfort in category A (<10), although the lower floors have the minimum level of occupants' dissatisfaction. For instance, the atrium 1/2 and 1/4 of the office proportion based on the PD Due to Radiant Temperature Asymmetry have thermal comfort conditions in the zones of the lower floors regardless of the atrium placements.

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APPENDICES

Appendix A: Energy Performance of the Passive Single-Floor Atrium Building

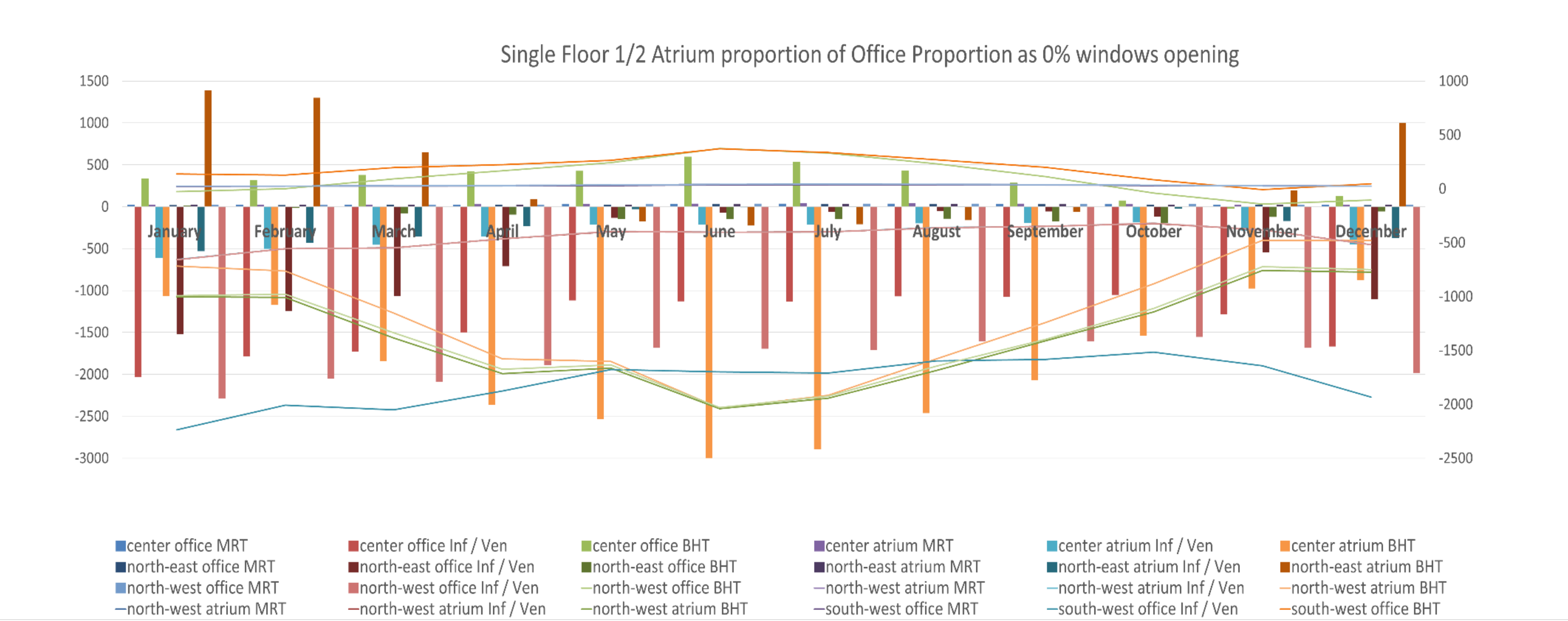

Figure 39: The Single-Floor atrium building with atrium proportion 1/2 of the office proportion and 0% opening ratio for all windows.

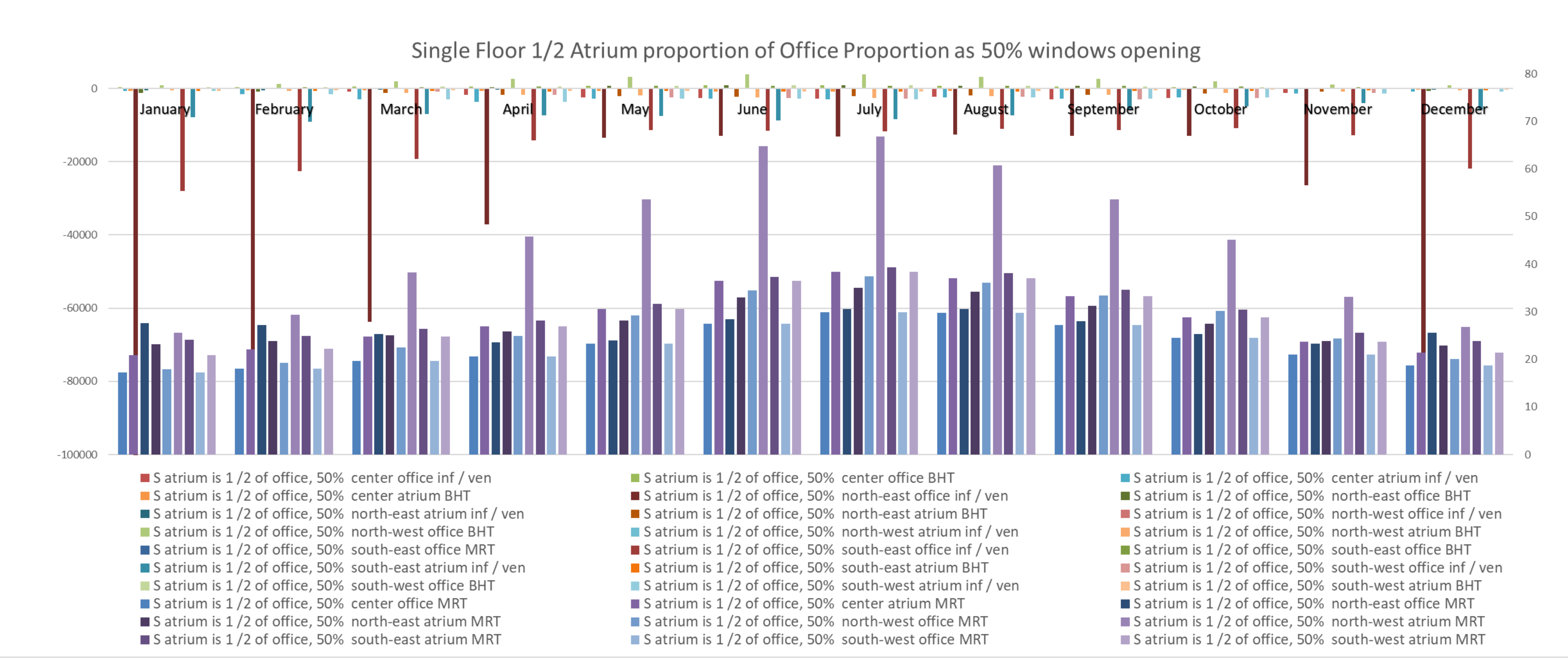

Figure 40: The Single-Floor atrium building with atrium proportion 1/2 of the office proportion and 50% opening ratio for all windows.

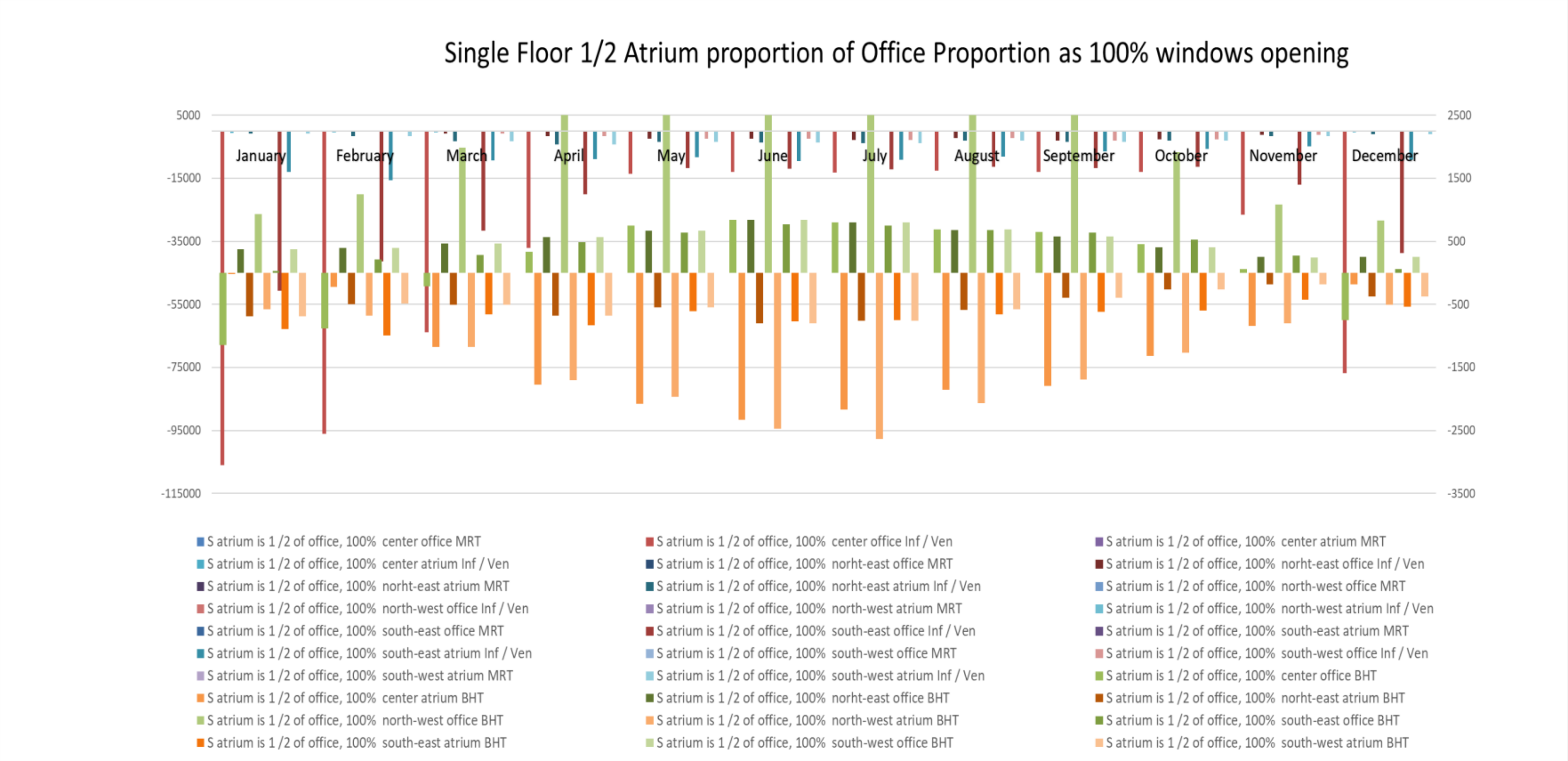

Figure 41: The Single-Floor atrium building with atrium proportion 1/2 of the office proportion and 100% opening ratio for all windows.

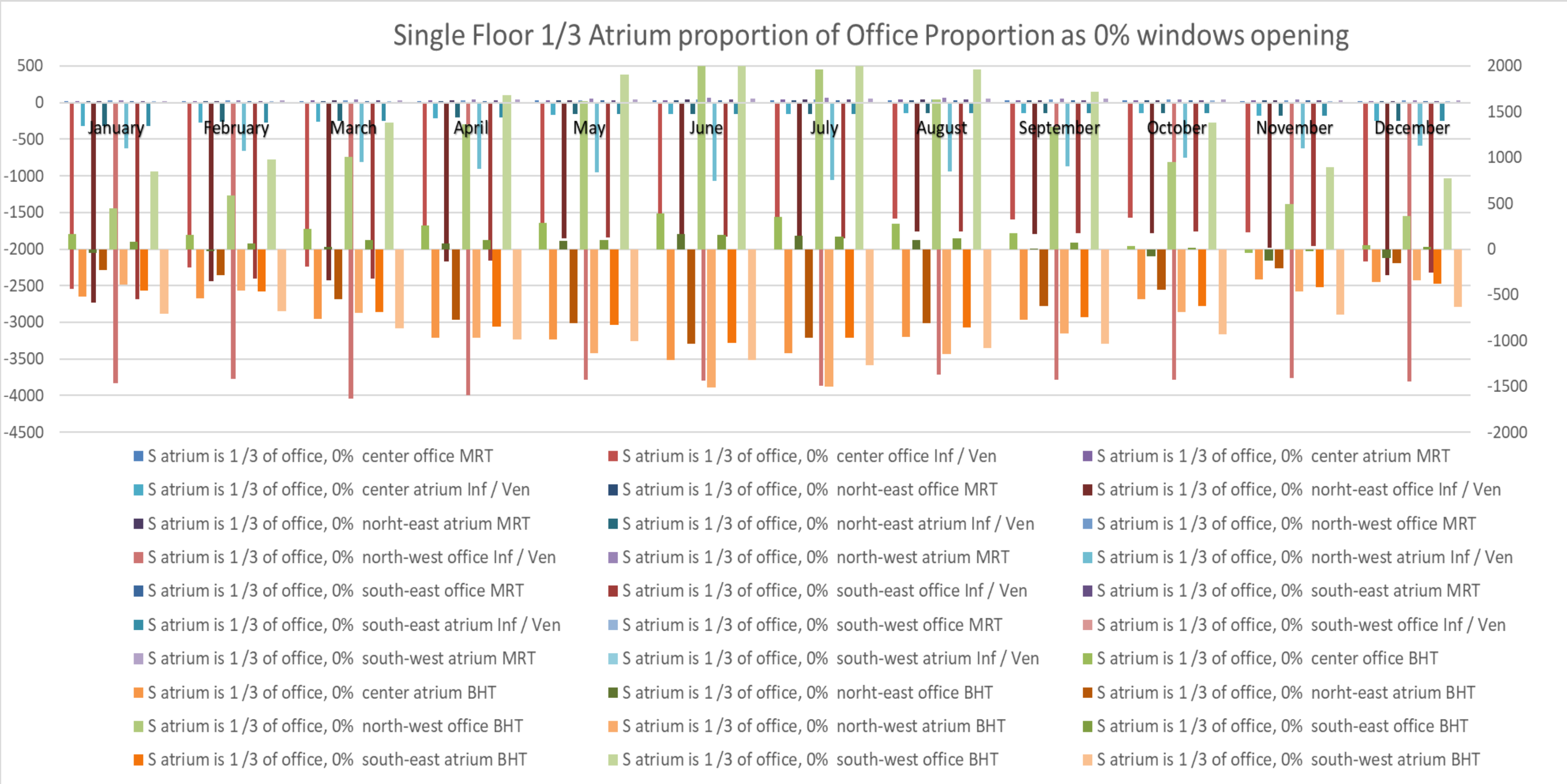

Figure 42: The Single-Floor atrium building with atrium proportion 1/3 of the office proportion and 0% opening ratio for all windows.

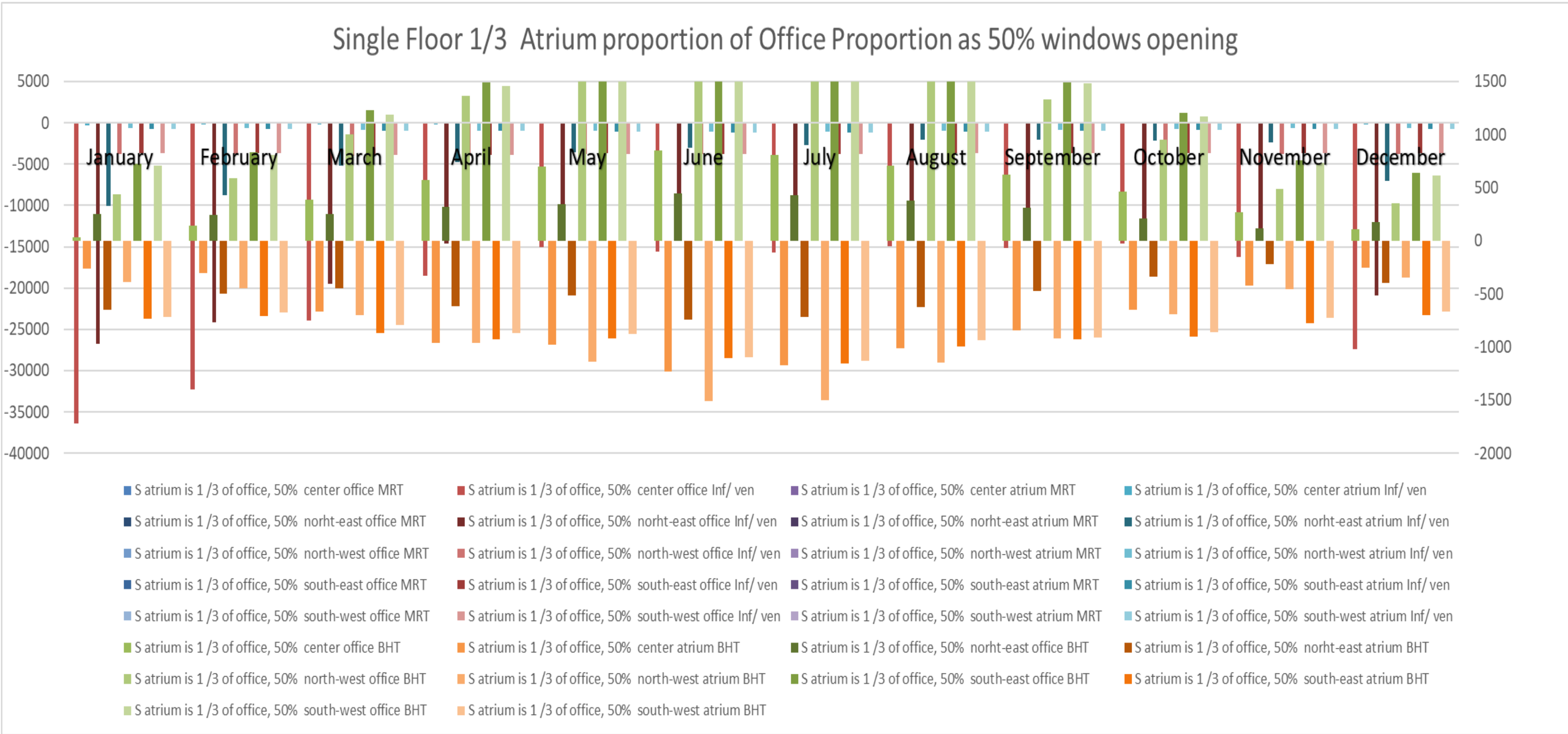

Figure 43: The Single-Floor atrium building with atrium proportion 1/3 of the office proportion and 50% opening ratio for all windows.

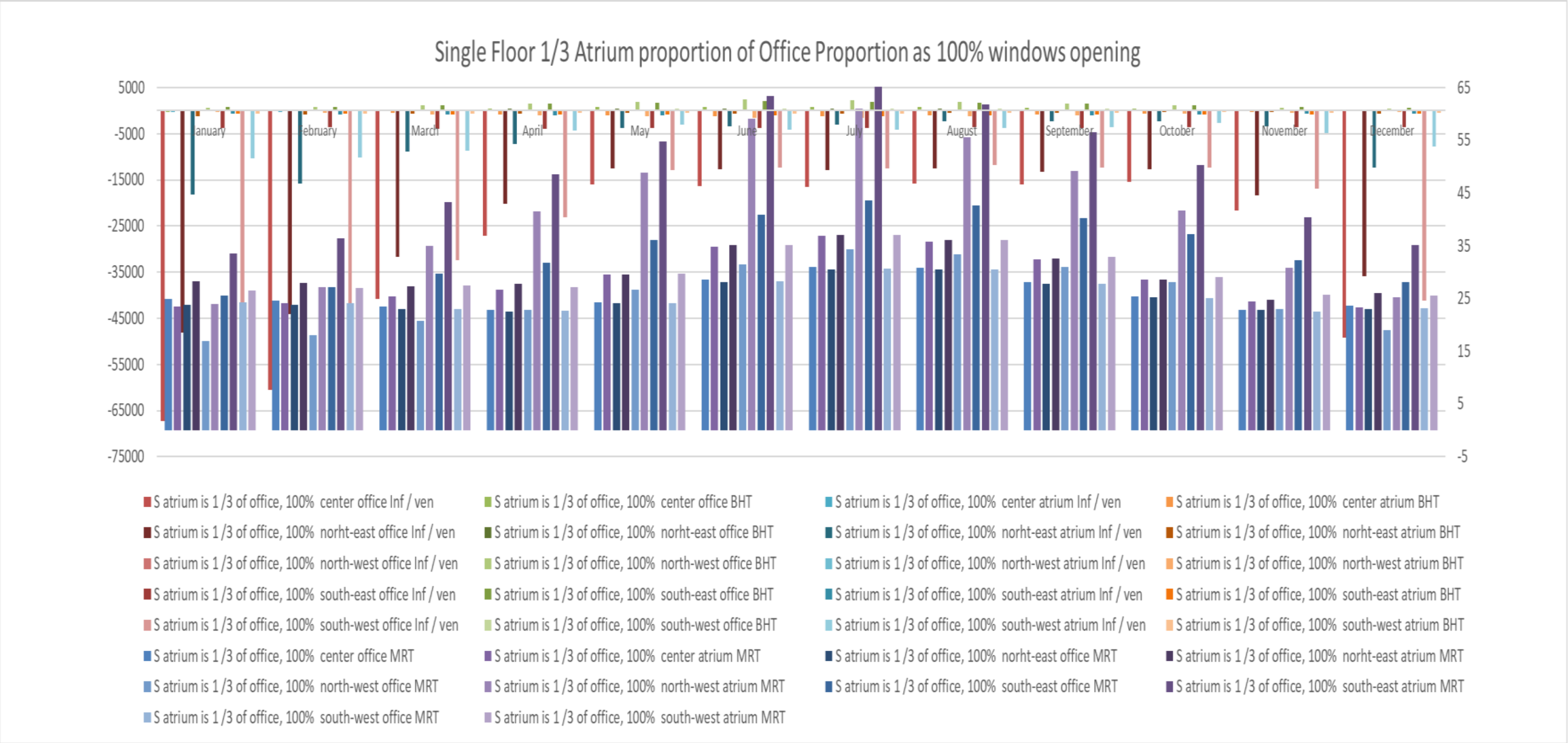

Figure 44: The Single-Floor atrium building with atrium proportion 1/3 of the office proportion and 100% opening ratio for all windows.

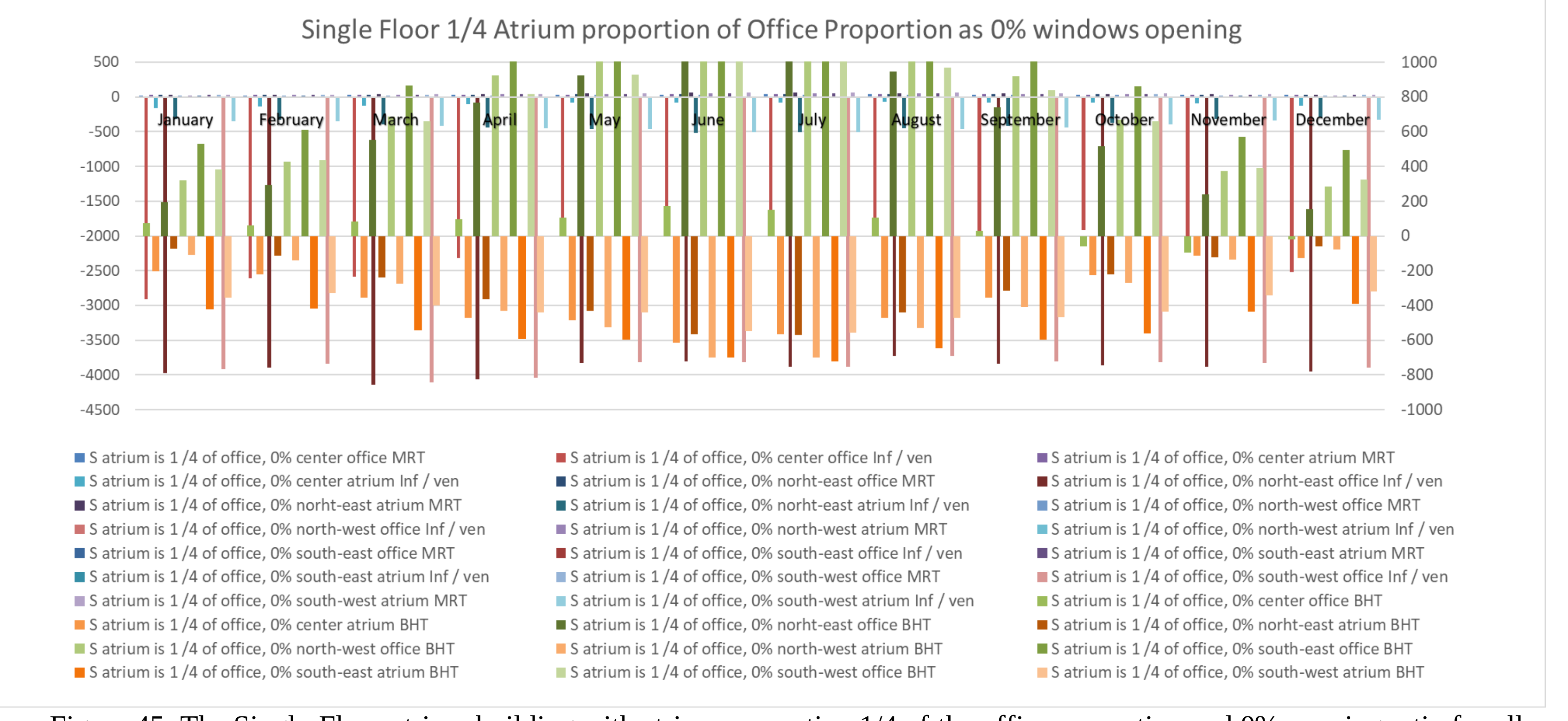

Figure 45: The Single-Floor atrium building with atrium proportion 1/4 of the office proportion and 0% opening ratio for all windows.

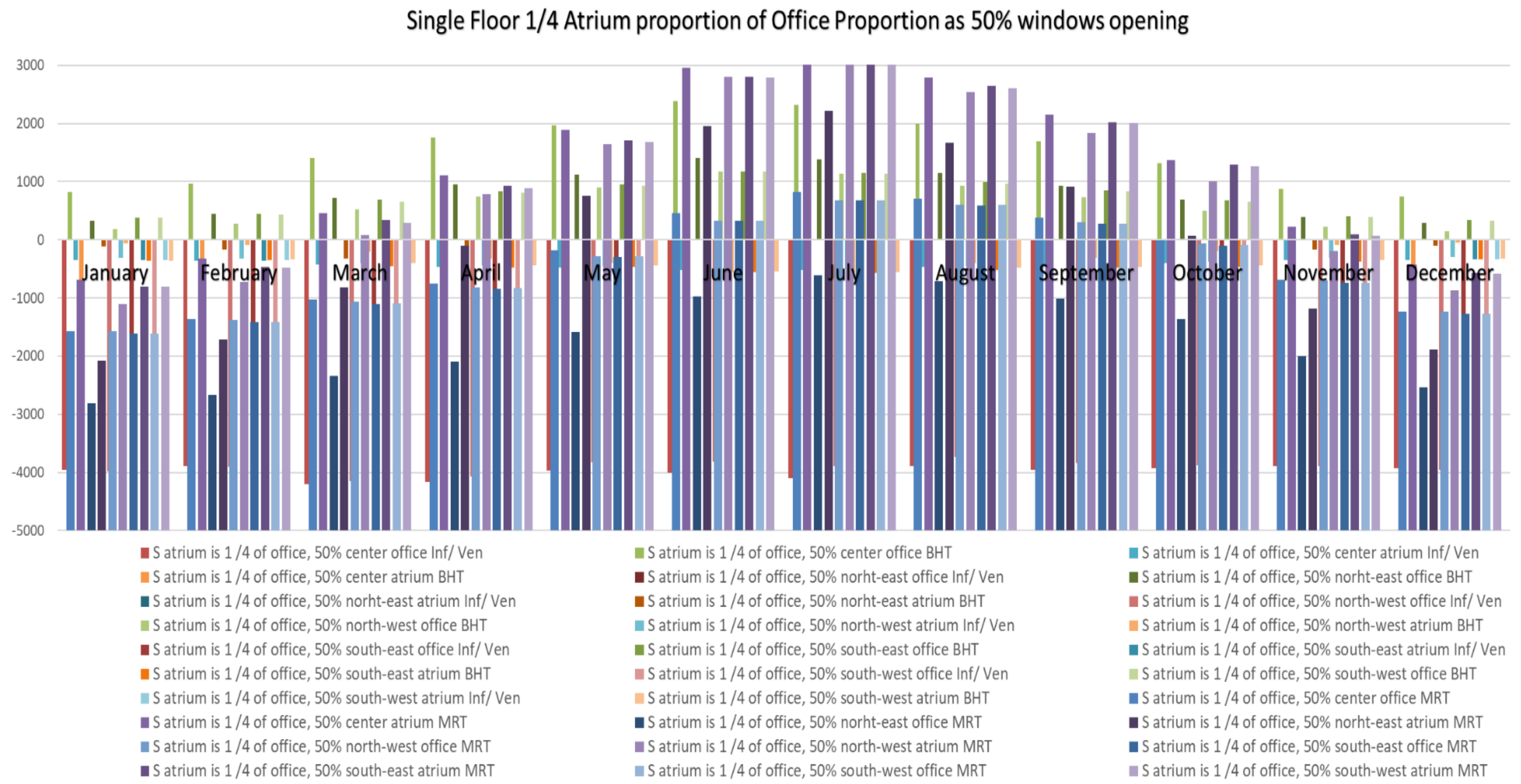

Figure 46. The Single-Floor atrium building with atrium proportion 1/4 of the office proportion and 50% opening ratio for all windows.

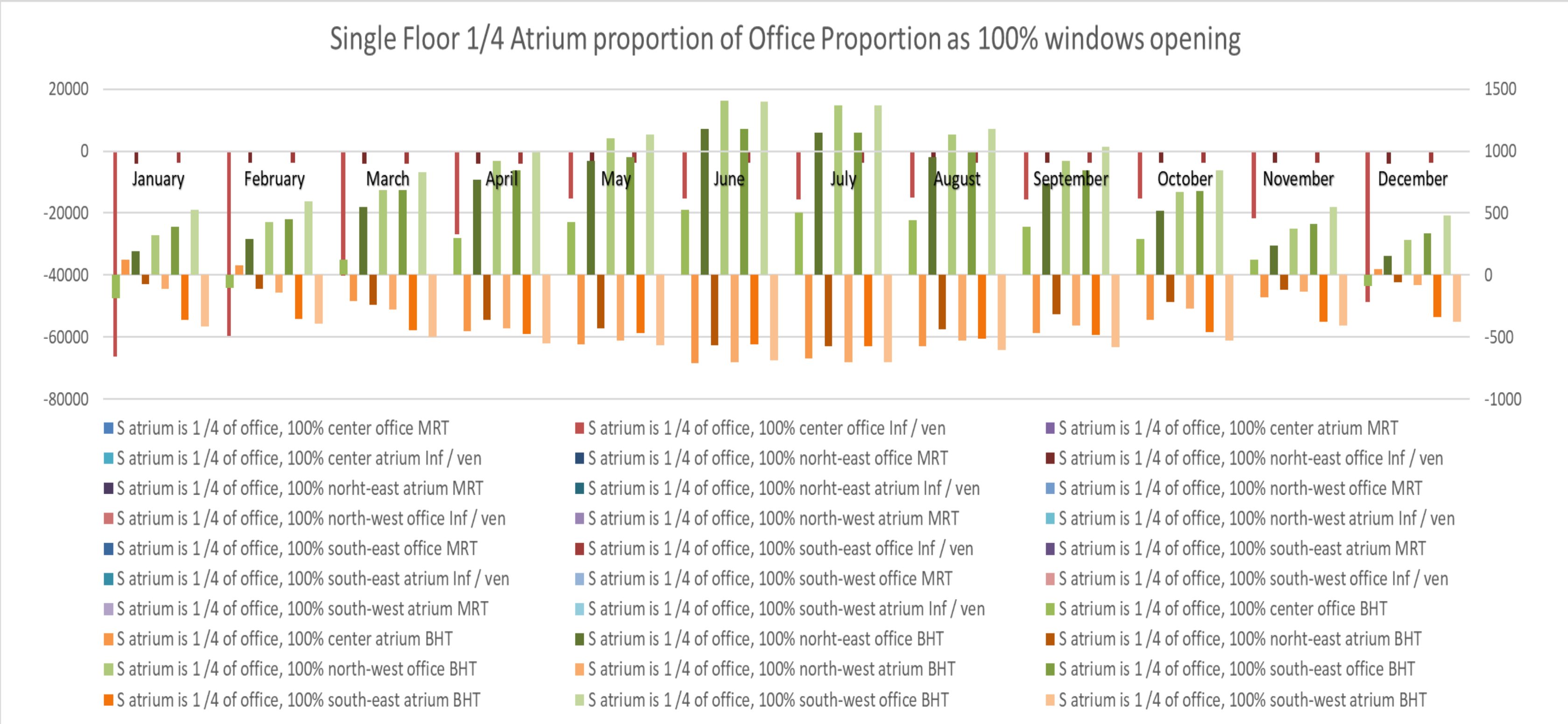

Figure 47: The Single-Floor atrium building with atrium proportion 1/4 of the office proportion and 100% opening ratio for all windows.

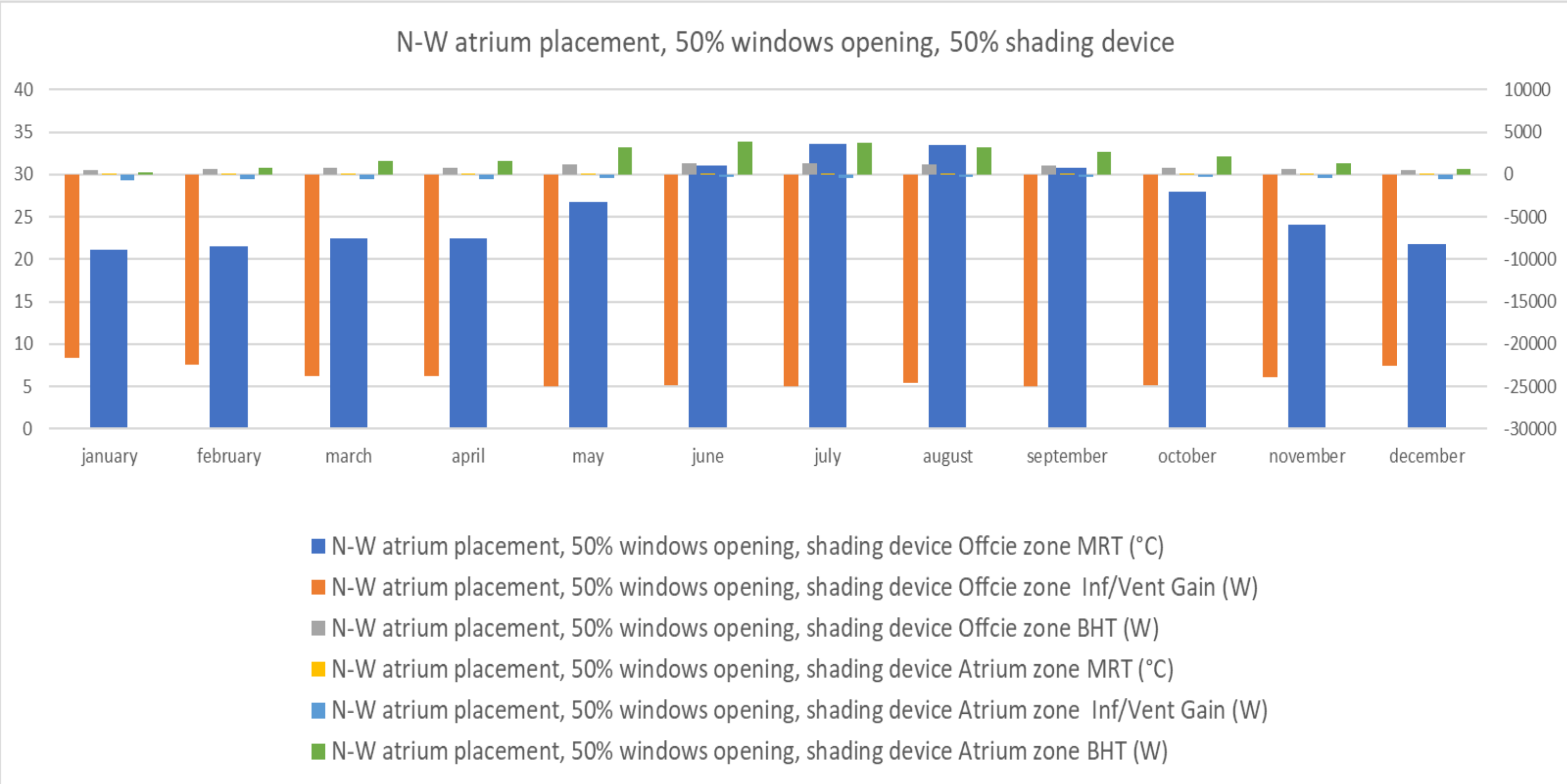

Figure 48: The Single-Floor N-W atrium building with atrium proportion 1/2 of the office proportion and 0% opening ratio for all windows, and 50% shading device for each atrium facade.

Appendix B: Energy Performance of the Passive Medium-Rise Atrium Building

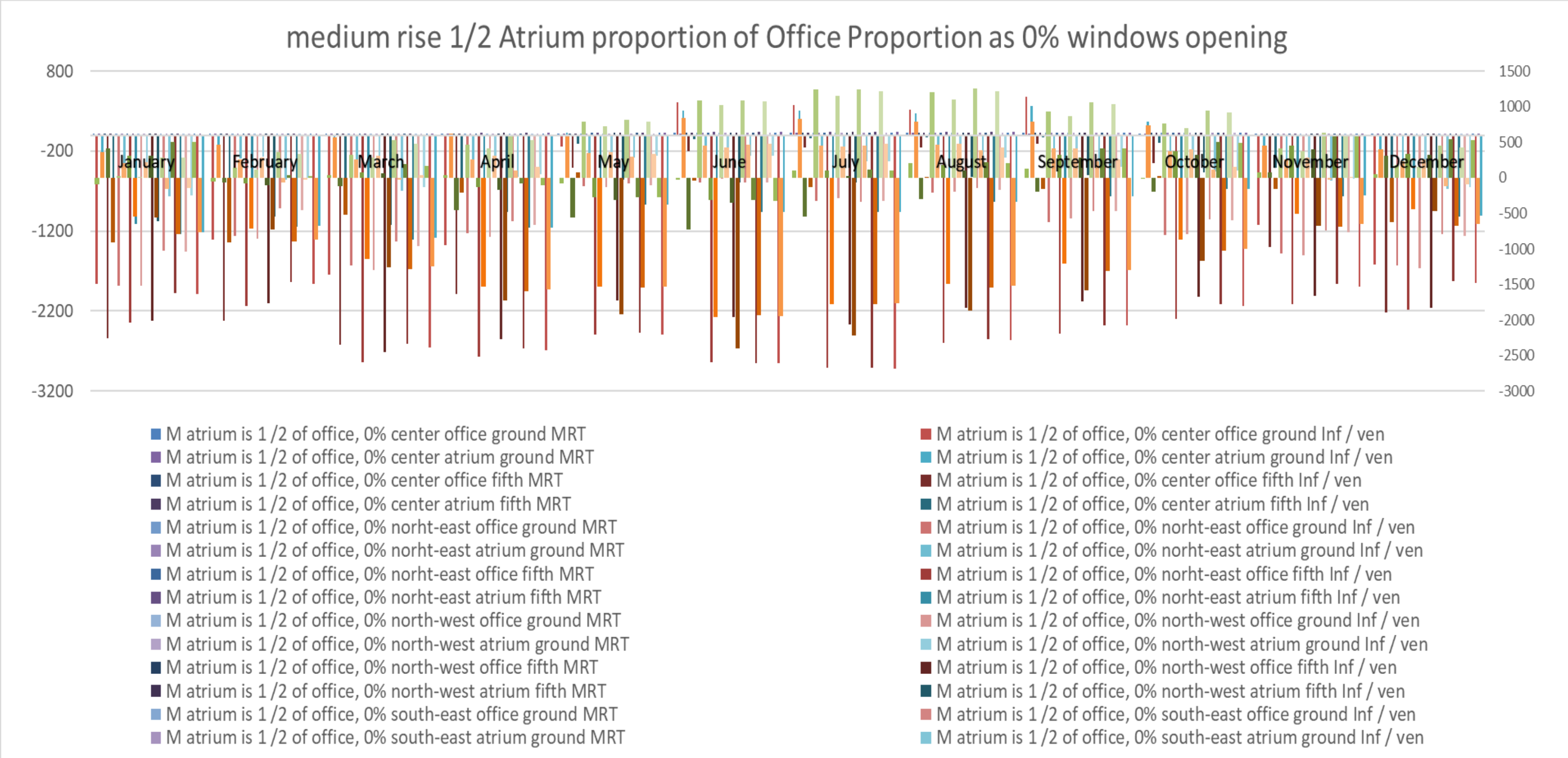

Figure 49: The Medium-Rise atrium building with atrium proportion 1/2 of the office proportion and 0% opening ratio for all windows.

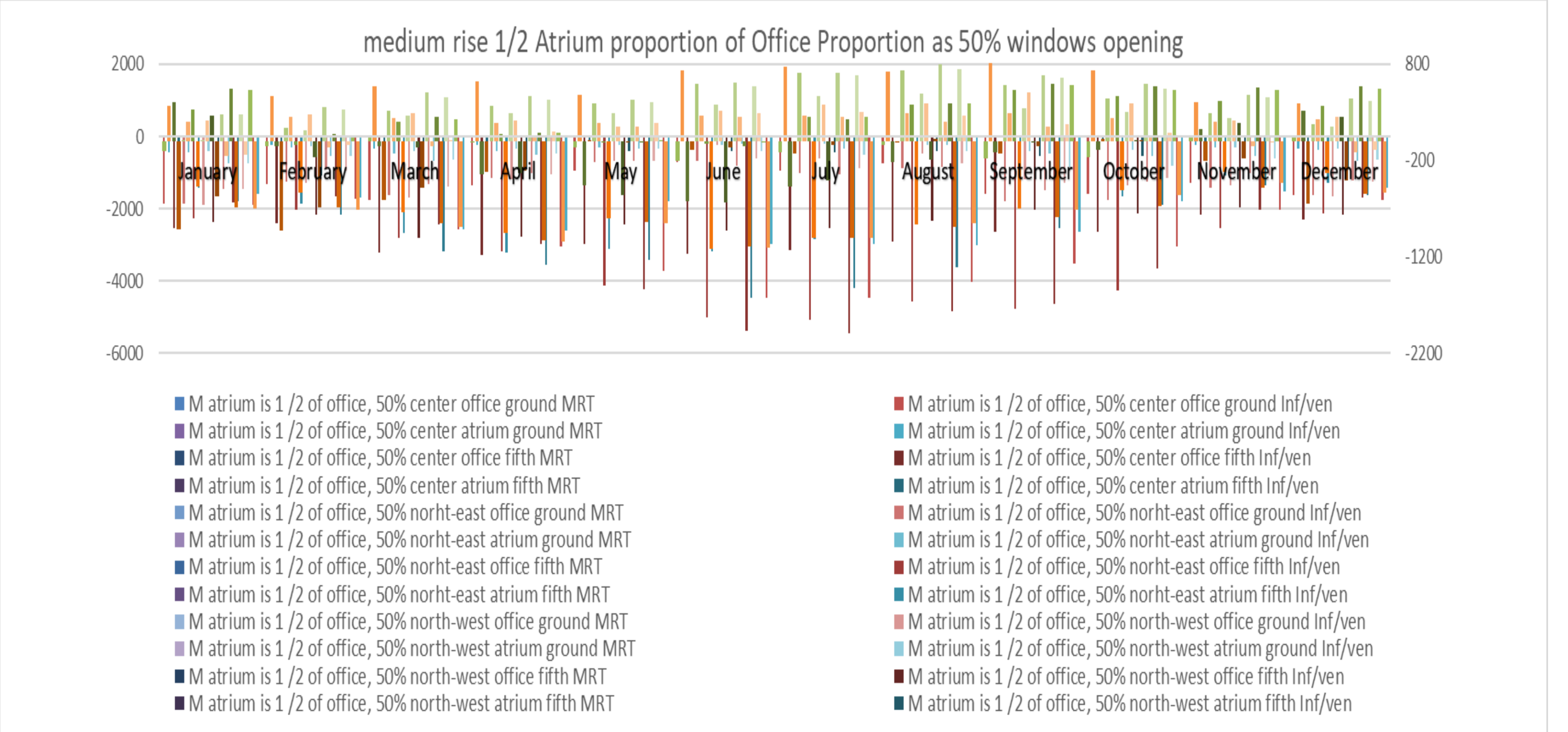

Figure 50: The Medium-Rise atrium building with atrium proportion 1/2 of the office proportion and 50% opening ratio for all windows.

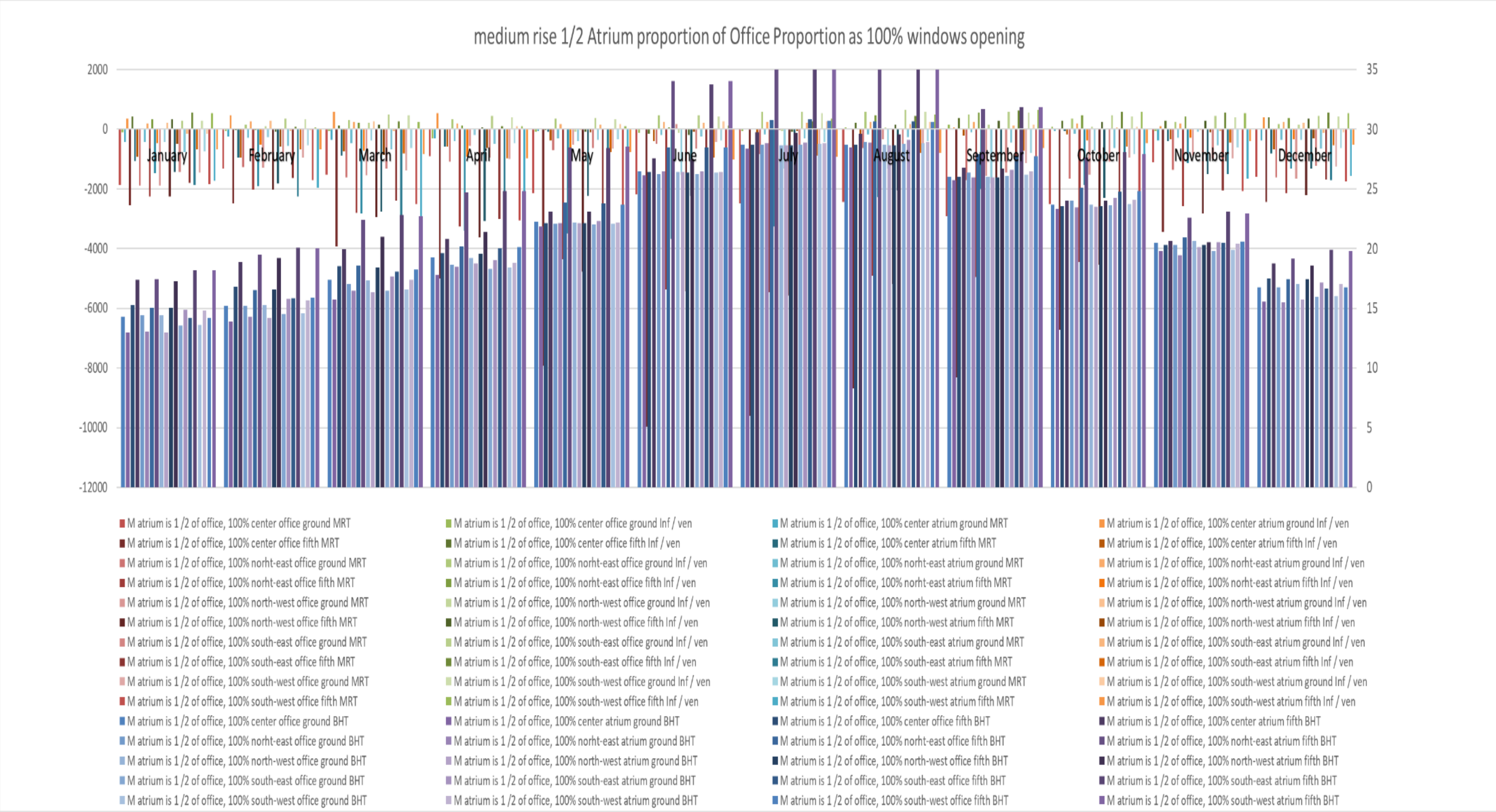

Figure 51: The Medium-Rise atrium building with atrium proportion 1/2 of the office proportion and 100% opening ratio for all windows.

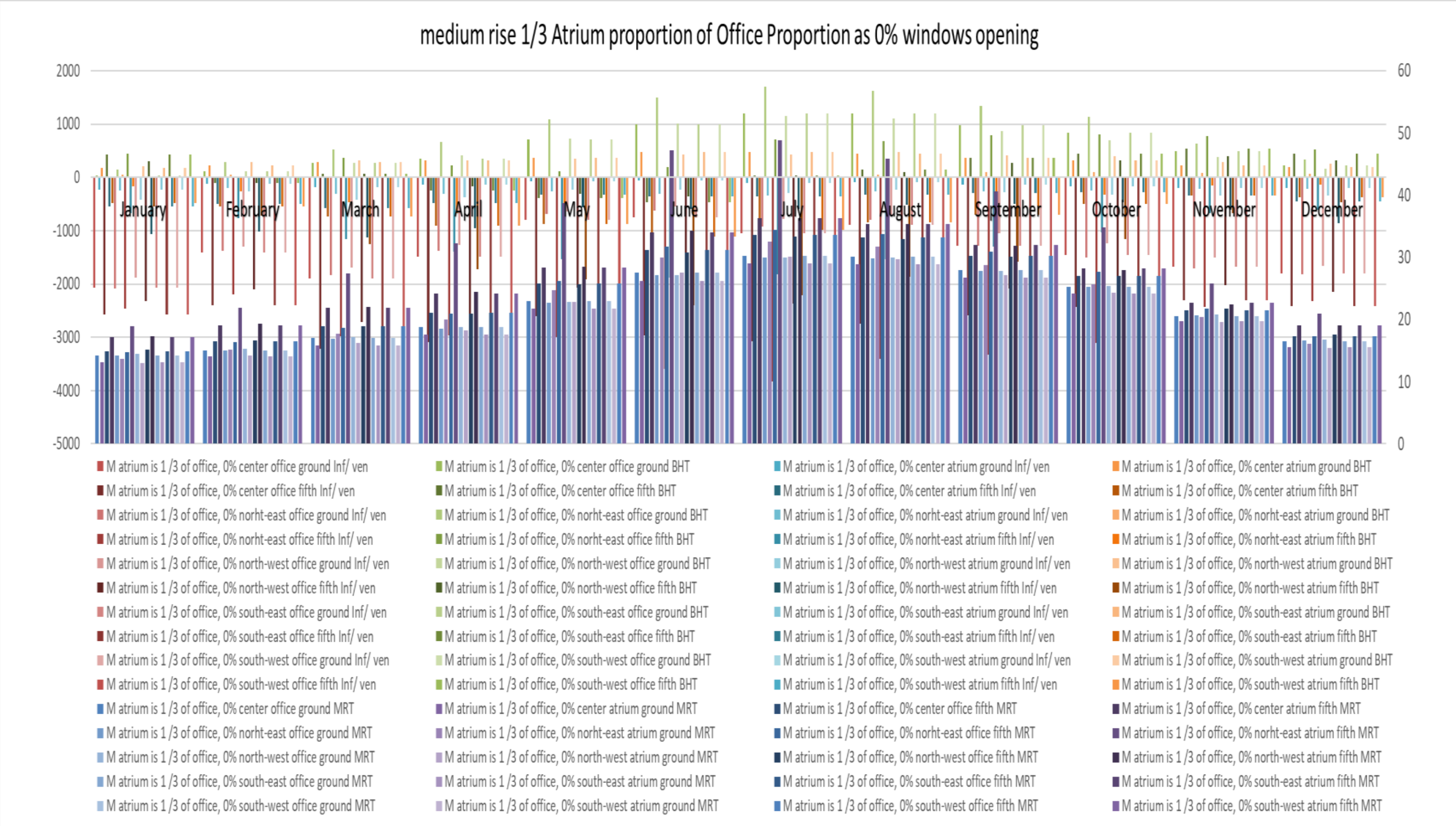

Figure 52: The Medium-Rise atrium building with atrium proportion 1/3 of the office proportion and 0% opening ratio for all windows.

Figure 53: The Medium-Rise atrium building with atrium proportion 1/3 of the office proportion and 50% opening ratio for all windows.

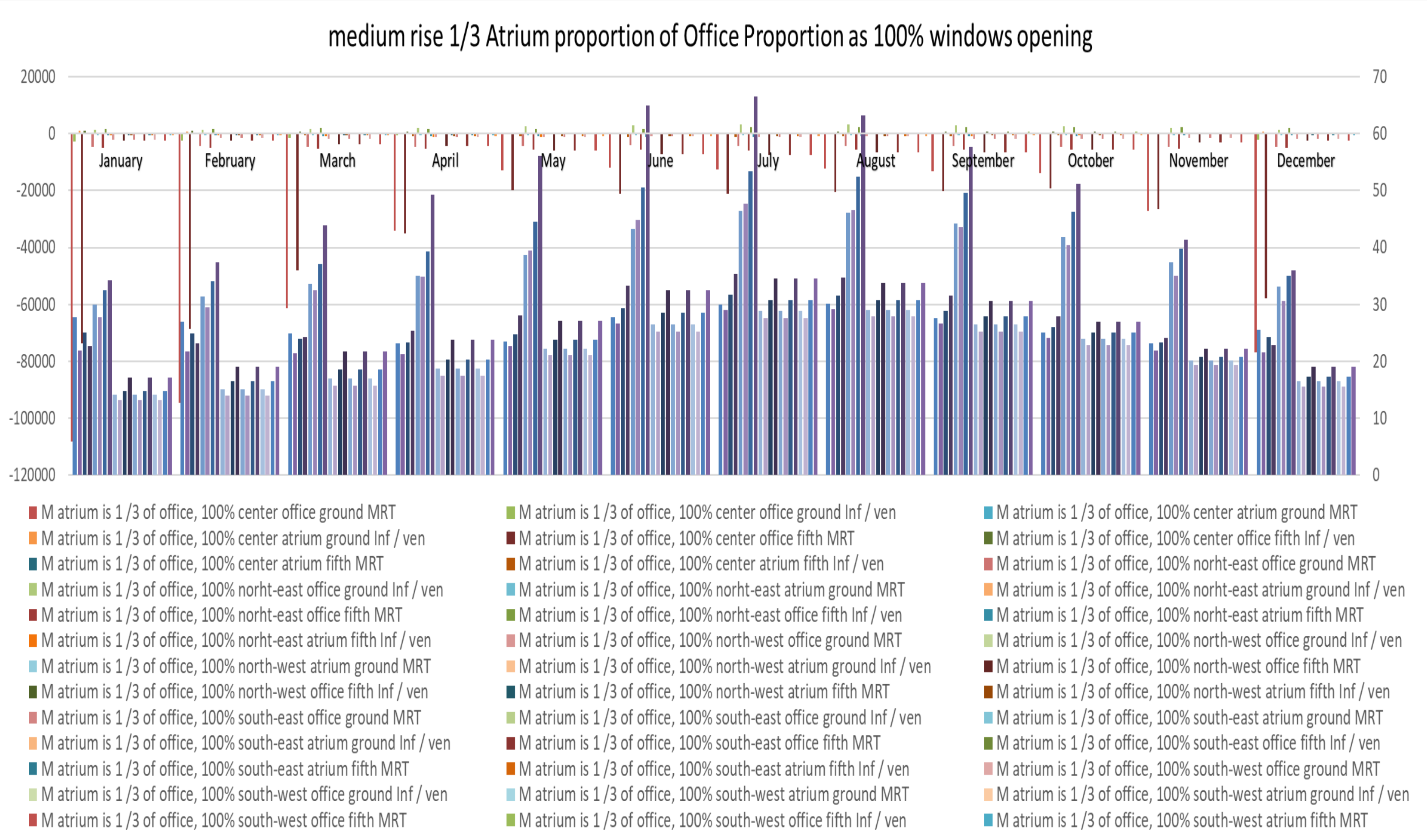

Figure 54: The Medium-Rise atrium building with atrium proportion 1/3 of the office proportion and 100% opening ratio for all windows.

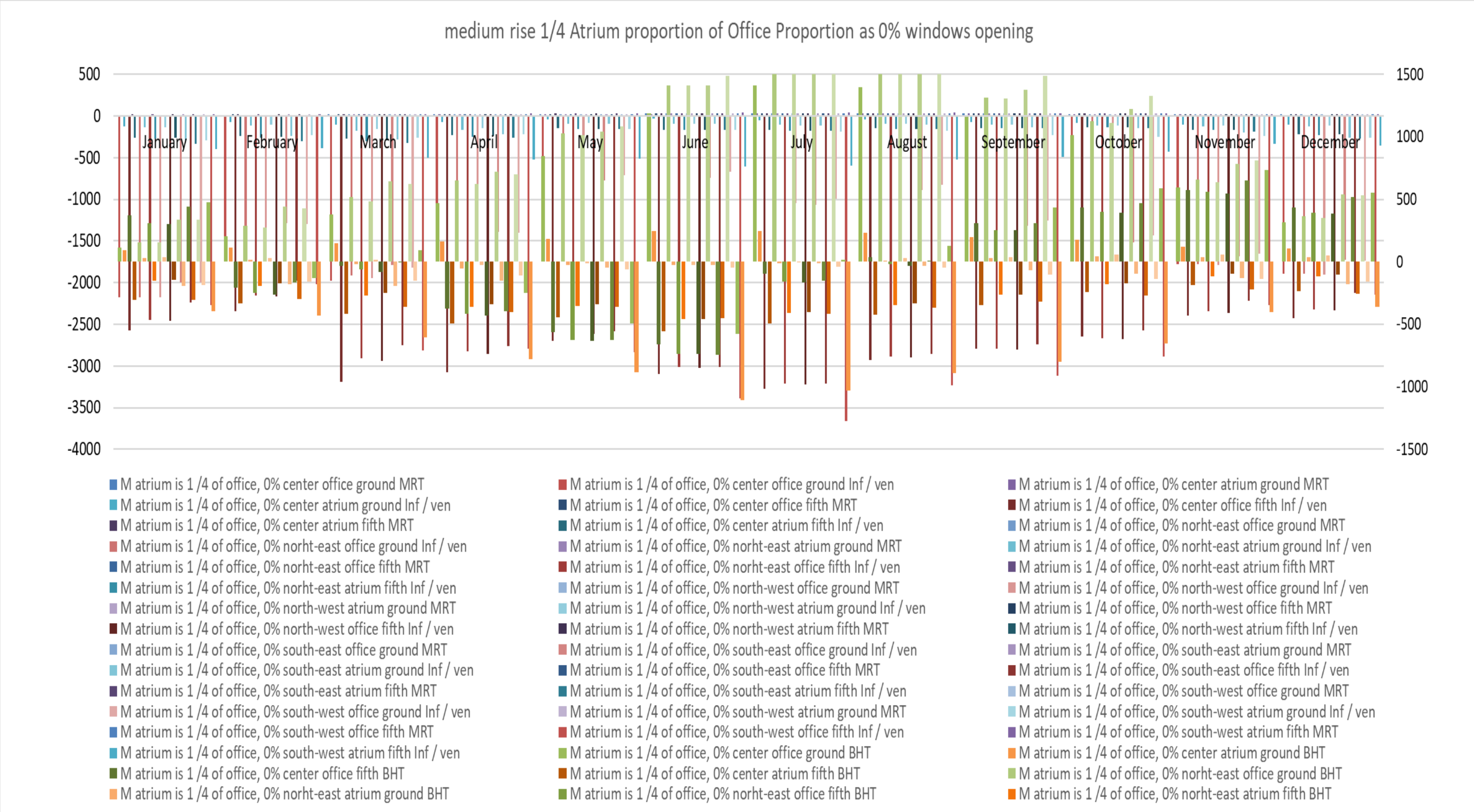

Figure 55: The Medium-Rise atrium building with atrium proportion 1/4 of the office proportion and 0% opening ratio for all windows.

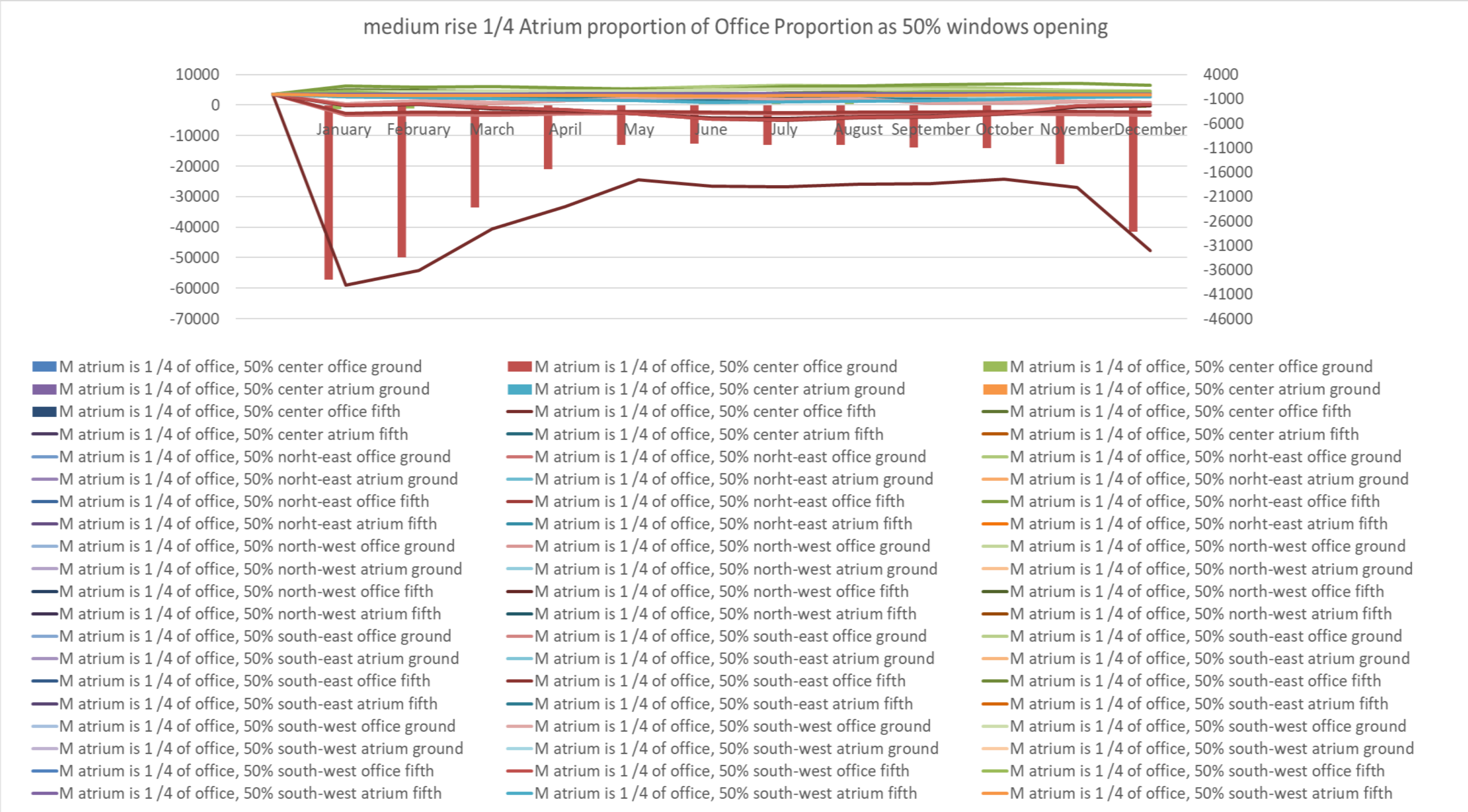

Figure 56: The Medium-Rise atrium building with atrium proportion 1/4 of the office proportion and 50% opening ratio for all windows.

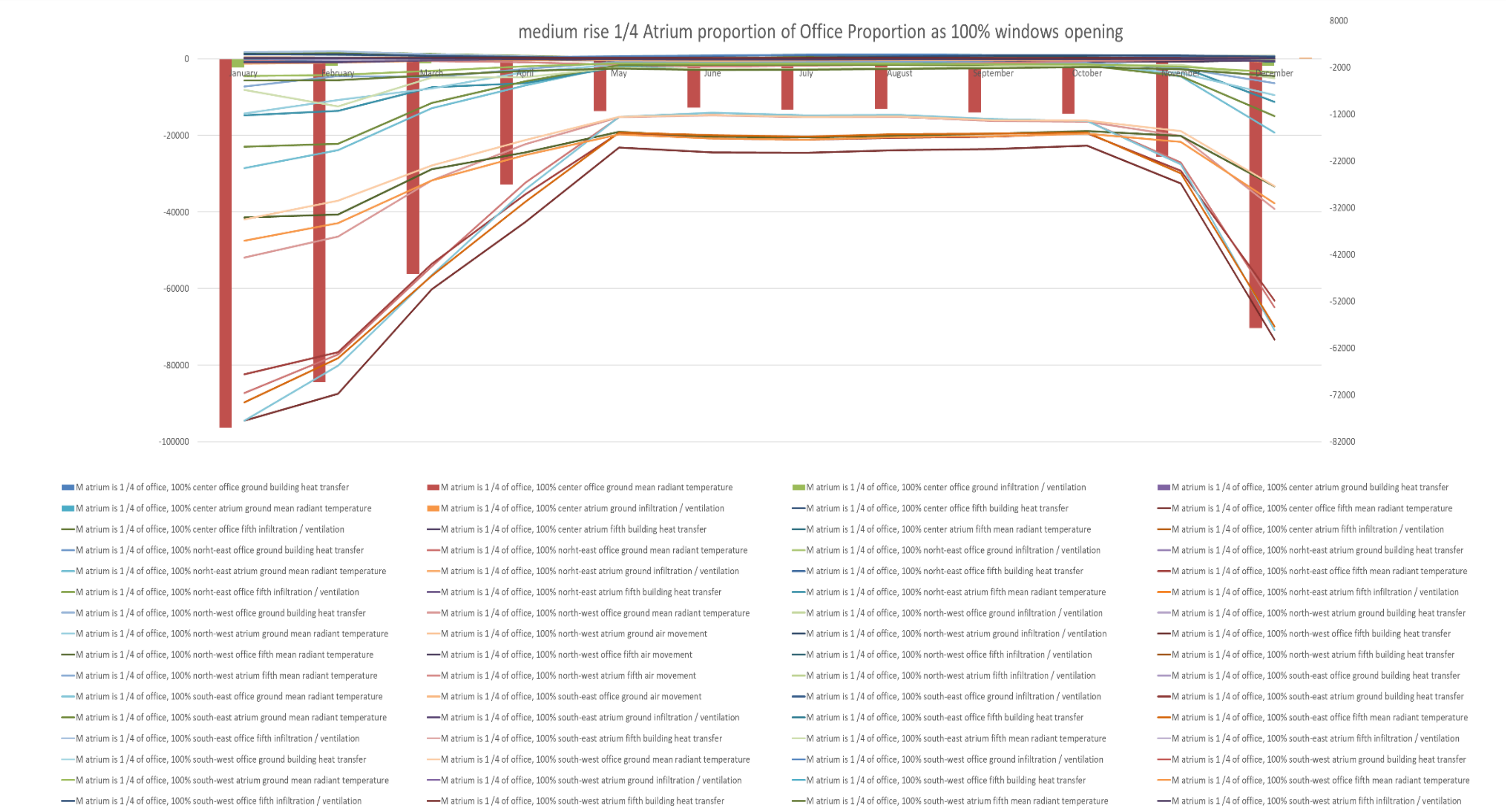

Figure 57: The Medium-Rise atrium building with atrium proportion 1/4 of the office proportion and 100% opening ratio for all windows.

Appendix C: Energy Performance of the Passive High-Rise Atrium Building

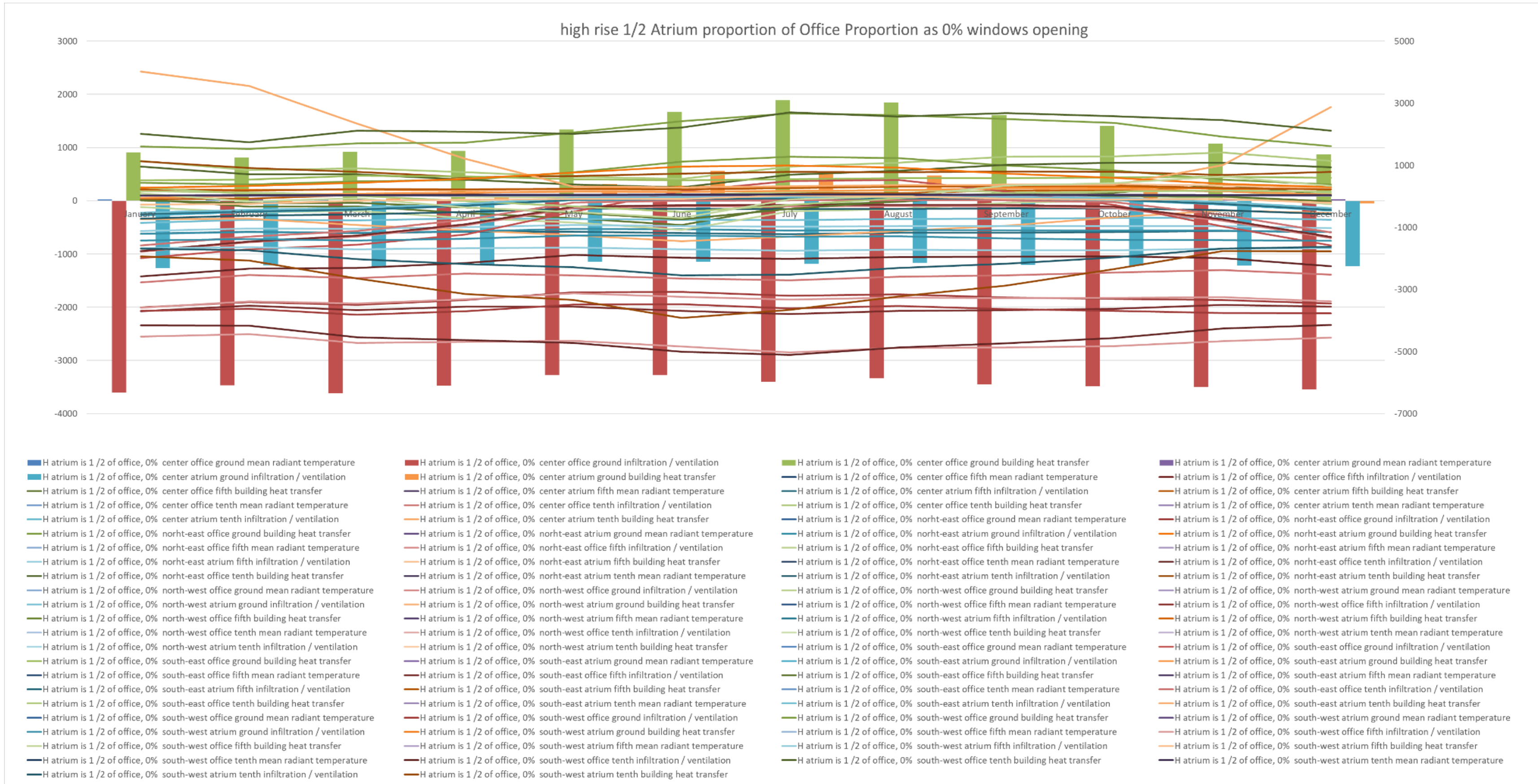

Figure 58: The High-Rise atrium building with atrium proportion 1/2 of the office proportion and 0% opening ratio for all windows.

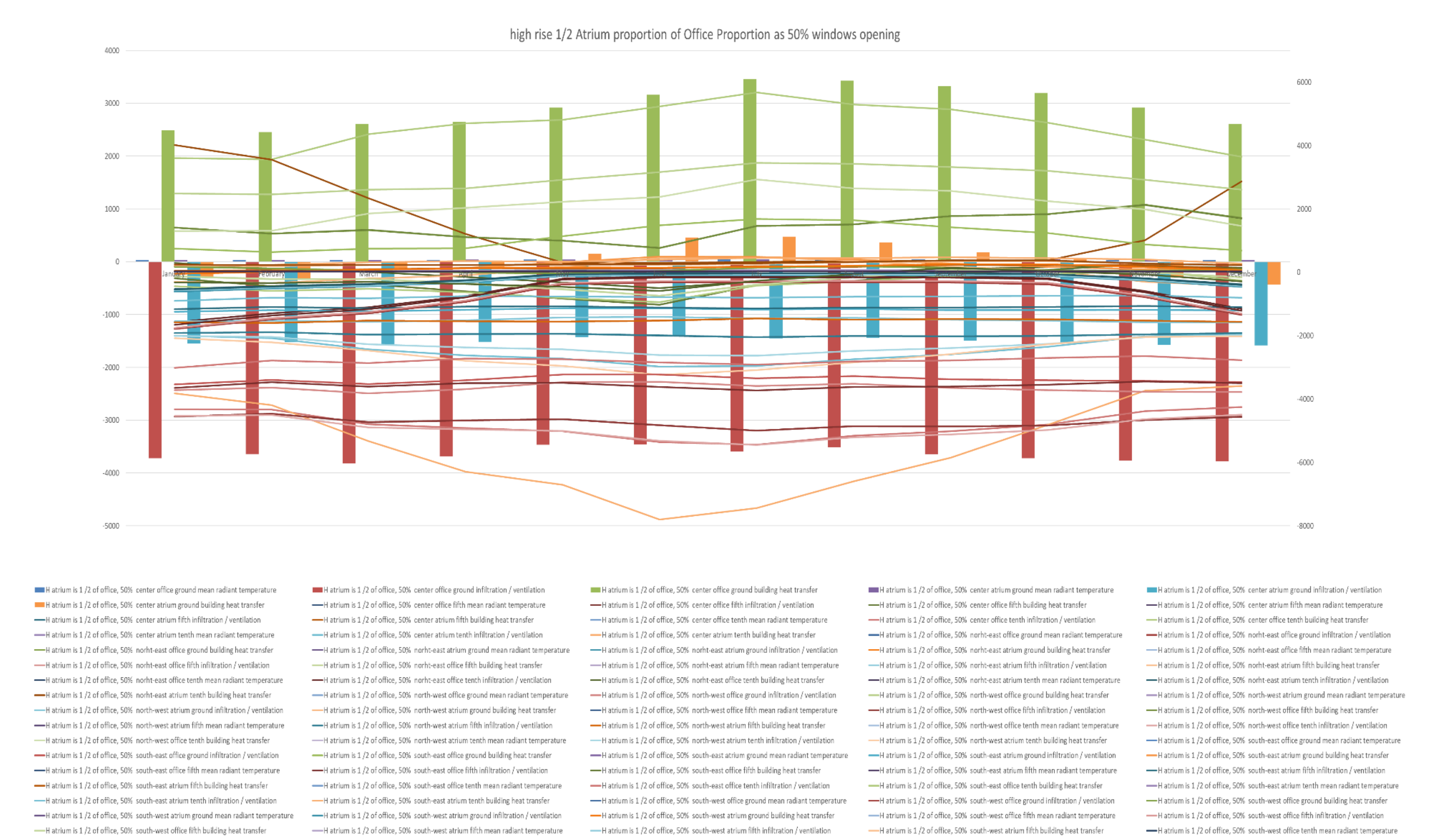

Figure 59: The High-Rise atrium building with atrium proportion 1/2 of the office proportion and 50% opening ratio for all windows.

Figure 60: The High-Rise atrium building with atrium proportion 1/2 of the office proportion and 100% opening ratio for all windows.

Figure 61: The High-Rise atrium building with atrium proportion 1/3 of the office proportion and 0% opening ratio for all windows.

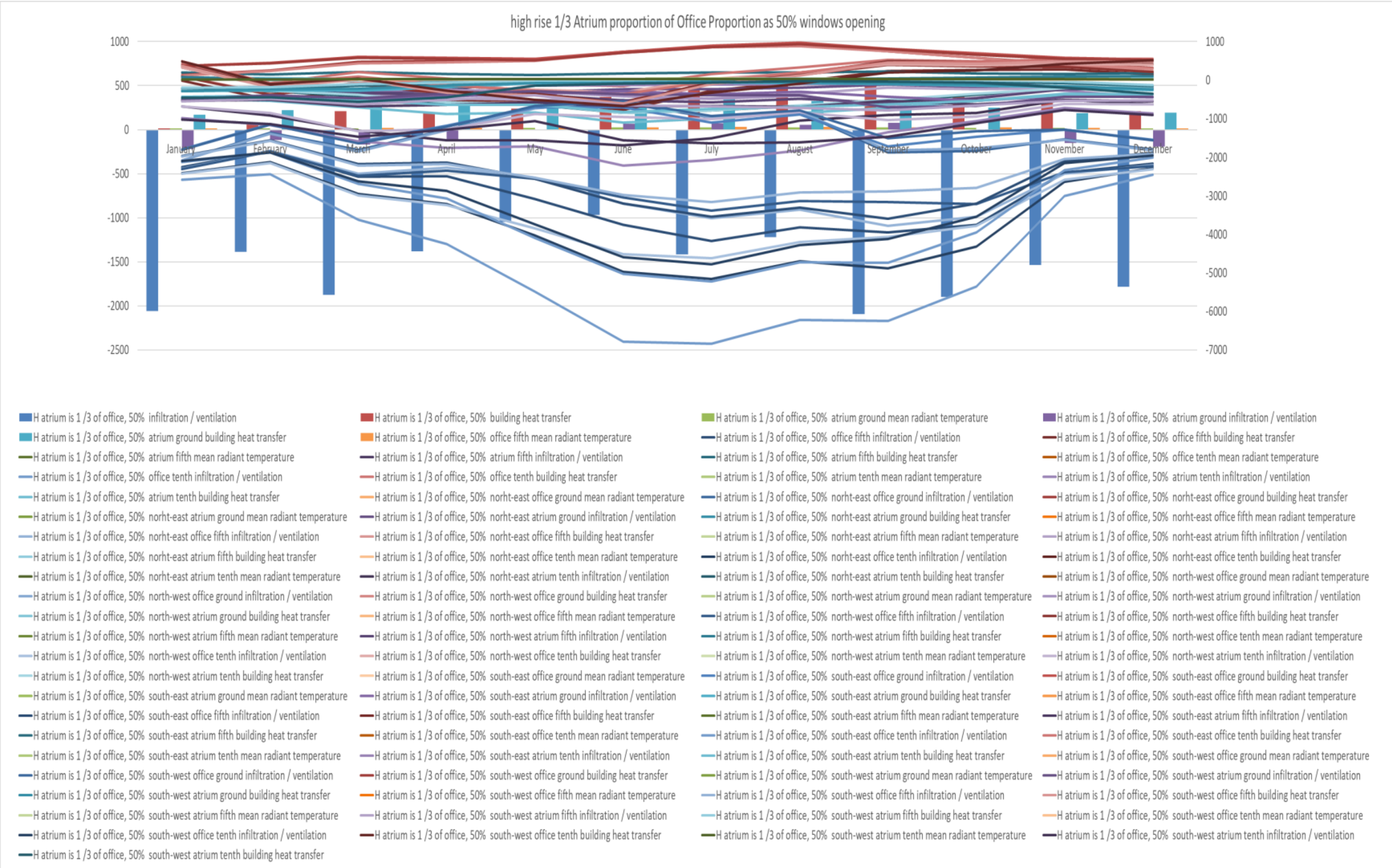

Figure 62: The High-Rise atrium building with atrium proportion 1/3 of the office proportion and 50% opening ratio for all windows.

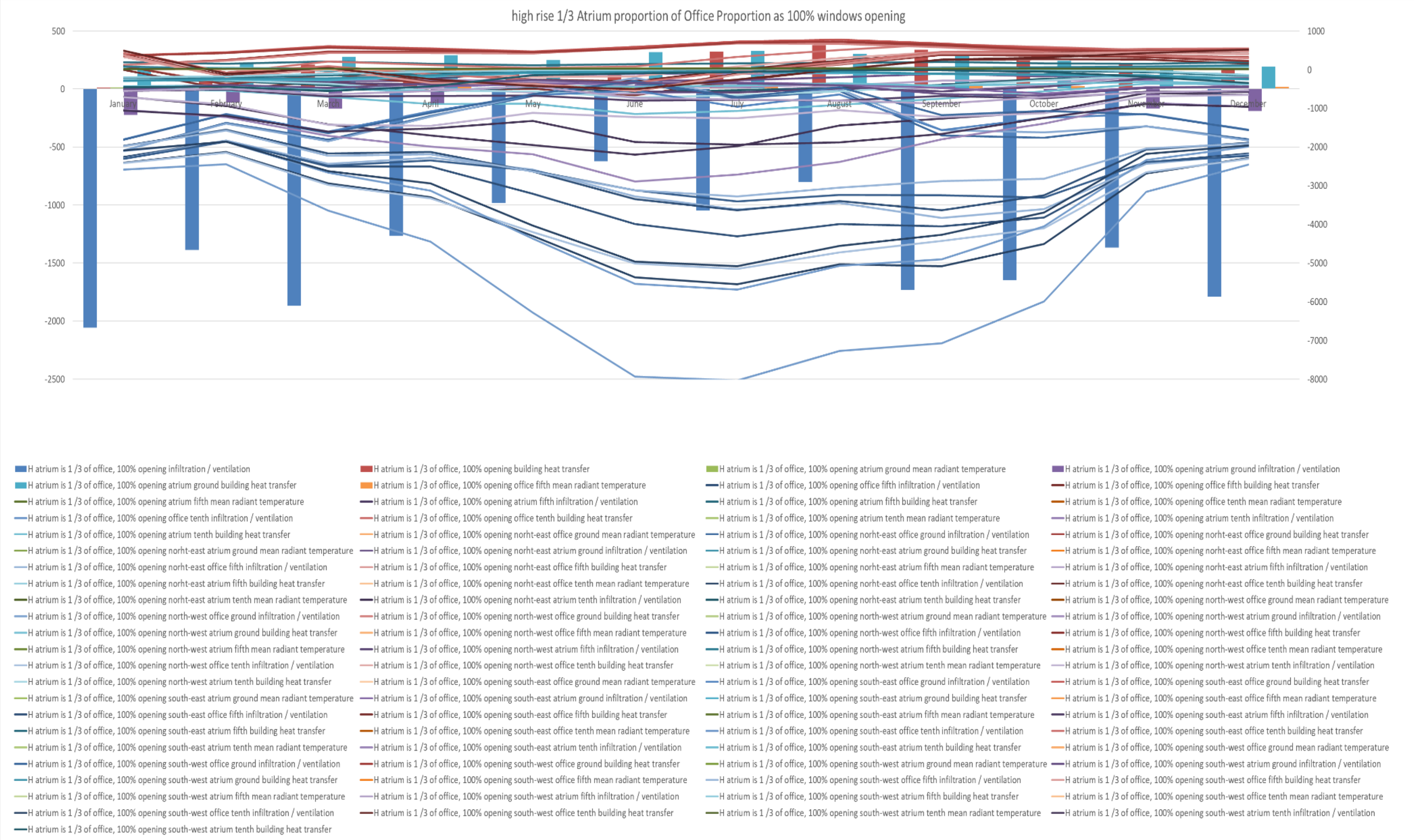

Figure 63: The High-Rise atrium building with atrium proportion 1/3 of the office proportion and 100% opening ratio for all windows.

Figure 64: The High-Rise atrium building with atrium proportion 1/4 of the office proportion and 0% opening ratio for all windows.

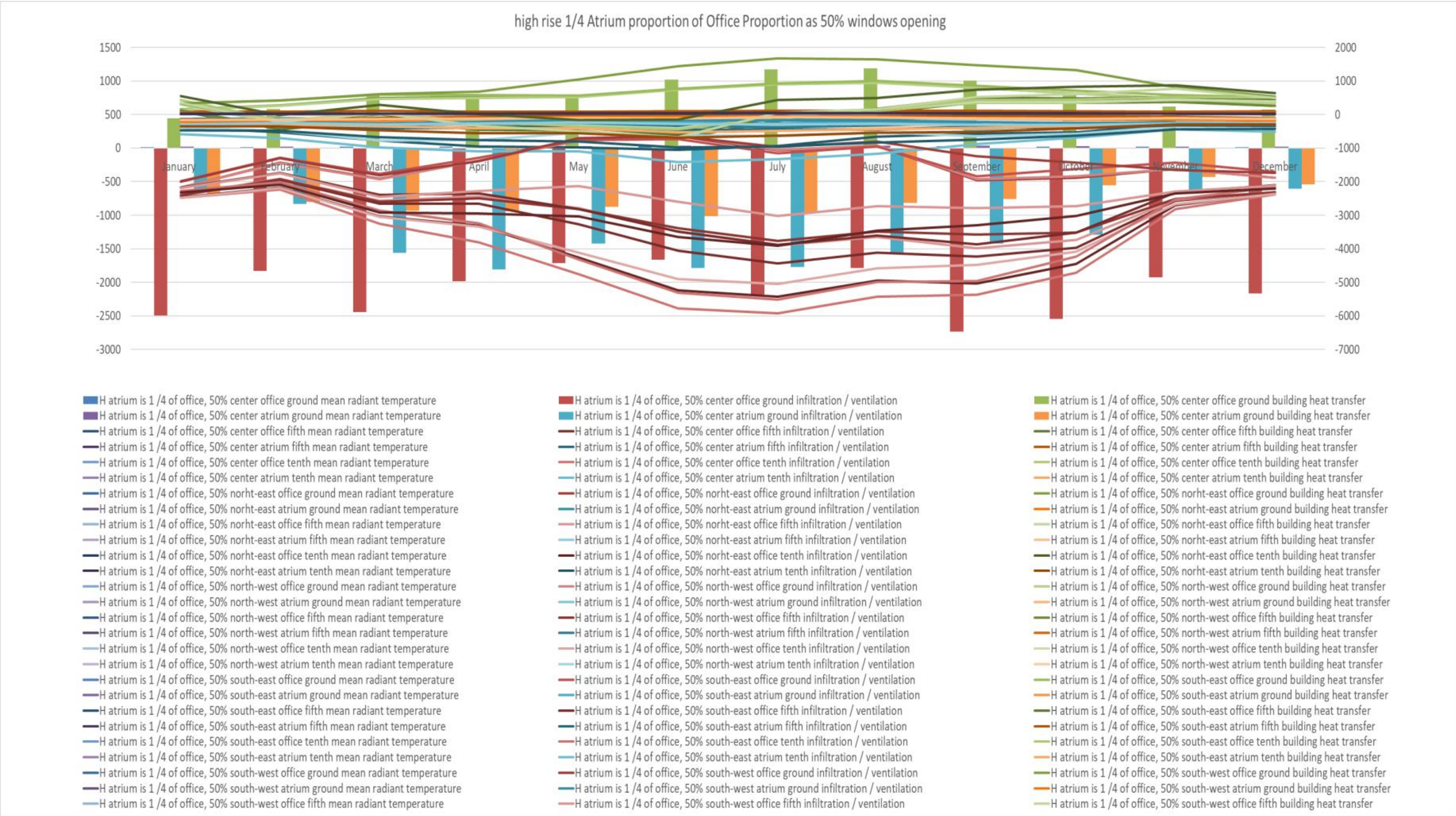

Figure 65: The High-Rise atrium building with atrium proportion 1/2 of the office proportion and 50% opening ratio for all windows.

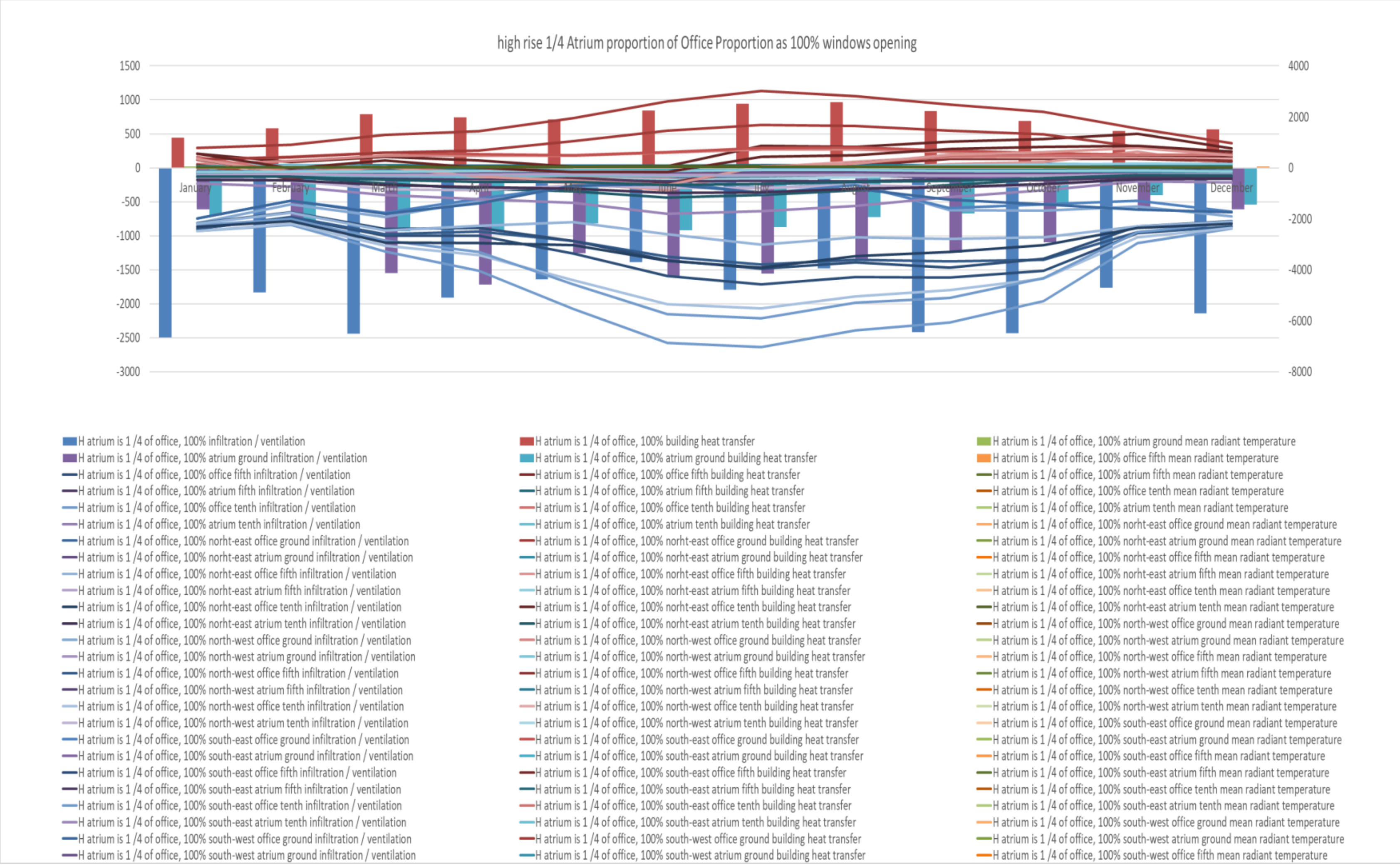

Figure 66: The High-Rise atrium building with atrium proportion 1/4 of the office proportion and 100% opening ratio for all windows.

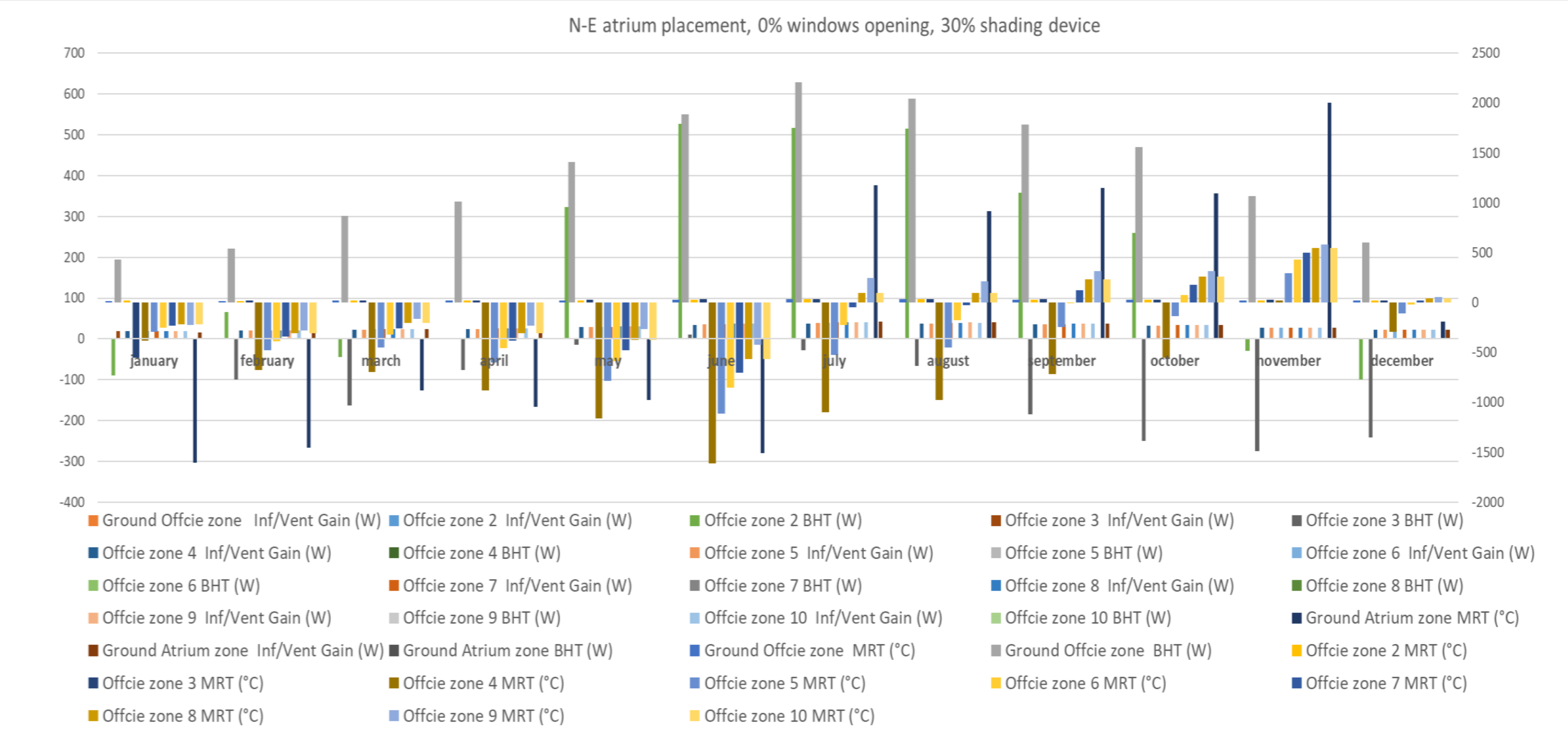

Figure 67: The High-Rise north- east atrium building with atrium proportion 1/2 of the office proportion and 0% opening ratio for all windows, 30% shading device over each atrium external facade.

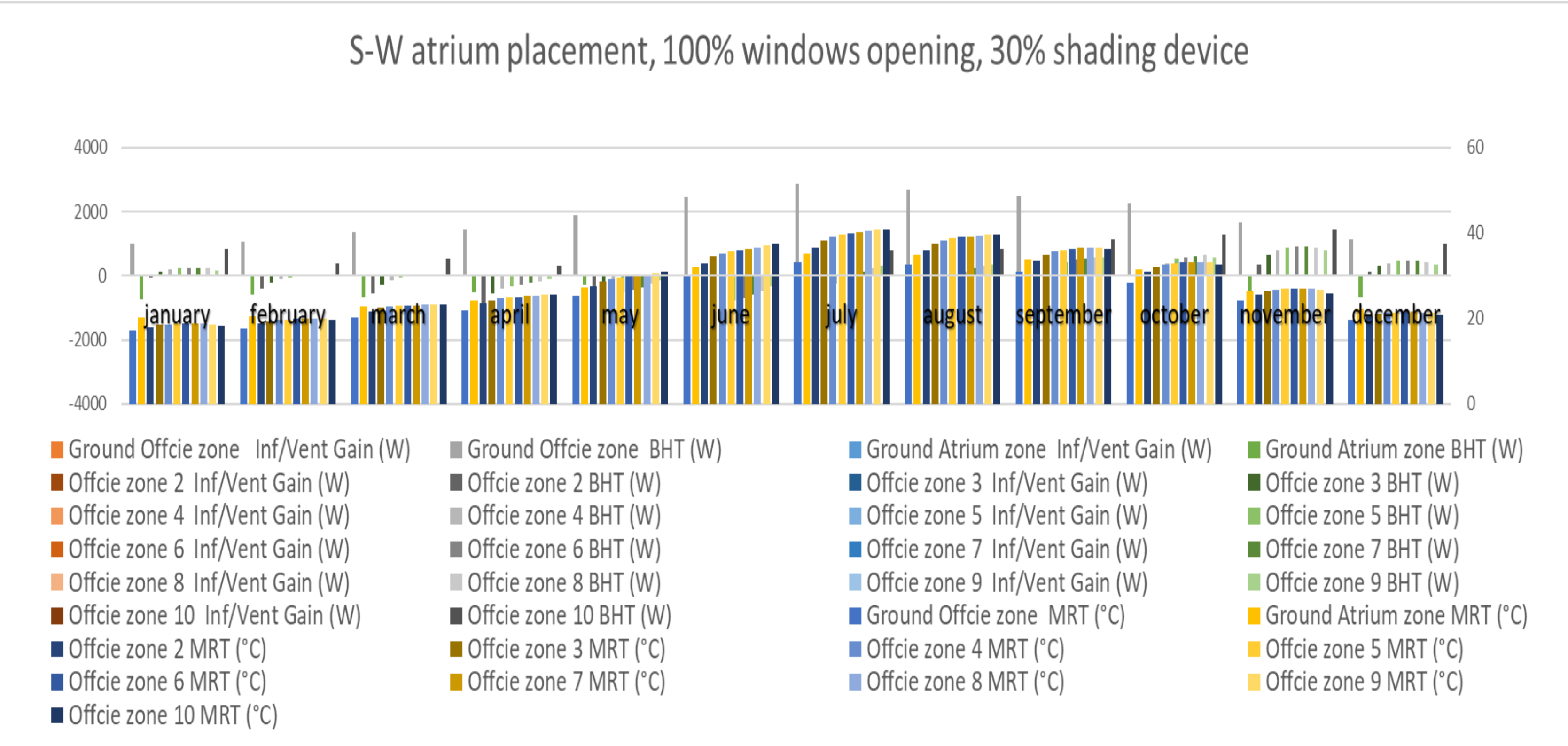

Figure 68: The High-Rise south- west atrium building with atrium proportion 1/2 of the office proportion and 0% opening ratio for all windows, 30% shading device over each atrium external facade.

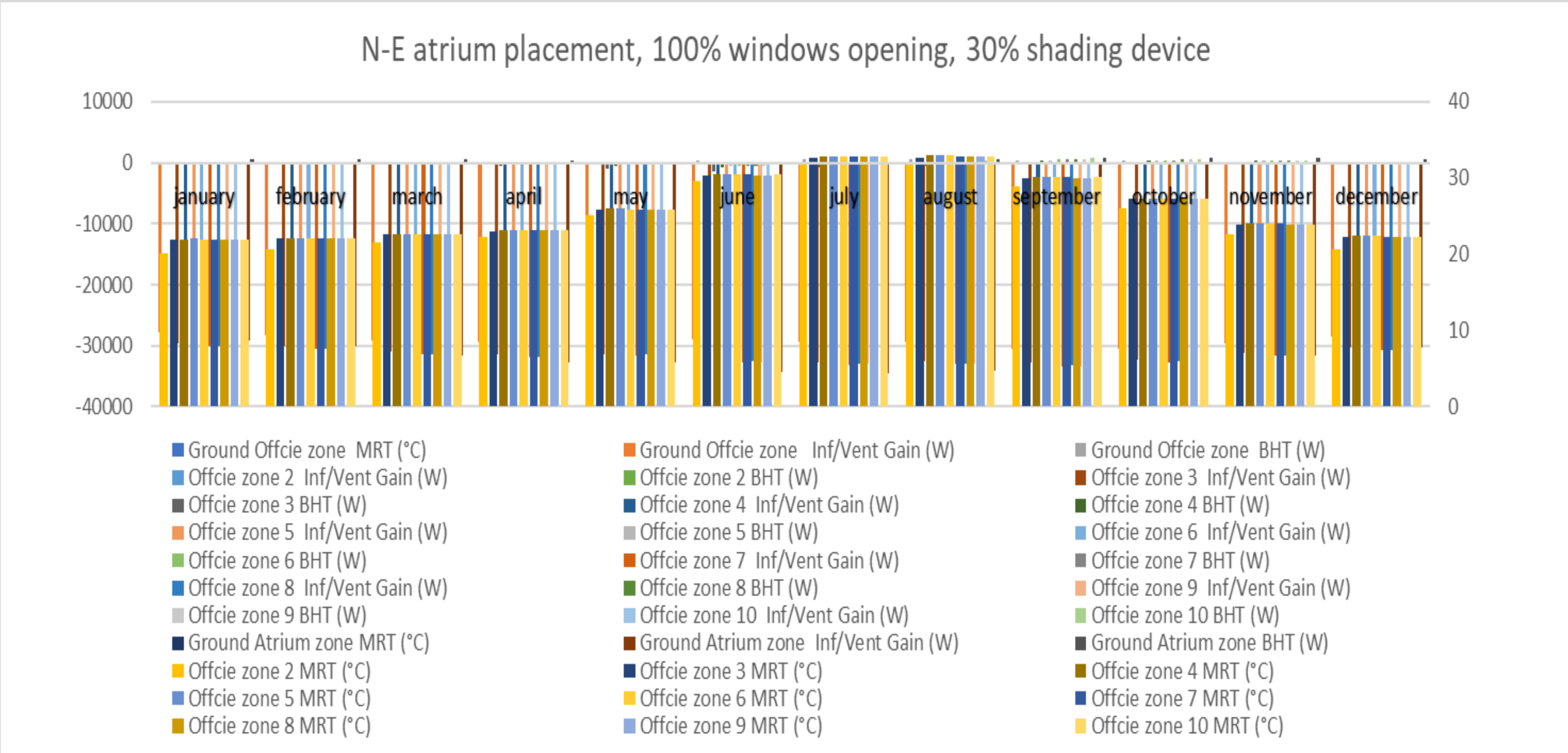

Figure 69: The High-Rise north- east atrium building as atrium proportion 1/4 of office proportion with 100% all windows opening and 30% shading device over each atrium external facade.

Appendix D: Energy Performance of the Active Single-Floor Atrium Building

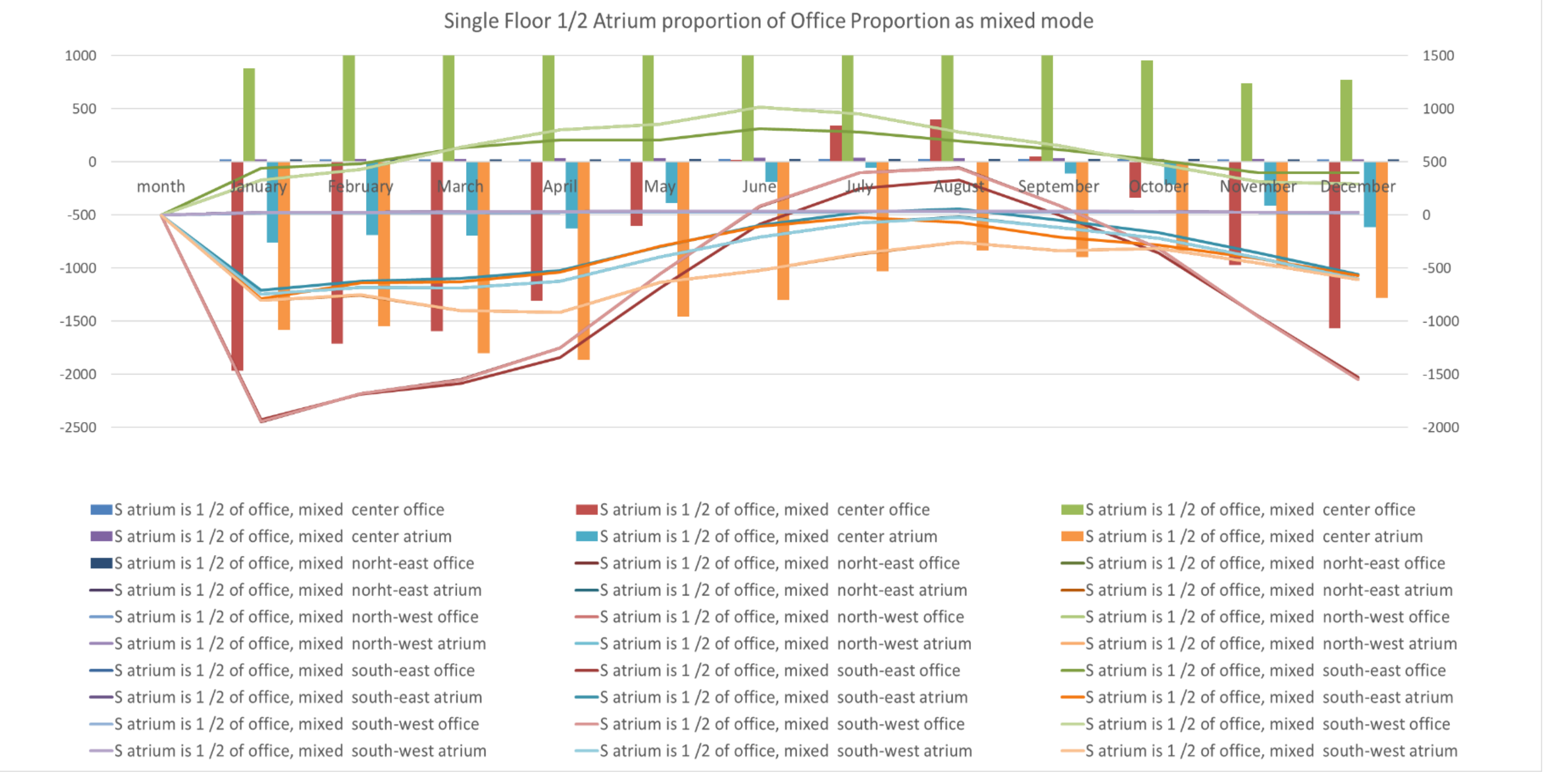

Figure 70: The active Single-Floor atrium building with atrium proportion 1/2 of the office proportion.

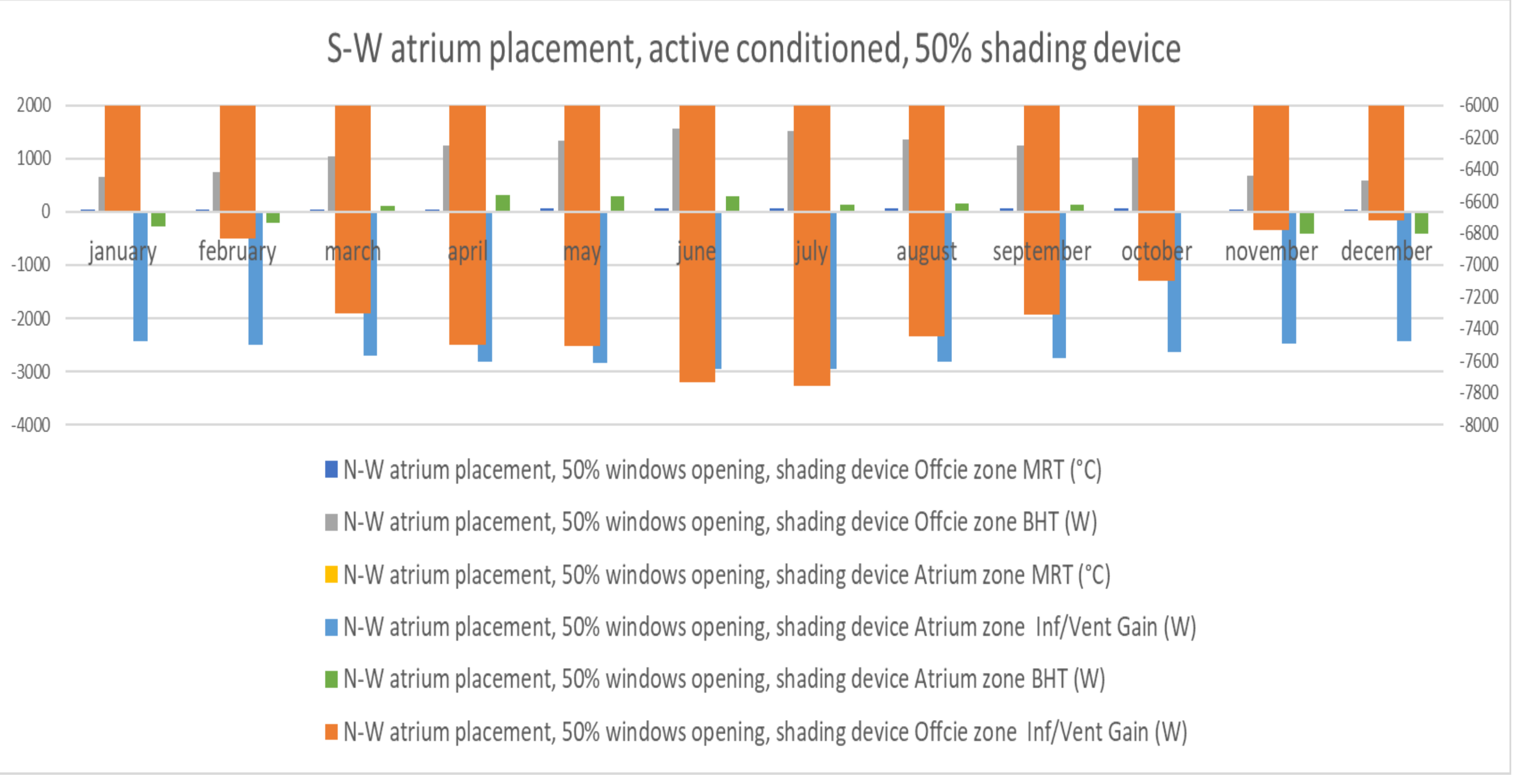

Figure 71: The active Single-Floor as S-W atrium building with atrium proportion 1/2 of the office proportion and 50% shading device for each atrium facade.

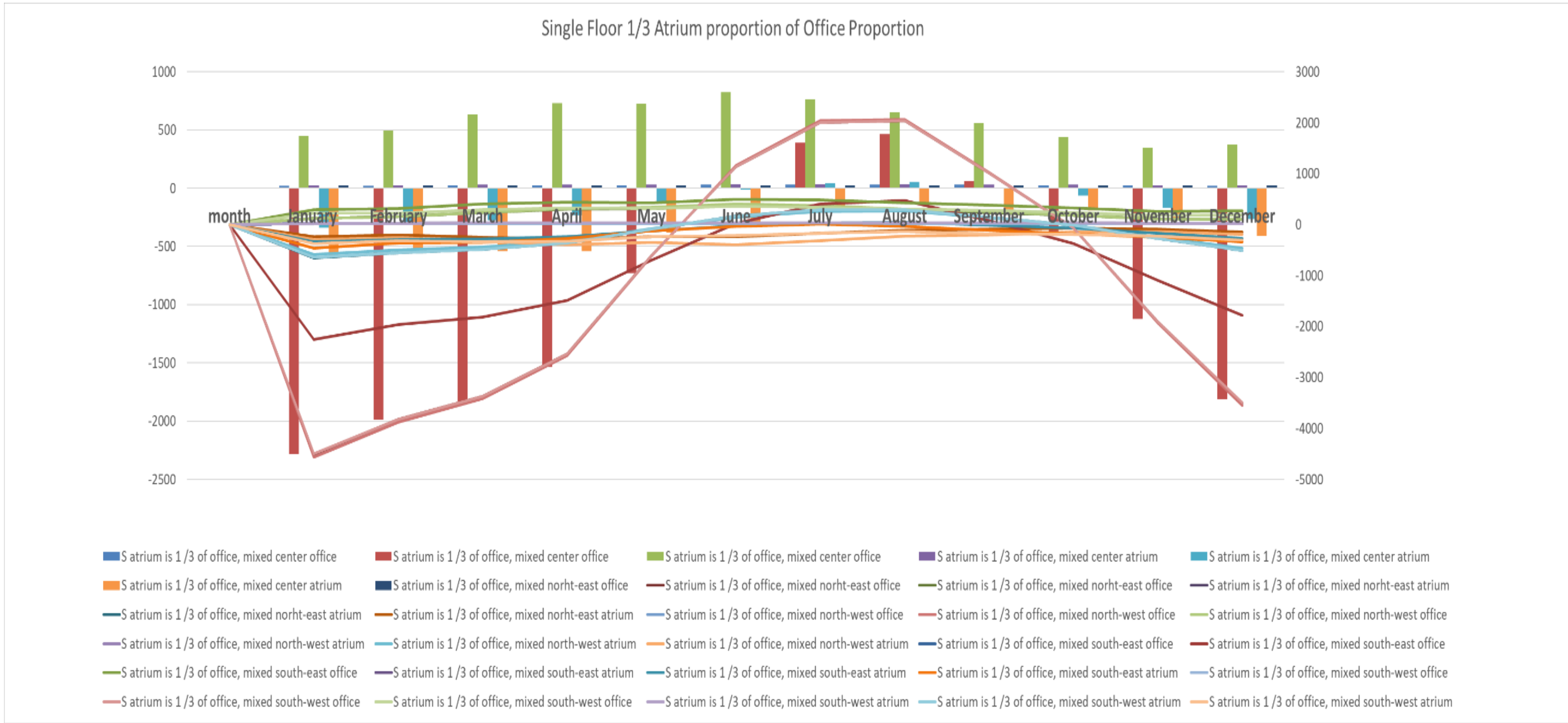

Figure 72: The active Single-Floor atrium building with atrium proportion 1/3 of the office proportion.

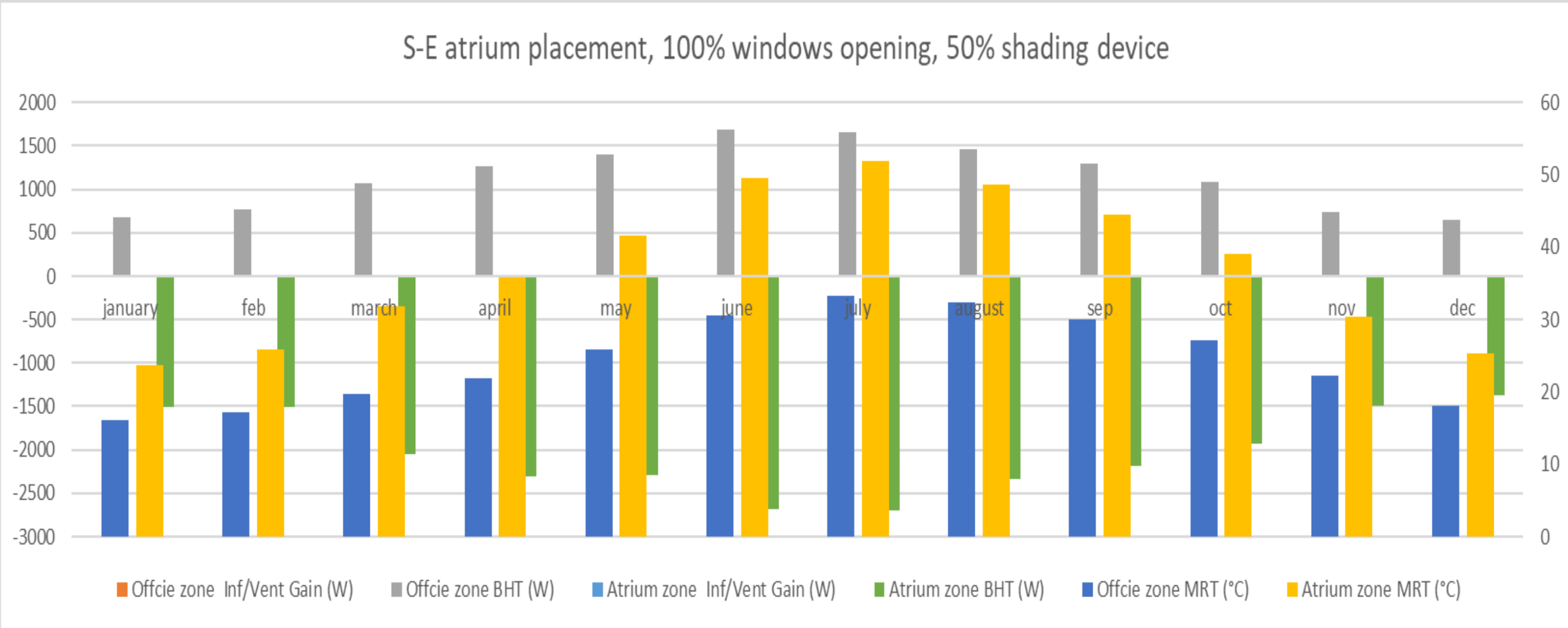

Figure 73: The active Single-Floor as S-E atrium building with atrium proportion 1/3 of the office proportion and 50% shading device for each atrium facade.

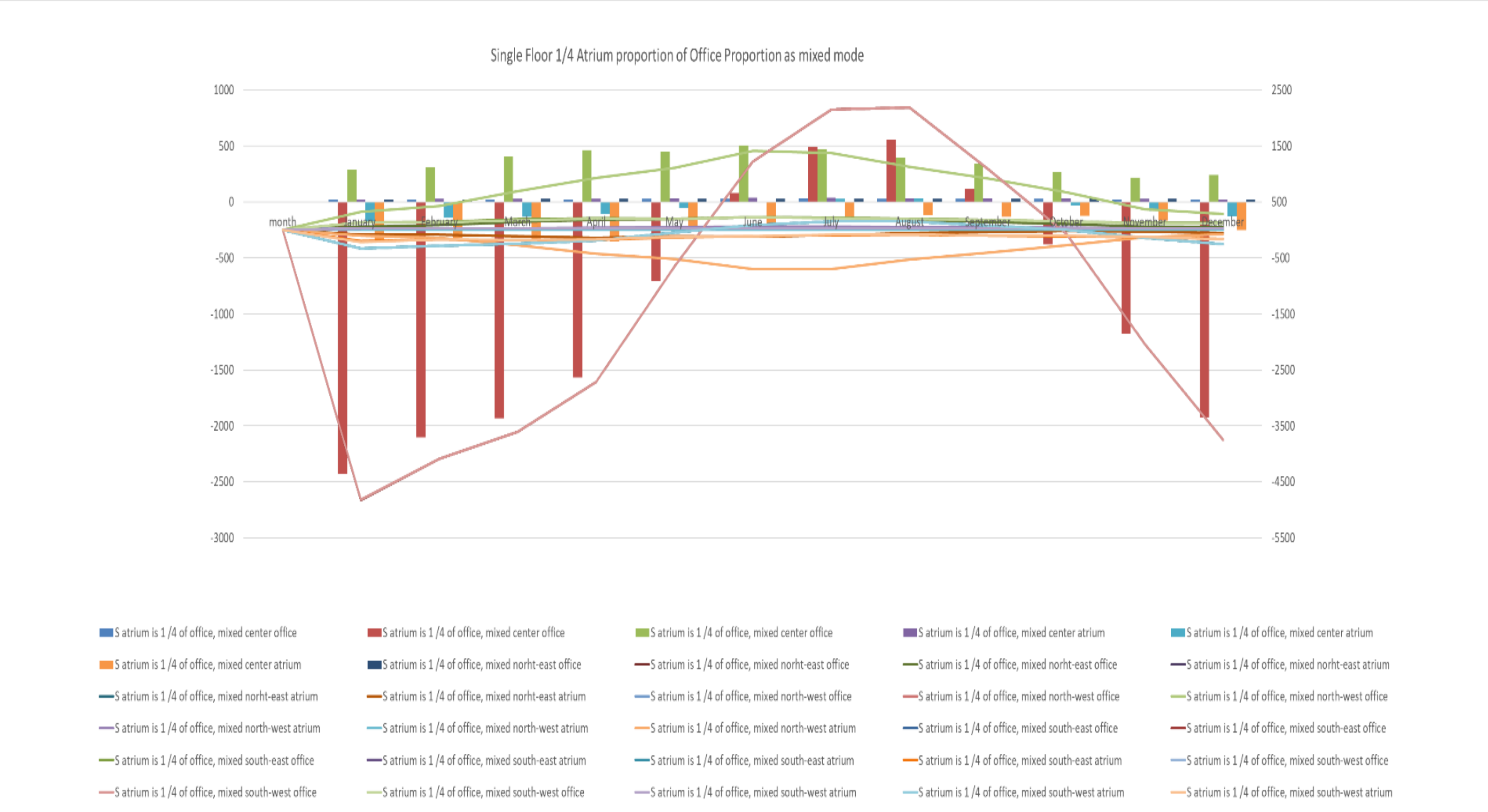

Figure 74: The active Single-Floor atrium building with atrium proportion 1/4 of the office proportion.

Appendix E: Energy Performance of the Active Medium-Rise Atrium Building

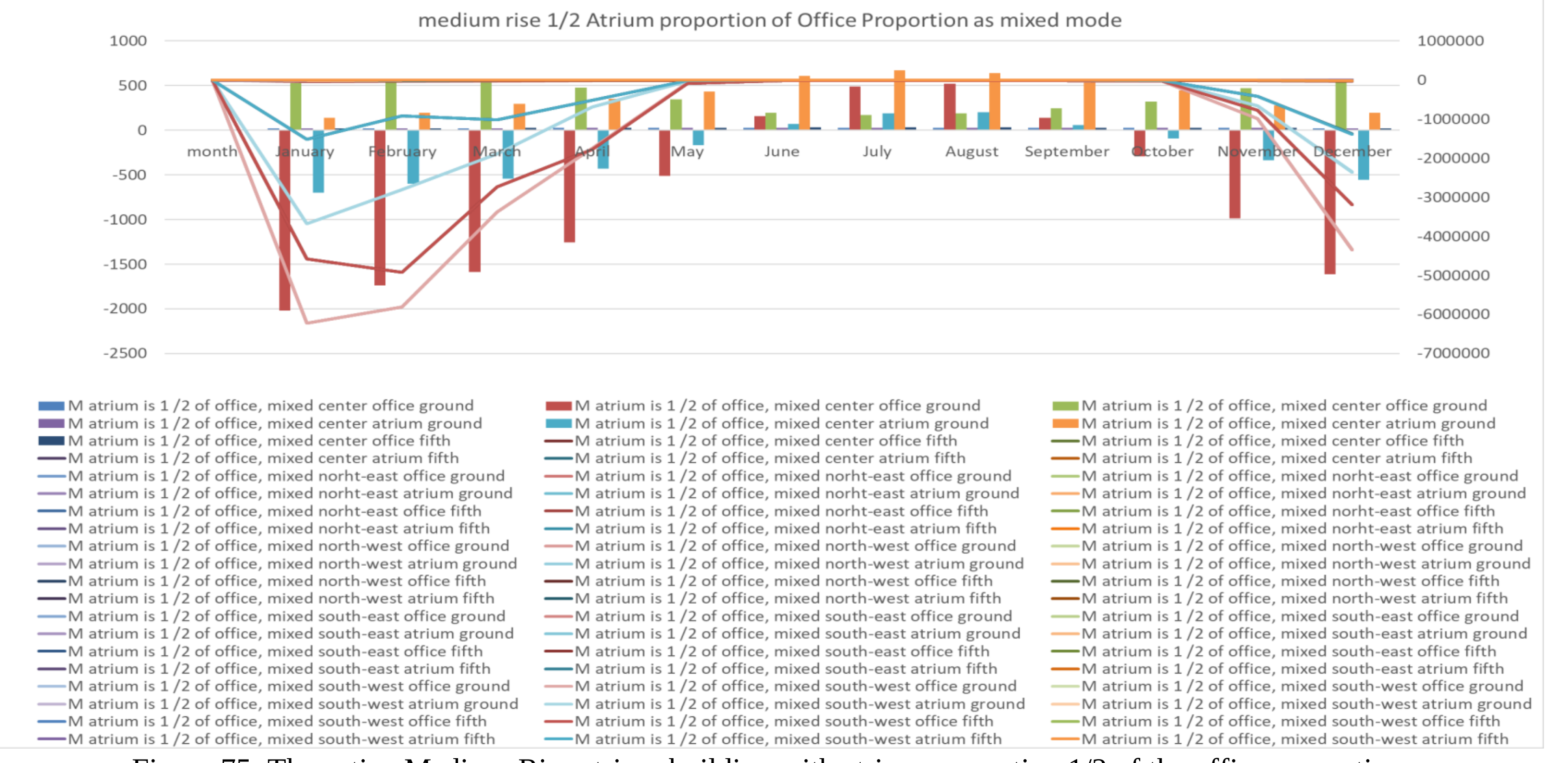

Figure 75: The active Medium-Rise atrium building with atrium proportion 1/2 of the office proportion.

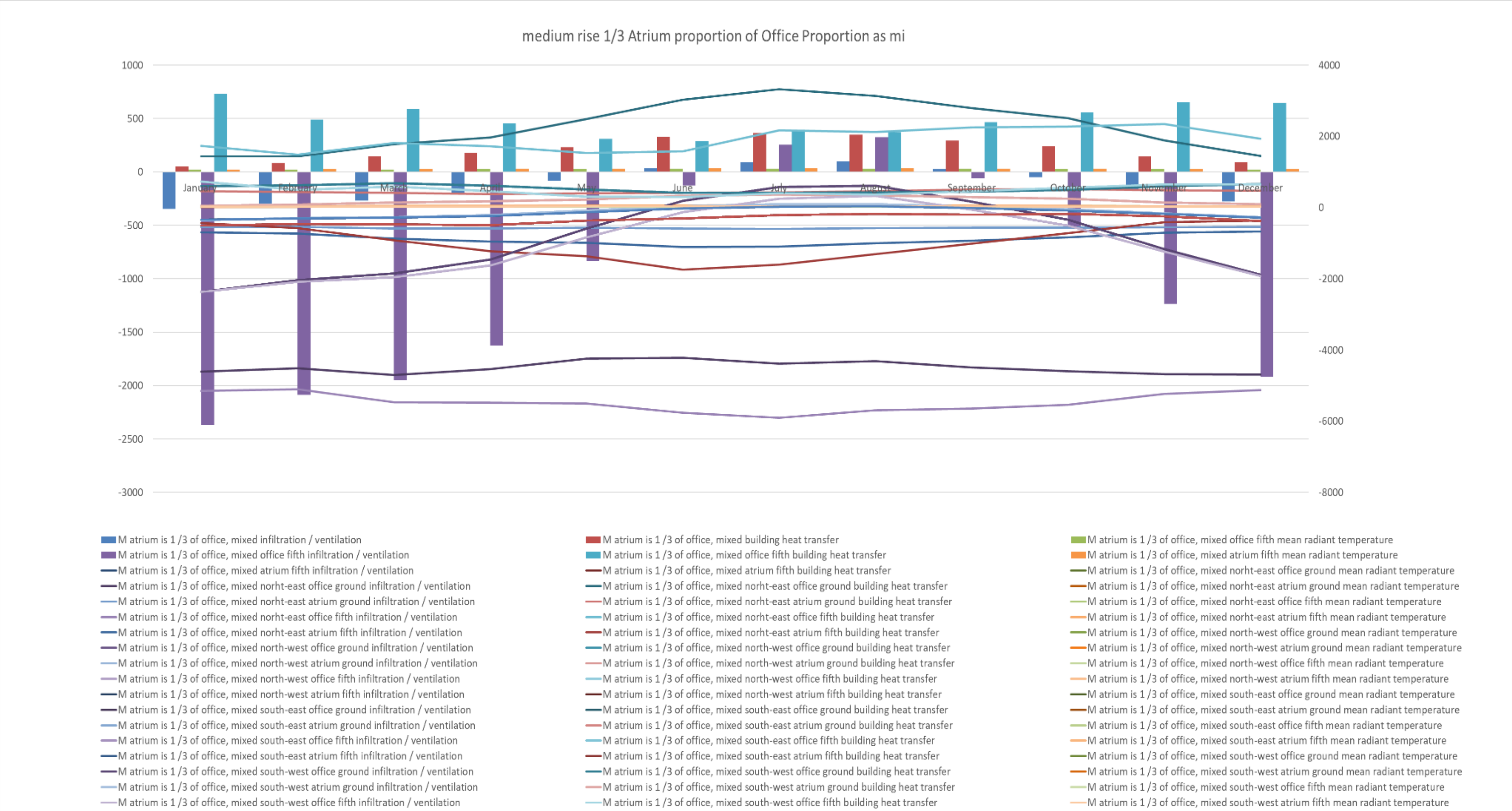

Figure 76: The active Single-Floor atrium building with atrium proportion 1/3 of the office proportion.

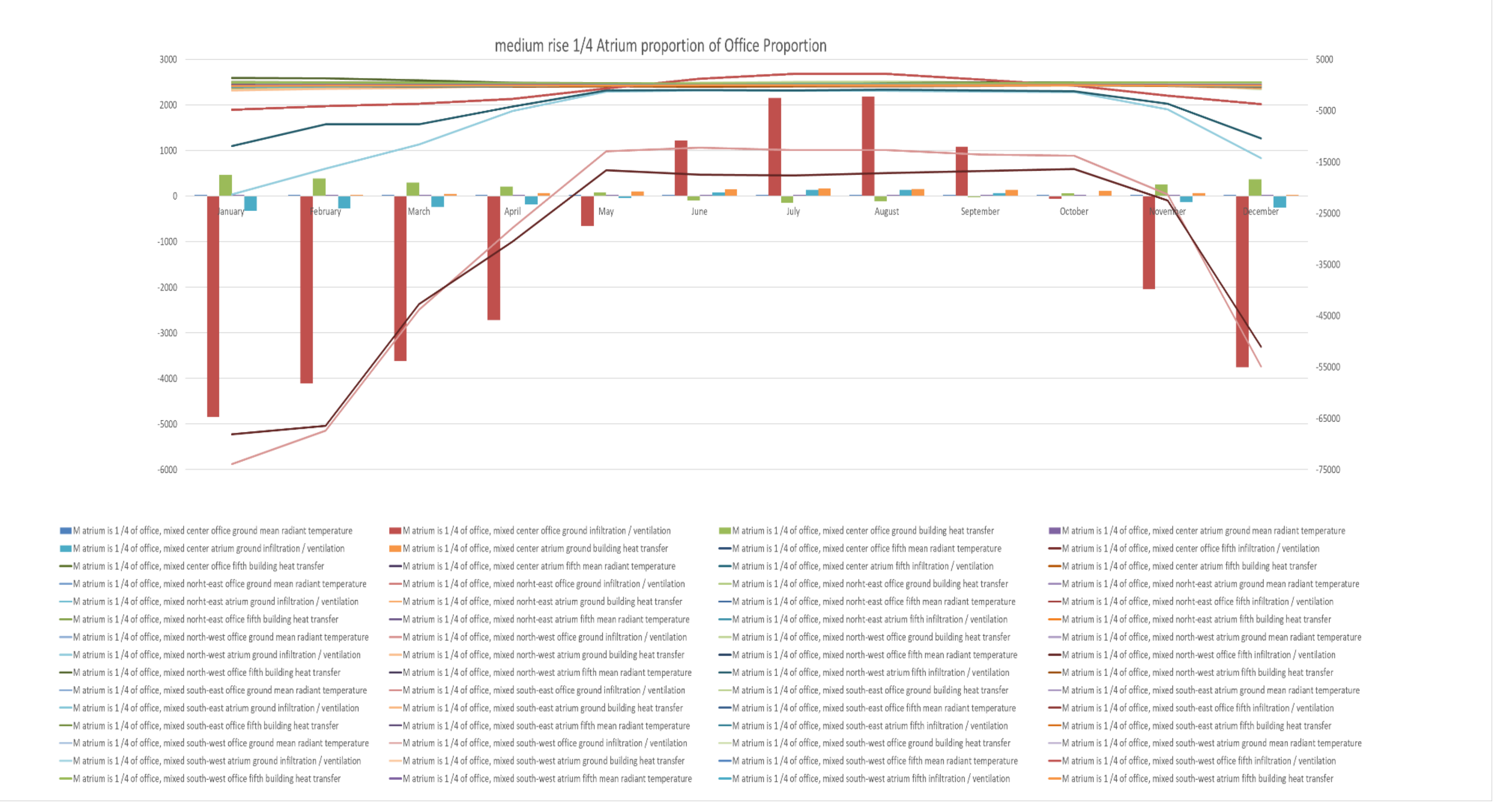

Figure 77: The active Single-Floor atrium building with atrium proportion 1/4 of the office proportion.

Appendix F: Energy Performance of the Active High-Rise Atrium Building

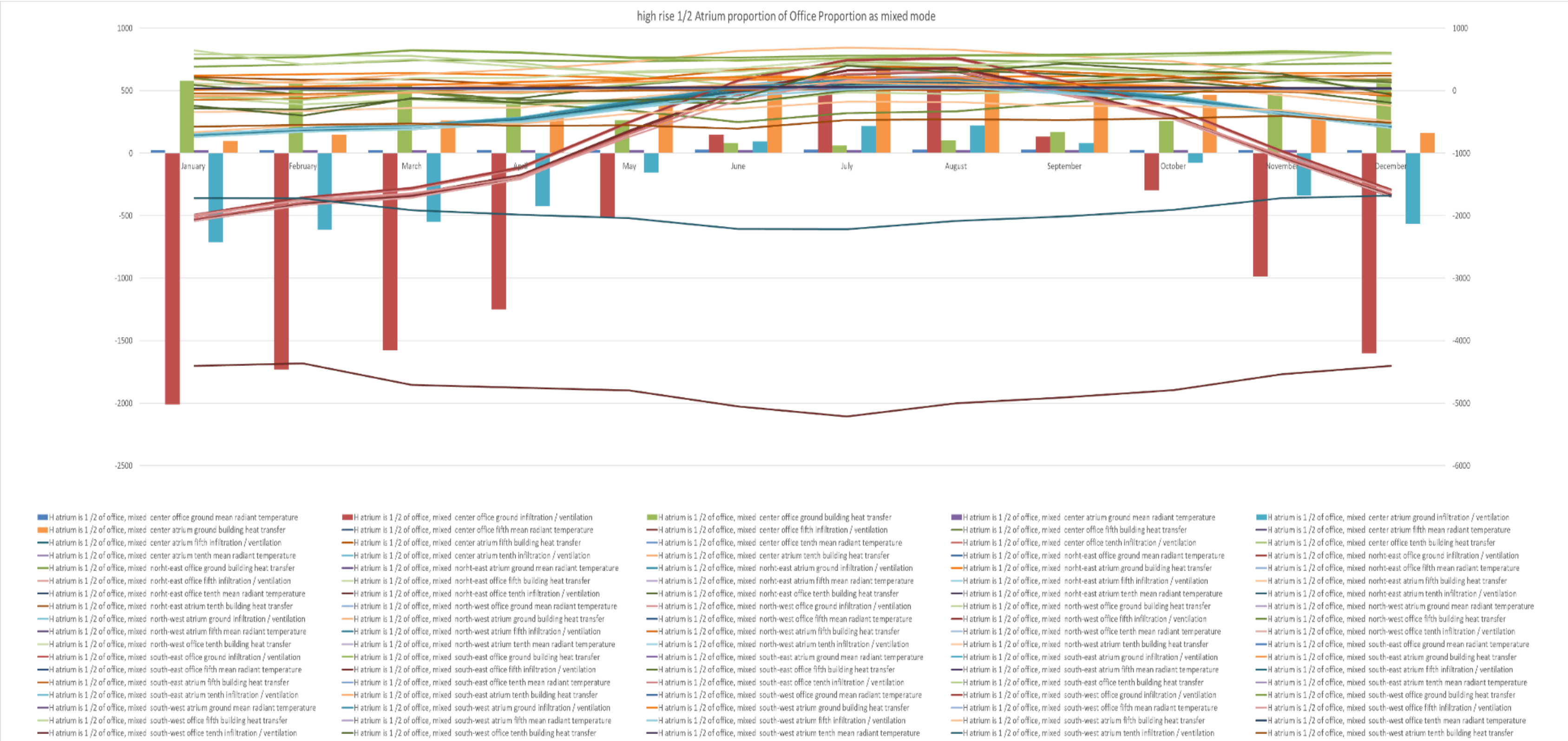

Figure 78: The active High-Rise atrium building with atrium proportion 1/2 of the office proportion.

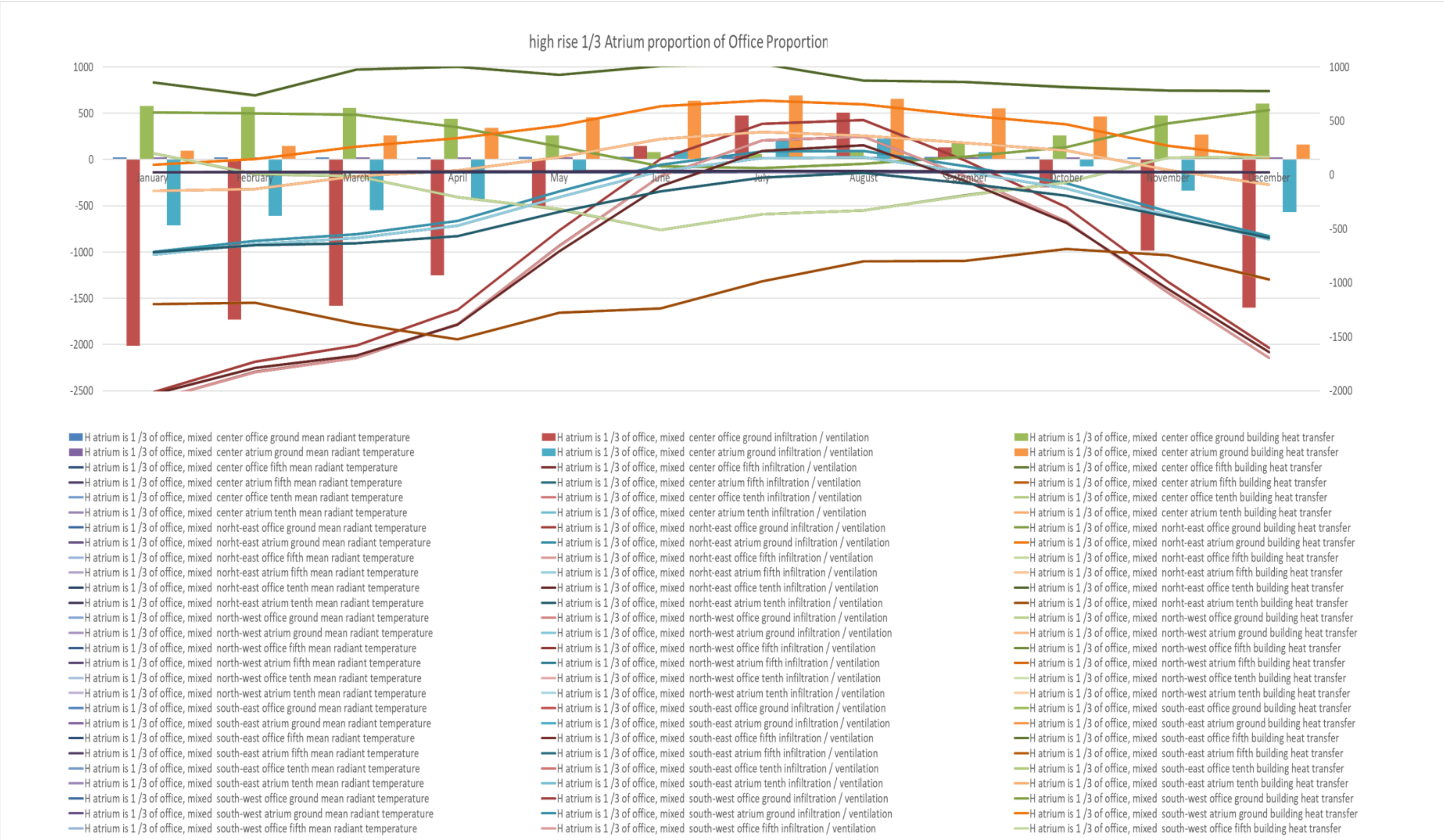

Figure 79: The active High-Rise atrium building with atrium proportion 1/3 of the office proportion.

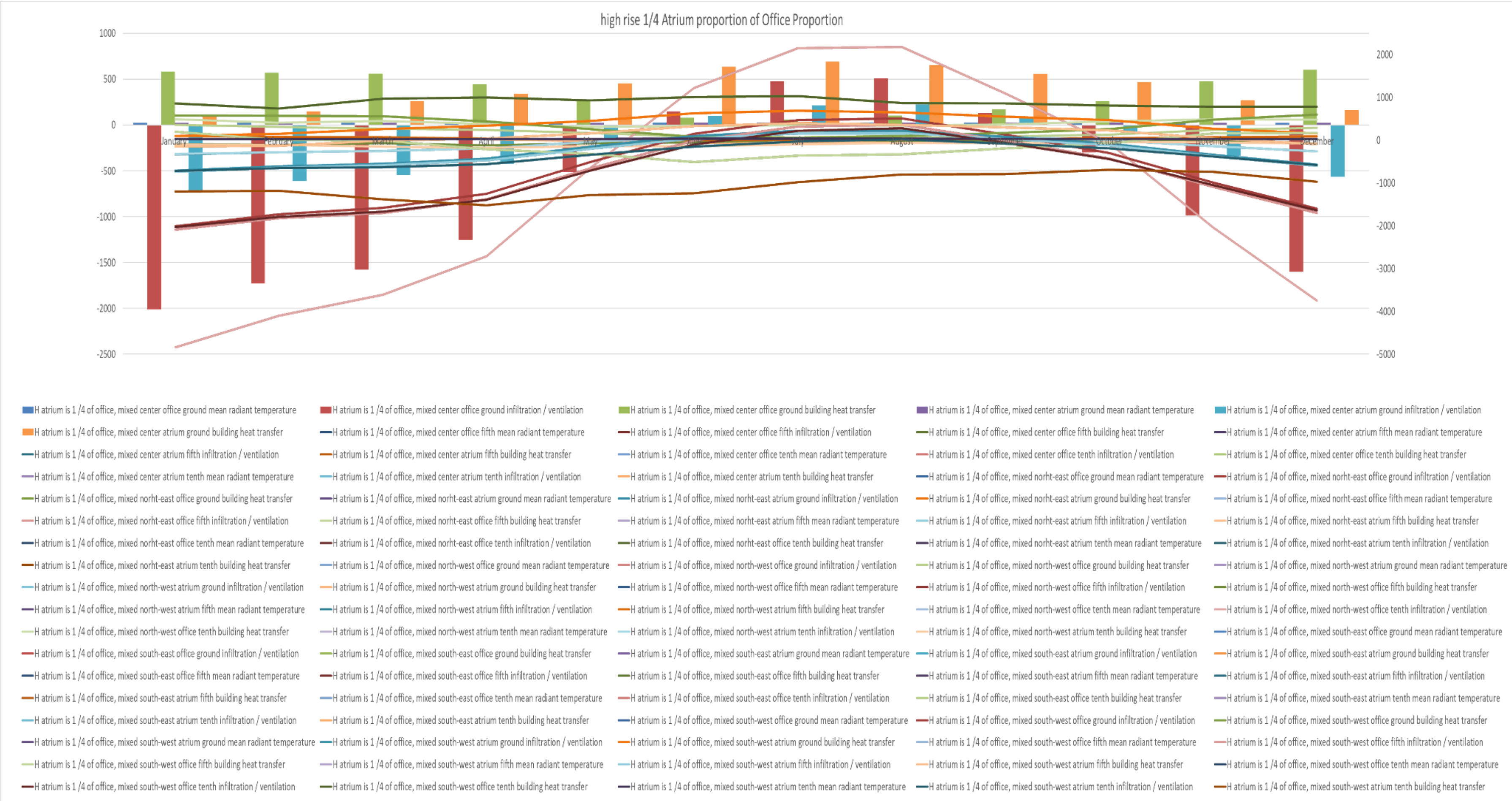

Figure 80: The active High-Rise atrium building with atrium proportion 1/4 of the office proportion.