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Potential for Passive Cooling of Buildings in Two Climatic Zones by Natural Night Time Ventilation

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ABSTRACT

In recent years, because of increased comfort expectations, cooling techniques are playing a crucial role in design process. At this point, night ventilation is one of the preferred passive-cooling concepts by architects and engineers. Considering that, natural ventilation approaches are becoming more of an issue due to the global warming, night ventilation is seen as an effective and energy-efficient passive-cooling strategy to improve the indoor thermal comfort in summer.

Many studies have shown that night ventilation is an effective method in order to reduce air conditioning loads and improve thermal comfort. This study presents the potential of natural night ventilation in two different climatic zones, in Istanbul and Vienna. In this context, a typical office building is modeled and the effects of different parameters such as air change rate of night ventilation, shading etc. are investigated for each city. It is resulted in comparison of cooling loads and indoor temperatures for various night ventilation scenarios and analysis of parameters that have an effect on night ventilation performance (in consideration of climatic conditions, which one has the largest/weakest effect) in Istanbul and Vienna.

Keywords: Night ventilation, thermal comfort, cooling demand, energy simulation.

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Abbreviations

ACH	Air changes per hour
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DV1	1 ACH Day ventilation
EP	EnergyPlus
NV0	None night ventilation
NV4	4 ACH Night ventilation
NV8	8 ACH Night ventilation
NV10	10ACH Night ventilation
ÖNORM	Österreichisches Normungsinstitut

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1. INTRODUCTION

1.1. Passive cooling concepts of buildings

During the warmer months of the year, the acceptable comfort conditions are provided by virtue of cooling systems in buildings. In recent years, the air-conditioning market is expanding continuously. Especially in southern countries in Europe, this expansion is higher due to the fact that higher outdoor mean temperatures in summer.

However, the rapid expansion of air conditioning in Europe causes critical increase in energy consumption. During 1990s, the cooling energy consumption in European countries was recorded around 1900 GWh. However, it is expected that this value will exceed 44.430 GWh in 2020 (Adnot, 1999).

Furthermore, it is seen that the use of air conditioning leads to substantial problems. Besides causing increase of energy consumption in buildings, it also causes an increase in the peak electricity load and some environmental problems related with ozone depletion and global warming. On the other hand, the electricity demand has been affected seriously by use of air conditioners. Air conditioning increases peak electricity demand and consequently, it is required to build additional power plants in order to satisfy increasing needs. Due to the fact that use of the new plants is limited, as a result the cost of peak electricity increases dramatically.

In this context, passive cooling design and technologies are promising approach thanks to lower energy use in buildings. Since, passive cooling is one of the most efficient and cheapest strategies to reduce energy demand in buildings.

Natural ventilation is achieved by using natural forces, e.g. wind and thermal buoyancy, as driving forces. This can be done by single-sided ventilation, cross ventilation or stack ventilation. Besides low energy spending, they have some other advantages by comparison with mechanical cooling systems, such as low maintenance requirements, low construction costs and low environmental impact. It can be claimed that using natural ventilation is not an exact solution to achieve efficient heat recovery due to the fact that fluctuations of airflow.

However, nowadays it is no longer a problem thanks to developing technology. It enables to control and predict of airflow in natural ventilation systems.

Furthermore, the combination of natural and mechanical ventilation which is called ‘hybrid’ or ‘mixed-mode’ ventilation systems, works by principle ‘utilization of advantages and elimination of disadvantages from both’. In other words, it aims to utilize the natural driving forces as effectively as possible, to minimize the energy usage for mechanical cooling and fans.

Building ventilation has two main goals; providing an acceptable indoor air quality and providing thermal comfort by supplying with a heat transport mechanism.[1][2][3] Within this context, the purposes of using natural daytime ventilation are; cooling of the building structure and cooling of the indoor air by way of changing or diluting it with outdoor air.

Additionally, the cooling of the building can be done indirectly by way of cooling down the structure of the building during night time. In other words, the building is ventilated during the night and this process is called ‘night ventilation’.

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[1] CIBSE Application Manual AM10.1997. *Natural ventilation in non-domestic buildings*. The Chartered Institution of Building Services Engineers, London.

[2] Allard, F. 1998 *Natural ventilation in buildings*. James & James, London.

[3] Awbi, H. B. 1991. *Ventilation of Buildings*. E&FN SPON, London.

1.2. What is night ventilation?

The basic concept of night-time ventilation is 'cooling the building structure overnight in order to provide a heat sink during the occupancy period'[4]. In other words, it is using of cold night air to cool down the building structure. Thus, it can absorb heat gains during the day. By virtue of this, the cooling load of air conditioning buildings can dramatically reduce and the thermal comfort levels of non air conditioning buildings can increase.

Even though solar and internal gains (due to occupants, lighting systems and appliances etc.) occur during the day, the most efficient period for cooling is during the night when the outdoor temperature is lowest. When night ventilation is applied to the building, its structural mass is cooled from inside by the way of convection. In other saying, it is transferring of internal energy into the structural mass which is used as a heat sink (Figure 1.2.1). As a result of this, it is clearly observed that in the next day's indoor temperature is lower and also peak indoor temperature is delayed. Previous studies have verified that night ventilation is effective in regions where day time temperatures are between 30ºC and 36 ºC, and night temperatures are below 20 ºC. [5]

Night time ventilation can be achieved either by natural means, i.e. by opened windows, or by mechanical means (with fans). In the case of natural ventilation, windows can be operated manually or by a building management system.

There are different parameters that have an effect on night ventilation performance such as building construction, heat gains, air change rates, climatic conditions on the number of overheating degree hours. The questions therefore, addressed in this work are:

- Under what conditions is night ventilation effective as a passive cooling concept?
- What are the potential impacts of night ventilation on comfort in the context of different climate zones?
- How does the night ventilation demand differ from in different climatic regions? On this basis, which type of night ventilation is applied in different regions?

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[4] Artmann, N. 2008. *Cooling of the building structure by night-time ventilation*. Ph.D. diss., Aalborg University.

[5] Givoni, B. 1994. *Passive and low energy cooling of buildings*. New York: Van Nostrand Reinhold.

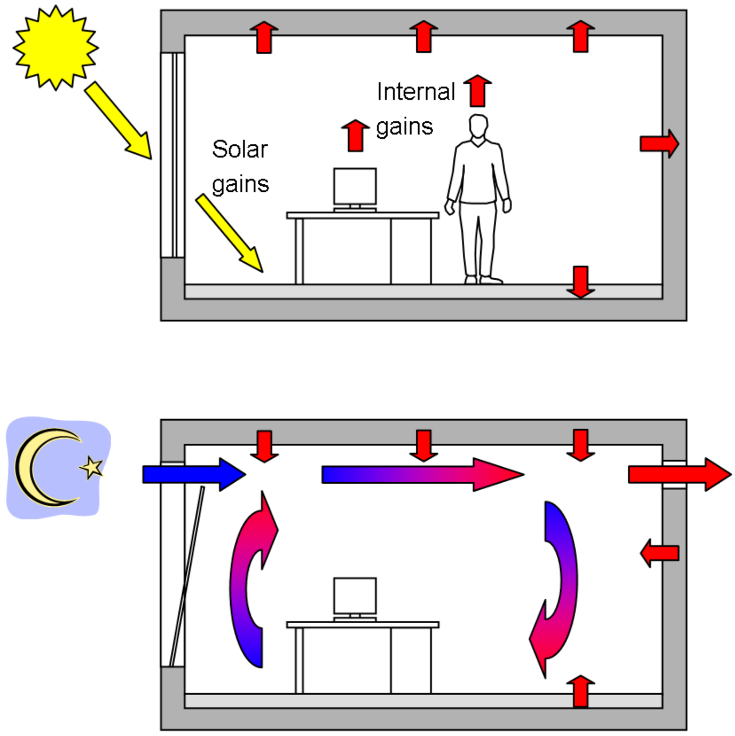

Figure 1.2.1: Basic concept of cooling by night ventilation

2. MOTIVATION AND BACKGROUND

2.1. Motivation

Why night ventilation?

During the design process of buildings, people and their requirements are main issues for architects and engineers. One of the significant requirements is indoor quality. It is aimed to achieve acceptable indoor quality by most people. Particularly, in Mediterranean and humid climate, it is seen as a necessary way to guarantee the healthy condition of air inside the building in summer.

Due to the fact that night ventilation improves the thermal comfort without increasing the electricity demand, it is becoming a promising passive cooling method that is preferred for office buildings.

Night ventilation is seen as an overheating prevention strategy that uses a little or no fossil energy. Moreover, when it is driven with other passive cooling strategies, for instance natural ventilation, shading etc., it helps to avoid or reduce the use of air-conditioning. This method saves energy and it requires lower maintenance than mechanical systems. Furthermore, it can be said that night ventilation has started to be accepted as one of the design options for green office buildings.

However, when the night ventilation is applied to the buildings by natural means, designers also should take into consideration of intrusion risks. Today, this is accomplished by integration of night ventilation techniques with building management system. Namely, windows can be controlled by either a timer or a thermostat-driven control system in accordance with weather conditions.

2.2. Background

2.2.1. Previous Studies

In 1998, Santamouris et al. reported a study that investigates the potential of night ventilation strategies when applied to full scale buildings which have different structure, design, ventilation and climatic characteristics. In this context, three different office buildings were selected in Athens, Greece. This study showed that the efficiency of night ventilation depends on three main factors; the relative difference between indoor and outdoor temperature during the night, the useful air flow rate applied during the night and the thermal capacity of the building. However, this study did not incorporate the comparison of results. Each building was evaluated in itself because they had different structure, different experiment conditions and periods, and different night ventilation mechanisms. Each building was reviewed within the scope of with/without night ventilation.

Another study (Aronis et al. 1999) focused on the applicability of night ventilation in air-conditioned office buildings in the UK and gave estimates of the potential energy savings and reductions in the required plant capacity. For this study, typical cellular office of 10 m width, 6 m depth and 3 m floor-to-ceiling height was chosen that is located in the south-east of England. According to ventilation strategy, during the day, the air-conditioning system was active and for the night, night ventilation was designed that was switched off at 7.00 am by a timer. In this context, 10 parameters had been investigated which were grouped as building parameters and cooling-system parameters. In order to examine the effect of each parameter on the performance of night ventilation, a reference case was created, by assigning a reference value to each of the parameters to be studied. At the end, two sets of results were obtained; one for the case of the reference air-conditioned building (without any night-cooling) and one for the case of a night-ventilated building. However, this study didn't show the effect of climatic regions on the night ventilation because it was examined in one office building in the UK.

Dascalaki and Santamouris reported another study in 2002 which was aimed to find out 'the energy conservation potential of selected retrofitting interventions on five office building types in four different climatic zones of Europe (South Mediterranean, Continental, Mid-Coastal, North Coastal Europe)'. As a conclusion, the study investigated the energy-saving potential of retrofitting scenarios proposed for ten office buildings in Europe. Each type was evaluated under four different climatic conditions. Within this context, night ventilation was found one of the useful techniques in order to improve the efficiency of the 'heating' scenario regarding both cooling/ lighting and in this process a determining factor was the climatic region of reference. On the other hand, this study had focused on energy consumption (for cooling/heating) of five building according to climatic regions. There was a lack of comparative study of the different night ventilation techniques and the impacts of climatic regions on night ventilation.

Furthermore, in 2009 Wang et al. investigated the potential of mechanical night ventilation cooling in air conditioned buildings and also analyzed various night ventilation control strategies. Based on this, typical six-storey office building that was located in the northeast of China was chosen. The simulations were carried out in a specific zone, located on the third floor of the building. To study the impact of ventilation duration and times, three modes were specified for night ventilation controlling. In each mode, night ventilation schedule was different. This schedule was also connected to external temperature ranges. In consequence of simulations, it was pointed out that night ventilation techniques could set back the active cooling operation and reduce cooling loads in air-conditioned offices. However, this study didn't offer any natural ventilation technique, and besides that the use of mechanical night ventilation caused increased energy consumption.

In 2004, Gratia et al. focused on natural ventilation strategies for cooling. They wanted to find out that if window openings can be enough for cooling the buildings; if so, which size, shape and location of the window openings should be preferred in order to reach sufficient day/ night ventilation rate. For this purpose, a middle-size, narrow plan office building was chosen in Belgium. The office modules were situated on two facades and they were separated by a corridor. Each floor of the office building included 30 office modules and as a result, this 5-storey-office building comprised 150 office modules. On account of providing natural day and night ventilation, each office had both two top and two below windows. Additionally, the internal wall which was between office space and corridor had an openable window in order to enable the air flow between two orientations, north and south. For the simulations, a sunny summer day (24th July) was chosen in Belgium. In the framework of evaluation of this study, different scenarios were taken into account. As a result, night ventilation by window apertures helped reducing the cooling loads in summer. Besides, results showed that night ventilation was more effective than day ventilation. A single-sided and cross day ventilation can reduce the cooling loads by around 30%. Instead, a single-sided and cross night ventilation reduced cooling needs by about 40%. On the other hand, the biggest contradiction about this study was run period. The results were recorded on 24th July and it is not reliable to generalize them for the entire summer period. In addition, due to the fact that the reference building was chosen from Belgium, this study didn't show the impact of climatic regions on natural ventilation strategies.

Another study (Shaviv et al. 2001) investigated the impact of thermal mass and night ventilation on the maximum indoor temperature in summer. In this context, a typical Israeli apartment building was chosen to calculate the maximum summer indoor temperature. To study the impact of various night ventilation and thermal mass, four levels of night ventilation (no night ventilation/ 5 ACH natural night ventilation/ 20 ACH forced night ventilation/ 30 ACH forced night ventilation) and thermal mass were defined. Four locations along the coastal plane were chosen in Israel for simulations. In order to make a prediction for the maximum temperature, the hottest month of this region, which is August, was chosen as a run period. The results showed that the indoor temperature can be reduced by 3-6ºC in heavy constructed Israeli apartments due to the thermal mass and night ventilation. It was found out that the rate of night ventilation had an important influence on indoor temperature decrement. However, in the framework of this study, other parameters which can affect indoor temperature were neglected.

Generally speaking, previous studies had only focused on energy-saving strategies and within this framework; night ventilation was also seen as one of the methods that improves energy performance. However, this research will address the comparison of night ventilation demand of similar office buildings in different climatic zones and it will be stated that how the night ventilation performance differs from in different climatic regions according to various parameters that have important roles on night ventilation demand.

2.2.2. Night Ventilation Implementations

The Elizabeth II Court project that is located in Winchester, UK, is one of the refurbishment projects in order to transform old 1960s office block into a modern and energy efficient one for usage by Hampshire County Council. Bennetts Associates Architects executed the project with cooperation with structural and services engineer teams and it was completed in 2009.

In order to create highly sustainable working environment, some design strategies were generated as part of project which also contained night ventilation strategy. Within this scope, the new building is cooled by automated opening windows during the summer months at nights. As a result of that ventilation period, during the day the cooled structure releases an additional 25 W/m² of cooling which soaks up heat from occupants, computers, etc.

Another case study is Wessex Water Operations Centre Building in Bath, UK. It was designed by Bennetts Associates Architects and completed in 2001. The main design purpose of the project is sustainability. Within this context, night ventilation is one of the favored implementation because of its energy-efficient feature.

In that project, night ventilation is achieved by high-level windows that are controlled by building management system. During the summer, the coffers are pre-cooled by controlled high-level windows. In that way, the structure enables to soak up heat during the day.

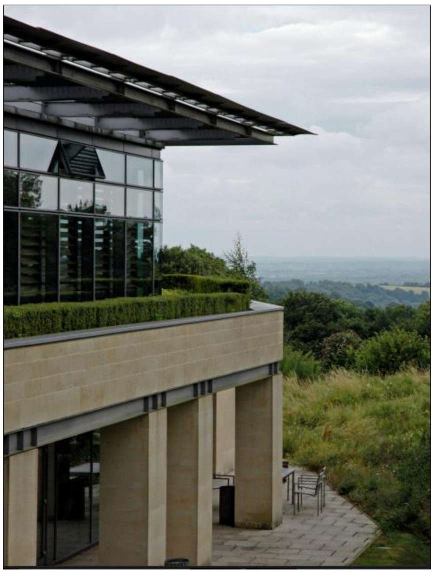

Figure 2.2.1&2.2.2: High-level windows for nigh-time ventilation in Wessex Water Operation Center Building in Bath, UK

One of the most innovative passive houses in Europe, the MIVA building (Christophorus Haus) was completed in 2003 in Stadl-Paura, Austria. The engineering consulting was executed by AEE Intec, Gleisdorf. The main design principle of this project was to reduce energy demand to 'passive house' standards. In accordance with this purpose, natural night ventilation was applied as a part of the cooling concept. In addition to mechanical ventilation system, the building is also cooled during night time by natural stack ventilation through automatically controlled vents. Consequently, by virtue of night ventilation, additional reduction in peak summer temperatures is achieved. Also, it assists in reducing the cooling demand.

3. METHODOLOGY

To analyze and compare the performance of night ventilation, first, a reference office building that is located in different climate regions will be modeled applying the main characteristics (e.g. construction materials for walls, floor, ceiling, windows). Climatic data from two cities, from Istanbul that has a borderline Mediterranean climate and humid subtropical climate, and from Vienna which is classified in moderate continental climate are initial benchmarks for assessment process. Second, the parameters that affect on the night ventilation are categorized in three groups:

1. Building parameters (Thermal capacity, thermal conductivity and specific heat of the materials)

The dimensions of the office building (total area, total wall area, glazing area) are examined. Additionally, the construction elements with overall heat transfer coefficients (for outside walls, windows, floors, roof) are analyzed.

2. System parameters (Air flow rate, process of ventilation)

Cooling period is determined with regard to occupancy period. Occupancy period for these offices is from Monday to Friday between 08:00-18:00 and on Saturday between 08:00-12:00.

3. Climatic parameters (Exterior temperature, mean outdoor temperature)

In this work, cooling season is assigned between May and September. Hence, the climatic data for Istanbul and Vienna are investigated for this period.

In this study, it is assumed that night ventilation continues all night.

These parameters will be applied to simulation model in Energy Plus. For each city, cooling loads and zone temperatures for various night ventilation rates will be evaluated separately. Finally, the results will be compared in charts.

3.1. Building Parameters

In the framework of comparison of night ventilation demand in different climatic regions, a mid-rise office building, located in Istanbul and Vienna, is generated.

- Degree of exposure: It is related to location of the building on the urban texture. Accordingly, the building can be free standing on the urban area, or it can be enclosed which is in between to the row of offices.
- Internal structure: According to consisting of large or small spaces, the building can have cellular, or open plan interior structure.
- Thermal mass: With regard to the kind of materials of structure, the thermal mass can be heavy, or light.

Moreover, atriums are accepted as a social area in the office buildings where tenants can gather for social activities. In addition to this function, they have a critical role in passive cooling strategies. When the atrium is designed as a part of energy saving strategy, it is clearly seen that the overall energy consumption of the building decreases. Since, it creates comfortable buffer zones between indoor and outdoor environment. By means of these buffer zones, the energy transfer from building surfaces to the outdoor environment decreases. Besides that, atriums take part in natural ventilation strategy. Atriums and adjacent occupied zones can be ventilated naturally by stack effect. Thus, there is no need to use air conditioning to cool the building.

In order to investigate the contribution of atriums on the natural ventilation strategy, the studied office building will be created with atrium area.

In the following section, the studied building will be described in detail on the basis of this classification.

3.1.1. Description of Studied Building

As a reference building, a typical five-story office building was created. It is based on a typical office building with 36 m width, 30 m depth and 15 m height. Each storey's floor-to-ceiling height is 3 m. Basically, the building consists of four spaces: Offices, atrium, zone 1 and zone 2 (that include service zones such as stairwell, WCs etc.). In the core, it has an atrium and offices are located around it, next to the façade. Atrium is also 15 m height, with roof window.

Offices have windows in three directions. Namely, north office space has north, east and west facing glazed areas; south office space has south, east and west facing glazed areas. As a representative of the air-conditioned office, glazing ratio is 0.6. In other words, the glazing is formed 60% of the façade. As a result, in 1980 m^2 total wall area, 1180 m^2 window opening area is existed (Table 3.1.1).

The windows are modeled as double-glazed with 13 mm air fill.

The building is free standing on the urban texture. Due to its structure and materials of construction, it has a heavy thermal mass. (Table 3.1.3)

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	1980	540	450	540	450
Above Ground Wall Area [m2]	1980	540	450	540	450
Window Opening Area [m2]	1180.9	316.9	270	324	270
Gross Window-Wall Ratio [%]	59.64	58.69	60	60	60
Above Ground Window-Wall Ratio [%]	59.64	58.69	60	60	60

Table 3.1.1: Window-wall ratio of reference office building

Total Closed Area of the Building	5400 m^2
Total Office Area	3600 m^2
Total Office Area in Each Floor	720 m^2
Total Atrium Area	800 m^2
Height of the Each Floor	3 m
Height of the Atrium	15 m
Total Volume of the Building	16200 m^3
Glazed Area/Façade Area Ratio	60%

Table 3.1.2: Main parameters of reference office building

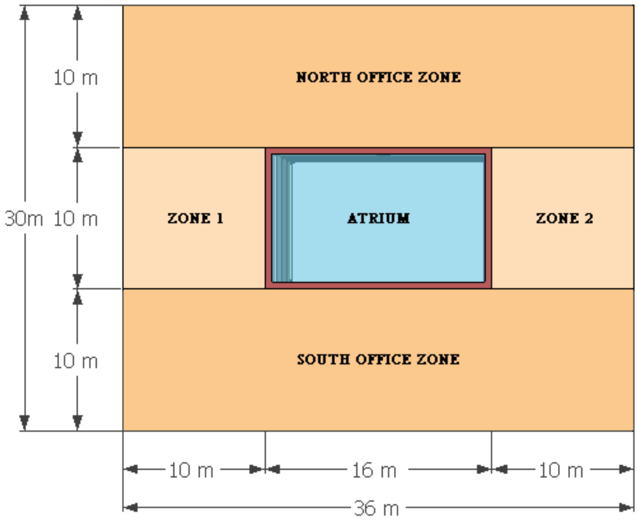

Figure 3.1.1: Floor plan and zones of reference office building

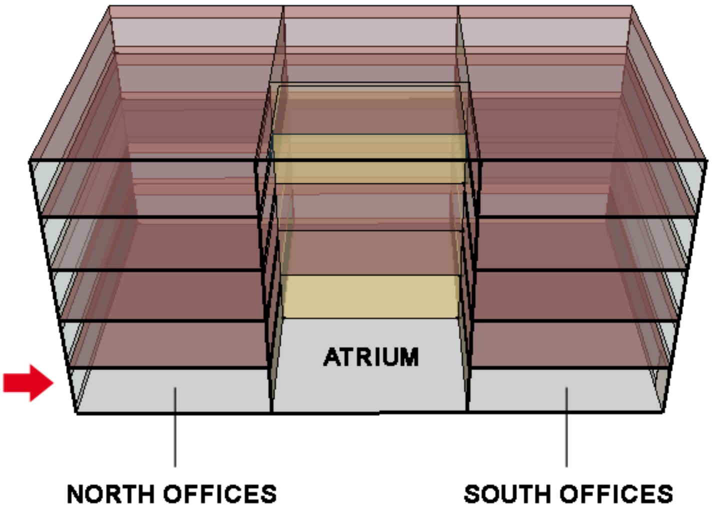

Figure 3.1.2: Cross section of reference office building

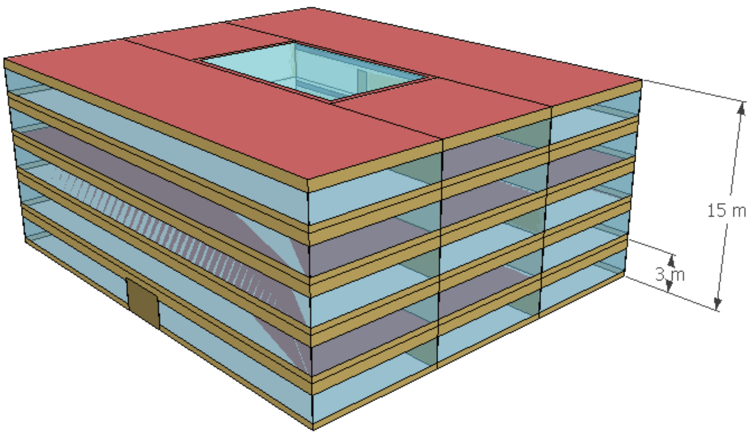

Figure 3.1.3: 3d sketch up model of reference office building

	d (m)	λ (W/mK)	ρ (kg/m³)	c (J/ kg K)
Floor Slab				
Timber/tiles	0.03	1.1	2100	837
Insulation	0.025	0.03	43	1210
Concrete	0.20	1.95	2240	1110
Interior Ceiling				
Acoustic tile	0.03	1.1	2100	837
Insulation	0.025	0.03	43	1210
Concrete	0.20	1.95	2240	1110
Exterior Roof (for 4th floor)				
Roof membrane	0.0095	0.16	1121	1460
Roof insulation	0.2105	0.049	265	836.8
Metal decking	0.0015	45.006	7680	418.4
External Wall				
Plaster ext.	0.0095	0.58	800	830
Concrete	0.20	1.95	2240	1110
Insulation	0.10	0.03	70	840
Concrete	0.20	1.95	2240	1110
1/2IN Gypsum	0.01	0.16	785	830
Internal Wall				
Gypsum board	0.019	0.7	1400	1090
Concrete	0.2	1.1	2000	1110
Gypsum board	0.019	0.7	1400	1090
Exterior Windows				
Double-glazed with a 13 mm Air fill	0.019			
Interior Windows				
Single glazed	0.003			

Table 3.1.3: Thermal properties of building materials for reference office building

3. 2. System Parameters

3.2.1. Indoor Thermal Comfort Conditions

Some researches point out that indoor thermal comfort has a crucial role on people's performance of work in offices. Inadequate indoor environment affects negatively productivity of employees.

In ASHRAE Standard, the comfort zone is defined 'in terms of a range of operative temperatures that provide acceptable thermal environmental conditions or in terms of the combinations of air temperature and mean radiant temperature that people find thermally acceptable'.[6]

ASHRAE Standards also provides optimum temperature levels for comfortable thermal indoor conditions. According to this, the upper limit of comfortable temperature in living environment should be 26ºC.

As a matter of fact, some experiments about thermal appreciate environment found out that comfort zone highly depends on where you have been in the world. As it is described above, the comfort zone is directly related to outdoor temperature. Due to that variation, in the framework of this study, it should be considered both countries national standards which include also indoor thermal comfort requirements.

In Austria, Standard ÖNORM EN 15251:2007 specifies recommended values of indoor temperature for various building types. According to Standard ÖNORM, the operative temperature ranges for offices is between 25.5-27ºC.

Type of building	Category	Max Operative Temperature for Cooling (ºC)
OFFICE	I - high level of expectation	25.5
	II - normal level of expectation	26
	III - acceptable, moderate level of expectation	27

Table 3.2.1: Recommended values of indoor temperatures in ÖNORM EN 15251:2007

[6] ASHRAE 2004,4

In Turkey, there is no specific Turkish standard to define any temperature ranges for indoor thermal comfort.

Hence, in the framework of this study, operative temperature for indoor thermal comfort in offices will be accepted 26ºC and this value will be taken as a benchmark for the evaluation of indoor temperature analyzes.

3.2.2. Simulation Assumptions

Taking account of indoor thermal comfort conditions as explained above, some assumptions are made for cooling system and ventilation settings before simulation studies.

- During the day:
  The cooling system is active with the set point temperature 26ºC. It is from Monday to Friday between 08:00-18:00 and on Saturday between 08:00-12:00 (provided by thermostat controlled HVAC template).
  The ventilation rate is assumed constant 1 ACH during the occupied hours.

- During the night:
  In base model, it is assumed that the building is not ventilated during the night. Moreover, different scenarios are considered regarding night ventilation which will be discussed in following chapters. According to these scenarios, it is presumed that night ventilation is at a constant 4 ACH/ 8ACH or 10 ACH during the unoccupied hours. The unoccupied period for night ventilation is presumed from 21:00 pm to 07:00 am for weekdays and Sunday.

- Atrium:
  The ventilation rate for atrium is defined constant level during the day and night, with 2 ACH.

- During the simulations, the infiltration rate is constant which is assigned 0.5 ACH.

- Use of Occupants:

  The offices are occupied 6 days in a week; 10 hours per day from Monday to Friday (between 08:00-18:00) and 4 hours on Saturday (between 08:00-12:00).

It is assigned that number of people per zone floor area is 0.1 with an activity level of 117 W/person.

- Lightings and Other Factors:

  In these offices, lighting power is 10 Watts per zone floor area. Additionally, main office equipments such as computers, named as ‘electric equipments’ and it is assumed that their output as a heat gain is 6 W per zone floor area.

3.3. Climatic Parameters

In the framework of this study, the period between May and September is defined as a cooling period. Hence, summer conditions are examined for both cities.

Summer Conditions in Istanbul

Istanbul has a borderline Mediterranean climate (Csa) and humid subtropical climate (Cfa) according to the Köppen climate classification system. High humidity is one of the most remarkable characteristics in Istanbul climate that reaches 80 percent most days. In summer days, this humidity tends to disperse by midday, yet the lingering humidity leads to exacerbating high summer temperatures. During these summer period, the high temperatures average is around 29 ºC. Moreover, precipitation is so uncommon in summer months, as follows between June and August, only fifteen days receive measurable amount of rainfall.

Summer Conditions in Vienna

According to the Köppen climate classification, Vienna lies within a transition of oceanic and humid continental climates which is classified in a Cfb (oceanic) climate. Summers are warm in the city with average high temperature between 22 and 26ºC. Rarely, the high temperature may exceed 30 ºC and the maximum low temperature may be around 15 ºC. It is known that precipitation is moderate in Vienna throughout the year. Nevertheless, it is clearly seen from the Figure 3.3.1, precipitation reaches the highest amount in summer month, particularly in June.

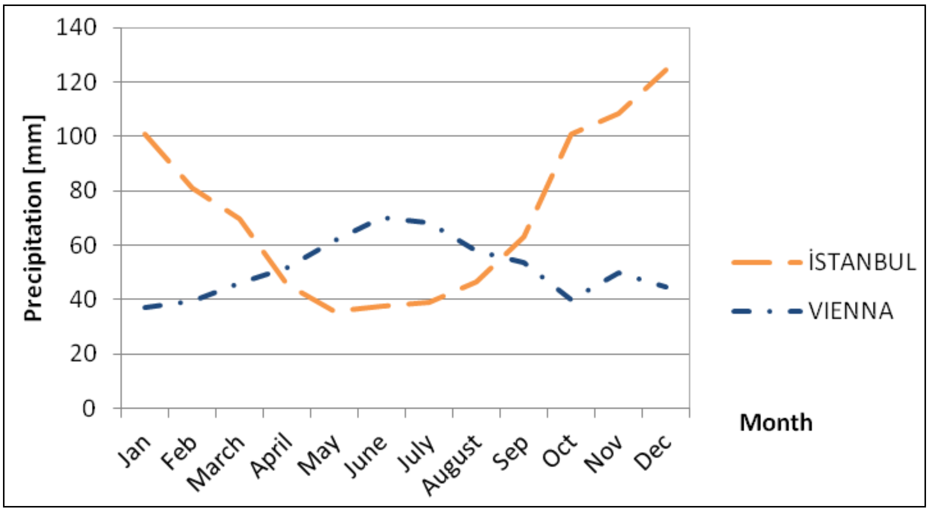

Figure 3.3.1: Annual precipitation amount for Istanbul and Vienna (mm)

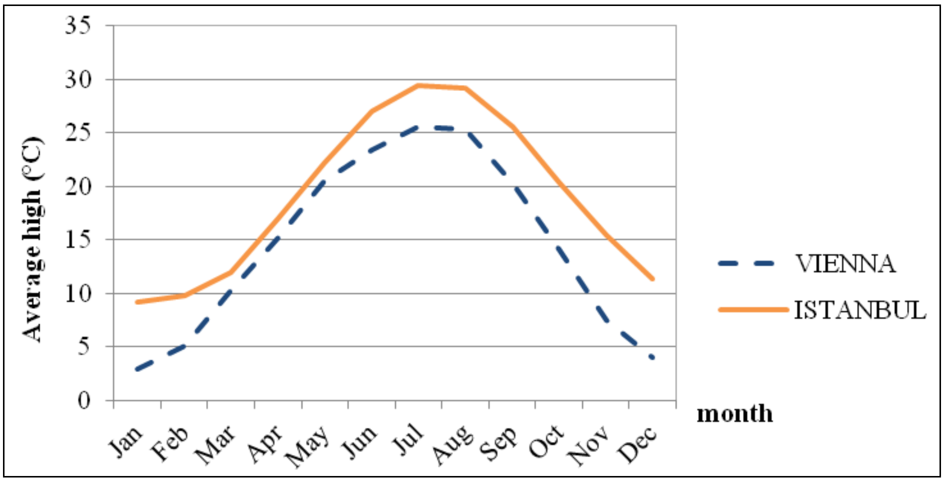

Figure 3.3.2: Annual average high temperature of Istanbul and Vienna

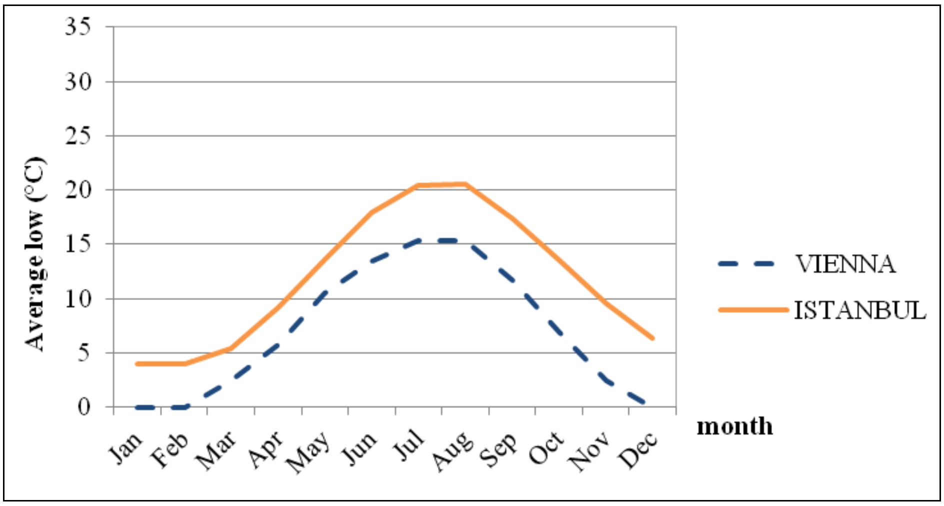

Figure 3.3.3: Annual average low temperature of Istanbul and Vienna

In order to analyse night-time ventilation demands in Istanbul and Vienna, hourly climatic data are provided. The monthly average high and low input data are used for the period of between May-September that is assigned as a cooling period.

The climatic data for Istanbul were recorded by Turkish State Meteorological Service [1]. Furthermore, Vienna's climatic data were provided by Central Institute for Meteorology and Geodynamics [2]. These weather data consist of 12 actual months' average high and low temperature.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high (°C)	9.2	9.8	12	17.1	22.2	27	29.4	29.2	25.6	20.4	15.5	11.4	19.1
Average low (°C)	4	4	5.4	9.2	13.6	18	20.4	20.5	17.4	13.6	9.5	6.3	11.8
Precipitation (mm)	100.9	80.9	69.6	45.4	35.5	37.5	39	46.3	62.9	100.7	108.6	124.7	852
Avg. precipitation days (≥ 0.1 mm)	16.1	14.1	11.9	10.8	7.3	5.2	3.5	3.9	5.4	9.7	11.1	15.9	114.9
Mean monthly sunshine hours	71.3	87.6	133.3	180	251.1	300	322.4	294.5	243	164.3	102	68.2	2,217.70

Table 3.3.1: Annual climatic data for Istanbul

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high (°C)	2.9	5.1	10.3	15.2	20.5	23.4	25.6	25.4	20.3	14.2	7.5	4	14.5
Average low (°C)	−2.0	−0.9	2.4	5.8	10.5	13.5	15.4	15.3	11.7	7	2.4	−0.5	6.7
Precipitation (mm)	37.2	39.4	46.1	51.7	61.8	70.2	68.2	57.8	53.5	40	50	44.4	620.3
Avg. precipitation days (≥ 1.0 mm)	7.3	7.6	8.3	7.5	8.5	9.1	9	8	7	6	8.3	8.2	94.8
Mean monthly sunshine hours	60.9	90.1	131.5	173.8	228	222.8	241.8	239.2	167.6	131.2	65.5	52	1,804.40

Table 3.3.2: Annual climatic data for Vienna

3.4. Description of Simulation Procedure

In this study, the studied building was modeled in SketchUp. In order to simulate the 3D model, EnergyPlus was used.

3.4.1. EnergyPlus

EnergyPlus is a detailed building energy simulation engine with input and output of text files. It is supported by Department of Energy, USA. It is used for modeling the building heating, cooling, ventilating, lighting etc. systems.

In order to make a building energy simulation in EnergyPlus, firstly the building geometry is defined. In this study, NREL SketchUp Plugin (Open Studio) was used for this purpose. Thereafter, the building systems data, such as heating, cooling, ventilating systems data, are provided. As a result, EP gives the simulation results as text files. These outputs help to evaluate the performance of building systems and accordingly, evaluate the energy performance of building.

3.4.2. Simulation Steps in SketchUp & EnergyPlus

- 3D model of the reference office building was drawn with Open Studio plugin for SketchUp.

- Secondly, thermal zones were assigned. Thermal zoning is one of the main steps of building energy simulation studies. It is done by means of grouping the spaces that have similar thermal properties, the same orientation etc.
  As explained before, in this study, each floor consists of four spaces, offices, atrium and two zones for service spaces. In the context of thermal zoning, offices are grouped into two zones that are north and south. So, at the end, each storey has 4 zones, for example; at the ground floor: north_ground, south_ground, zone1_ground, zone2_ground. As a result that is seen in Table 3.4.1, in total, that 3D building model has 21 zones (20+atrium zone).

- The 3D model was imported to EP for simulation studies.

- As a beginning in EP, the run period of simulation was defined. The begin day of run period was specified as 1st of May and the end day was 30th of September.

- In EP, firstly the building materials were defined for construction elements according to Table 3.1.3. Then, the construction elements were created.

- Following that, the construction elements were assigned to related surfaces and sub-surfaces. For example, the construction of 'Exterior Roof' was assigned to 4th floor ceiling surface. Furthermore, the construction of 'Interior Ceiling' was assigned to other floors ceiling surfaces.

	Zones	Ceiling Height [m]	Volume [m³]
Ground Floor	North_ground	3	1080
	South_ground	3	1080
	Zone1_ground	3	300
	Zone2_ground	3	300
First Floor	North_1st	3	1080
	South_1st	3	1080
	Zone1_1st	3	300
	Zone2_1st	3	300
Second Floor	North_2nd	3	1080
	South_2nd	3	1080
	Zone1_2nd	3	300
	Zone2_2nd	3	300
Third Floor	North_3rd	3	1080
	South_3rd	3	1080
	Zone1_3rd	3	300
	Zone2_3rd	3	300
Fourth Floor	North_4th	3	1080
	South_4th	3	1080
	Zone1_4th	3	300
	Zone2_4th	3	300
Atrium	Atrium_zone	15	2400

Table 3.4.1: Thermal zones of reference office building model

- The 3D model was created with two main office zones, north and south ones. In fact, each office zone consists of five cellular office spaces. Even the partitions between these spaces were neglected in 3D model; they were added as 'Internal Mass' in EP. As a result, four partition walls were defined for each office zone. Consequently, per floor, 240 m^2 partition was applied as an 'internal mass'.

- Required schedules, such as office occupancy hours, cooling system operation time, were defined.

  Office occupancy and cooling system schedules were defined under ‘Schedule: Compact’. Within the context of this study, occupancy period was defined between 08:00 -18:00 from Monday to Friday. Additionally, on Saturdays it was specified from 08:00 to 12:00. Moreover, it was presumed that the cooling system is active during the occupied hours. In other words; the cooling system works on weekdays from 08:00 to 18:00, on Saturdays from 08:00 to 12:00.

- The assumed infiltration and day/night ventilation rates were set.

- The ideal cooling system with a constant set point (26º C) was added to calculate the cooling load.

- In the sequel, the heat gains (e.g. people, lights, electric equipments) were added to the simulation model. Following values were set as internal gains for occupants, lights and electric equipments in the zone:

  Under ‘People’ class, number of office occupancy was defined as 0.1 people per zone floor area.

  Under ‘Lights’ class, lighting level of offices was specified as 10 Watts per zone floor area.

  Lastly, it was defined as 6 Watts per zone floor area for electric equipments such as computers etc.

- Since, according to daylight illuminance level, electric lighting can be controlled and reduced, daylight controlling was applied to the simulation model under ‘Daylighting: Controls’ class.

  For that purpose, the illuminance set point was defined as 500 lux. Moreover, lighting control type was set as ‘continuous/off’. It means that the electric lights switch off completely when the daylight illuminance reaches to set point which was specified 500 lux in this study.

- Within the scope of ventilation scenario with shading (see Page 24), the impact of shading system on building performance will be investigated. Hence, basic shading system was applied to simulation model.

  In this work, it is supposed that external blinds are used as a shading device. The properties of these devices were defined in EP under 'WindowMaterial:Blind' class (shown in Table 3.4.2). Following this, under the class of 'WindowProperty: ShadingControl', shading control type was set as 'on if high solar on window' which allows shading if solar radiation on windows exceeds defined set point. Accordingly, set point was defined for solar radiance incident. In this case, set point was 150 W/m². Thus, if the solar radiance on the windows exceeds 150 W/m^2, the shading devices are on.

Shading Type:	**External Blind**	
Properties	Units	
Slat Width	m	0.025
Slat Separation	m	0.01875
Slat Angle	deg	45
Slat Conductivity	W/m-K	221
Slat Solar Reflectance		0.8
Slat Infrared Hemispherical Emissivity		0.9
Blind to Glass Distance	m	0.05

Table 3.4.2: Properties of shading devices

- Because the results have been evaluated in two formats, one is a comparison of cooling loads and the second one is a comparison of hourly indoor temperatures, output variables were varied. In order to get results for cooling load comparison, the simulation was run with the 'Zone Ideal Loads Zone Sensible Cooling Energy' output variable selection. However, for the hourly temperature results, 'Zone Mean Air Temperature' output variable was chosen and the building cooling system was deactivated to analyse the performance of the building in 'passive' mode.

3.5. Comparison Scenarios

Principally, the effectiveness of night time ventilation depends on some parameters, such as ventilation air change rate, outdoor air temperature, shading devices on windows. To compare the impacts of these parameters, some scenarios are created for simulation studies.

Basically, two main scenarios were created (Table 3.5.1). In the first scenario, it is assumed that there are no shading devices on windows. However, in the second scenario, it is presumed that the windows are with external blinds and they are on if the solar radiation is higher than 150 W/m^2 on windows.

SHADING SCENARIOS	
1	In all cases, it is assumed that the windows are without any shading.
2	In all cases, it is assumed that external blinds are on if the solar radiation is higher than 150 W/m^2 on windows.

Table 3.5.1: Shading scenarios for temperature and cooling load evaluations

For both scenarios, the results were evaluated according to two variants: Zone mean air temperature (ºC) and zone cooling energy per floor area (kWh/m^2). Besides on the point of operating the whole simulation process, four basic cases were created that are named; base case, case 1, case 2 and case 3.

Firstly, it is aimed to investigate variation of indoor temperature. In order to see the impact of night ventilation on the temperature of occupied period, the building simulations are done when the building model is in passive mode. In other words, for the reliable results, it is supposed that there is no cooling system in that model. Firstly, base model was created without night ventilation. It has 0,5 constant infiltration air change rate. Additionally, during the occupancy period 1 ACH constant day ventilation is presumed (Table 3.5.2).

In the sequel, Case 1 was created with the same assumptions. With the difference of base case, it is assumed that during the unoccupied period, the ventilation rate due to the night cooling is 4 ACH.

Case 2 and Case 3 have the same conditions with Case 1. However, the night ventilation rate is assigned 8 ACH in Case 2 and 10 ACH in Case 3.

VENTILATION SCENARIOS					
CASES	COOLING SYSTEM	INFILTRATION RATE	DAY VENTILATION RATE	ATRIUM VENTILATION RATE	NIGHT VENTILATION
BASE CASE	OFF	0.5 ACH	1 ACH	2 ACH	Without NV
CASE 1	OFF	0.5 ACH	1 ACH	2 ACH	4 ACH
CASE 2	OFF	0.5 ACH	1 ACH	2 ACH	8 ACH
CASE 3	OFF	0.5 ACH	1 ACH	2 ACH	10 ACH

Table 3.5.2: Ventilation scenarios for temperature evaluations with all variations

VENTILATION & COOLING SCENARIOS					
CASES	COOLING SYSTEM	INFILTRATION RATE	DAY VENTILATION RATE	ATRIUM VENTILATION RATE	NIGHT VENTILATION
BASE CASE	ON - Constant set point 26°C	0.5 ACH	1 ACH	2 ACH	Without NV
CASE 1	ON - Constant set point 26°C	0.5 ACH	1 ACH	2 ACH	4 ACH
CASE 2	ON - Constant set point 26°C	0.5 ACH	1 ACH	2 ACH	8 ACH
CASE 3	ON - Constant set point 26°C	0.5 ACH	1 ACH	2 ACH	10 ACH

Table 3.5.3: Cooling scenarios for cooling load evaluations with all variation

Furthermore, in order to investigate range of cooling loads, simulations are carried out with a cooling system during the day which has a constant set point temperature 26°C (Table 3.5.3). In three cases for that scenario, air changes during the night are 4 ACH, 8 ACH and 10 ACH. Also in all cases, the constant infiltration rate is identified as 0.5 ACH and day ventilation rate is accepted 1 ACH.

In both scenarios, the air change rate for atrium is presumed constant, 2 ACH.

The simulations were run for each scenario separately for evaluating both variation of indoor temperature and range of cooling loads.

4. RESULTS

4.1. Main Simulation Purposes

For the simulations, the 2nd floor was taken as a typical one. Due to the fact that, the 2nd floor is in the middle of the building, there are no other factors in that level (such as solar radiation from the roof window on the 4th floor, or ground floor temperature factor on the ground floor) which can turn the scales.

In order to see the night ventilation potential in different climatic zones, the simulations were performed in both cities, in Istanbul and Vienna, separately.

The simulations were aimed to find out;

1. How does night ventilation effect on thermal comfort during the occupied hours?

2. Which air change rate of night ventilation is more efficient in order to decrease the indoor temperature during the occupied hours?

3. How does night ventilation effect on cooling load in summer? In which city does night ventilation have more critical effect in order to reduce cooling load?

4. Which air change rate of night ventilation is more efficient in order to reduce cooling load in summer?

5. How does shading control effect on thermal comfort and lighting demand during the occupied hours?

In the following section, the results will be performed into two benchmarks; indoor mean hourly dry-bulb temperatures (°C) and, monthly cooling loads per floor area (kWh/m^2).

4.2. Indoor Mean Hourly Dry-Bulb Temperature Results

In the framework of that metric, the indoor thermal performance was analyzed by calculating 'the percentage of hours with indoor temperature below 26°C during the occupied period'.

4.2.1. Ventilation Scenarios without Shading

After simulation process, first monthly results are shown in Figure 4.2.1 and 4.2.2 for Istanbul and in Figure 4.2.3 for Vienna. As the results show, in Istanbul, in May the percentage of hours with indoor temperature below 26°C was higher than other months due to the lower mean outdoor temperature. However, that percentage was decreasing in June and even almost zero in July and August.

On the other hand, in Vienna, as it is seen, generally the percentages were higher than Istanbul because of the fact that lower mean outdoor temperature in Vienna (as it is seen in Figure 3.3.2 & 3.3.3).

In both cities, the monthly results show the same general tendencies. May and September had the lowest mean outdoor temperature in Istanbul and also Vienna. As a result, the highest rate of hours with indoor temperatures below 26°C was found in these months.

In addition to this, in each month the percentages increased from base case to case 3. In other words, night ventilation resulted in lowering indoor temperature during daytime. Nevertheless, the higher air change rate of night ventilation (range from 4 ACH to 10 ACH) was assumed, the lower mean indoor temperature in occupied period was taken.

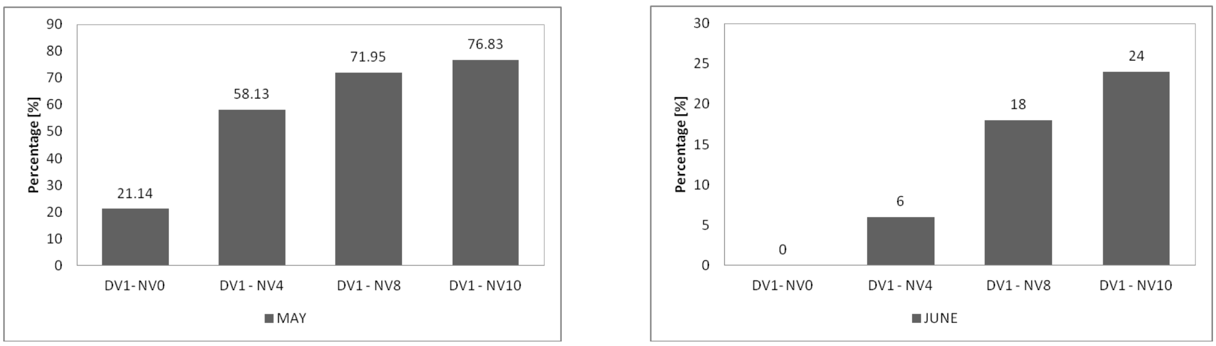

Figure 4.2.1: Monthly percentage of hourly temperature <26°C during the occupied hours in Istanbul

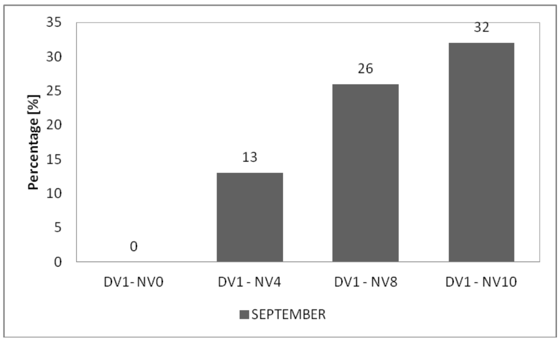

Figure 4.2.2: Monthly percentage of hourly temperature <26°C during the occupied hours in Istanbul

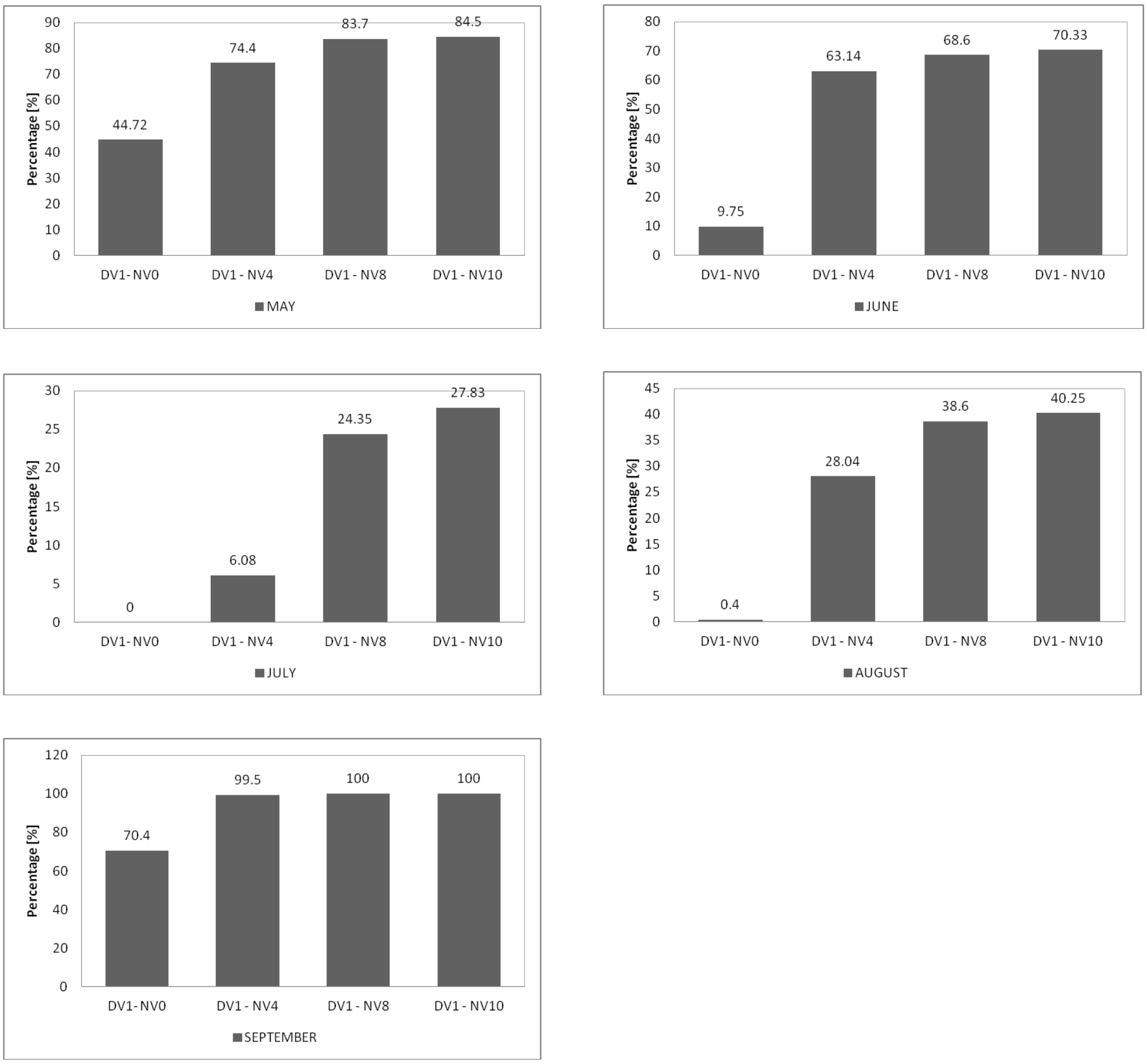

Figure 4.2.3: Monthly percentage of hourly temperature<26°C during the occupied hours in Vienna

In conclusion, as can be seen in the Figure 4.2.4 and 4.2.5 below, comparison of indoor temprature rates in the period between May and September in both cities showed the same general implications.

As expected, the highest hourly peak temperatures were found in base cases. On that account, the rate of hours with indoor temperatures below 26°C was the lowest under the base case.

The lowest daily peak temperatures were recorded under Case 3 which in assumed with 10 ACH night ventilation during the unoccupied period. Consequently, the highest percentage of hours with indoor temperatures below 26°C was under Case 3.

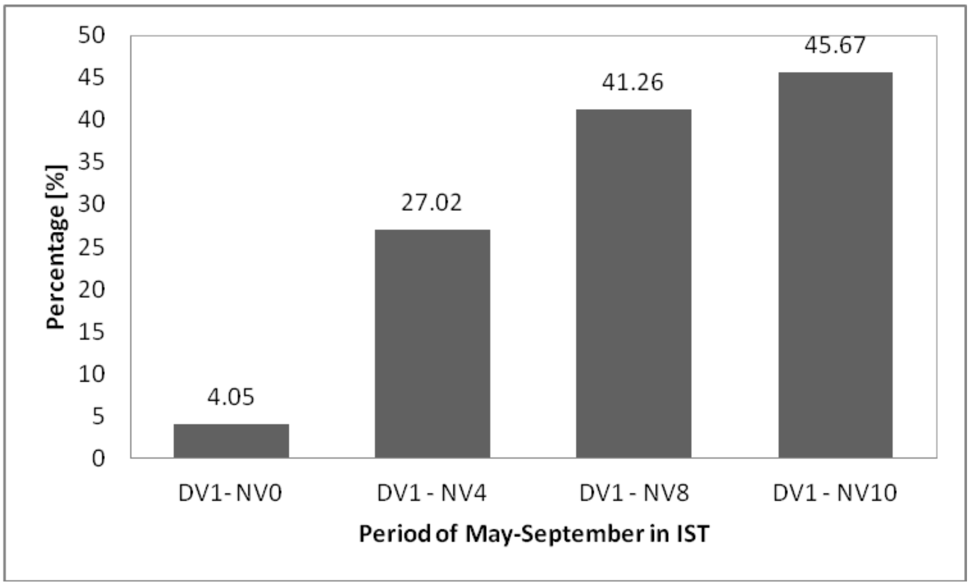

Figure 4.2.4: Percentage of hourly temperature < 26°C during the occupied hour in Istanbul

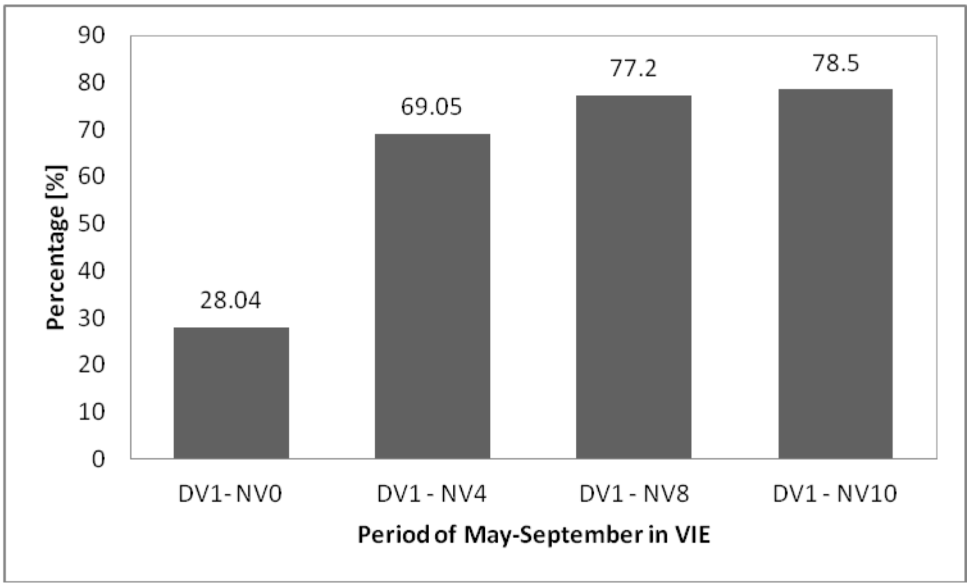

Figure 4.2.5: Percentage of hourly temperature < 26°C during the occupied hour in Vienna

Furthermore, when Istanbul and Vienna results are compared, as it is seen in Figure 4.2.6, the percentages of hours with indoor temperatures below 26°C for all cases are higher in Vienna than Istanbul. Nonetheless, the percentages reach the peak values in Case 3 both in Istanbul and Vienna.

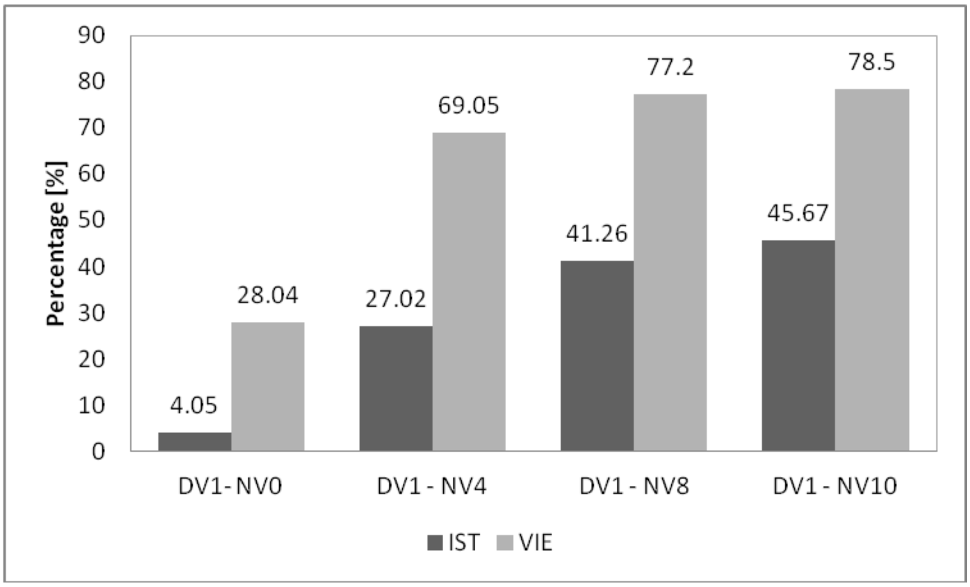

Figure 4.2.6: Comparison of percentage of hourly temperature<26°C during the occupied hours in Istanbul and Vienna

Additionally, cumulative distribution graphs in Figure 4.2.7 and 4.2.8 also present the same general results in both cities.

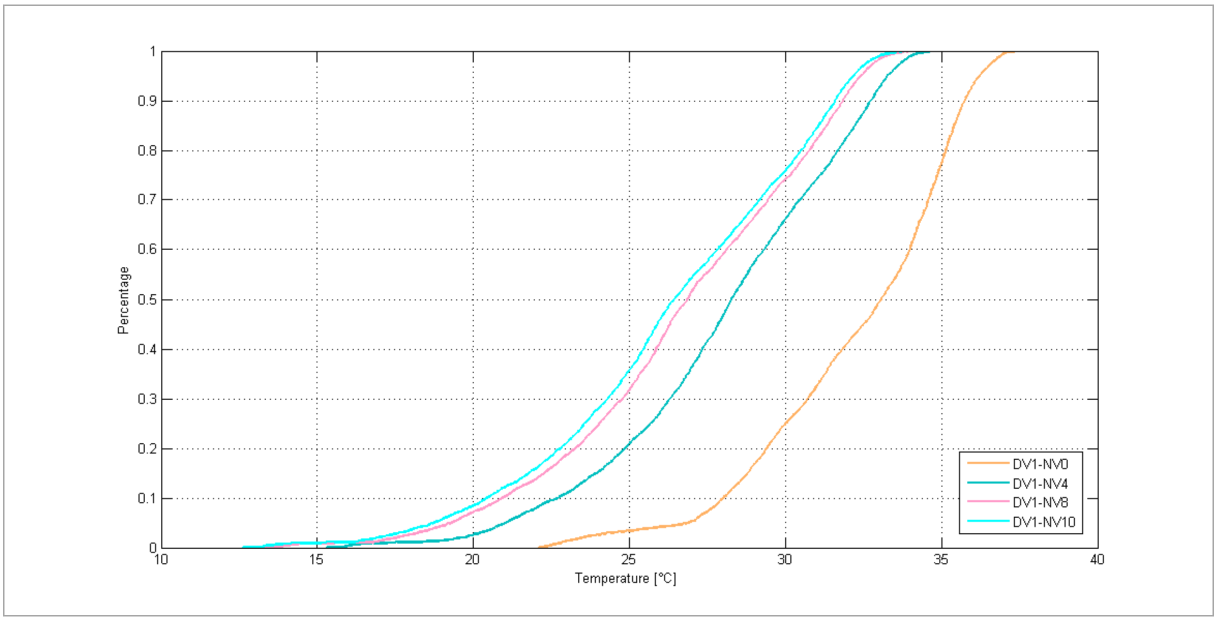

Figure 4.2.7: Probability of 26°C indoor temperature during the occupied hours in Istanbul

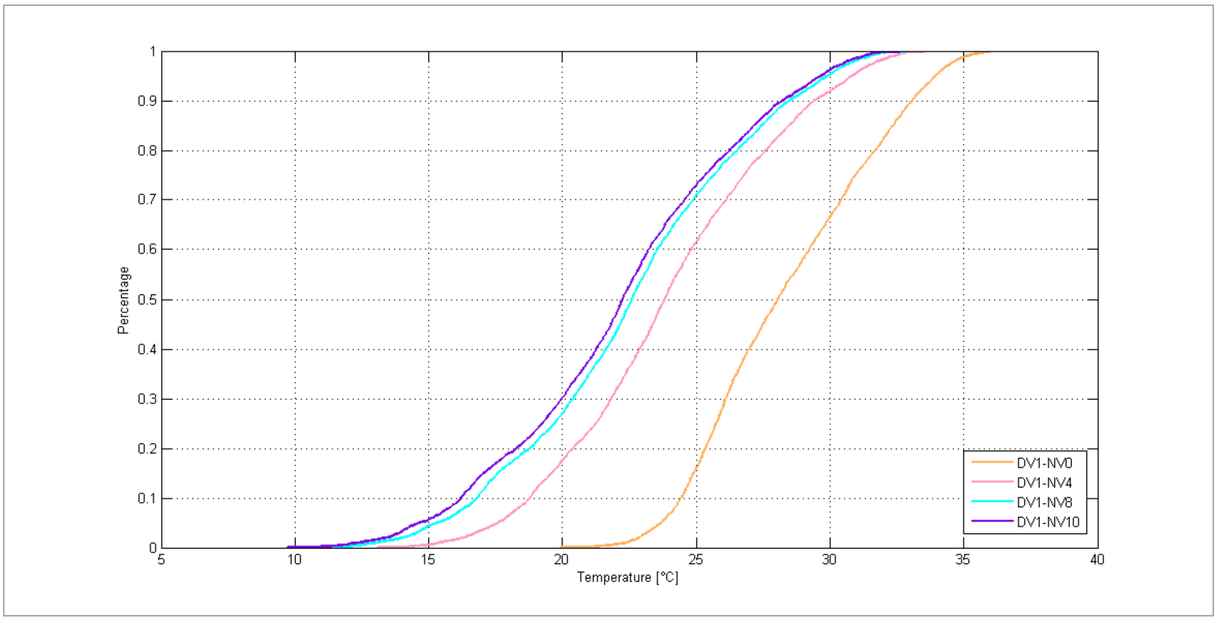

Figure 4.2.8: Probability of 26°C indoor temperature during the occupied hours in Vienna

4.2.2. Ventilation Scenarios with Shading

With the difference of the first scenario, in scenarios with shading, the windows have external blinds. Accordingly, it is expected that the effect of solar radiation can be decreased with controlling the shading devices.

After simulation process, firstly monthly results are shown in Figure 4.2.9 and 4.2.10 for Istanbul and in Figure 4.2.11 for Vienna. As it is shown in the results, in Istanbul, in May the percentage of hours with indoor temperature below 26°C was higher than other months due to the lower mean outdoor temperature. On the other hand, that percentage was decreasing in June.

However, in Vienna, as it is seen, generally the percentages were higher than Istanbul because of the fact that lower mean outdoor temperatures in Vienna (as it is seen in Figure 3.3.2 & 3.3.3). Especially, in September, the rates almost reached hundred percent.

In brief, the monthly results showed the same general results in both cities. May and September had the lowest outdoor mean temperature in Istanbul and also Vienna. As a result of that, the highest rate of hours with indoor temperatures below 26°C was recorded in these months. Additionally, in each month the percentages increased from base case to case 3. Namely, night ventilation resulted in lowering indoor temperature during daytime. Moreover, the higher air change rate of night ventilation (range from 4 ACH to 10 ACH) was assumed, the lower mean indoor temperature in occupied period was taken.

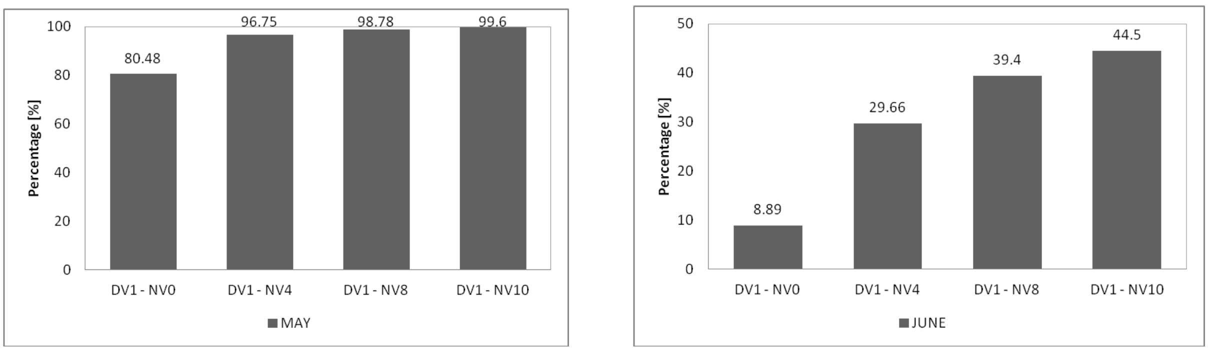

Figure 4.2.9: Monthly percentage of hourly temperature<26°C during the occupied hours in Istanbul

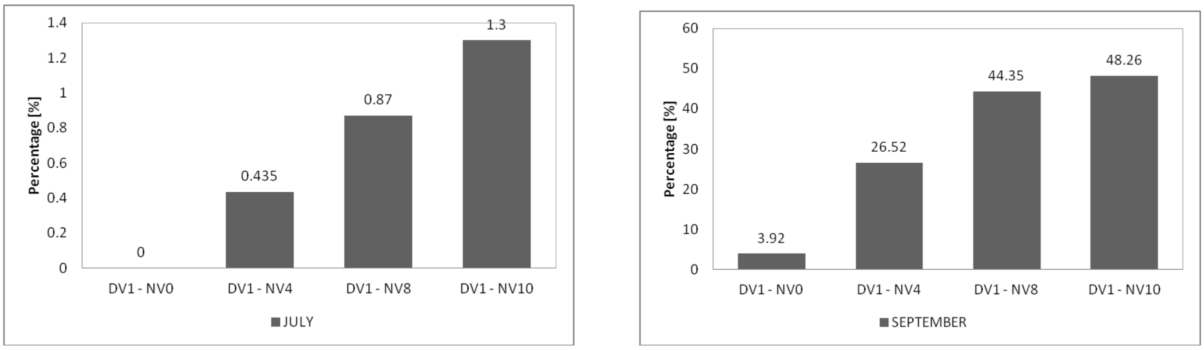

Figure 4.2.10: Monthly percentage of hourly temperature<26°C during the occupied hours in Istanbul

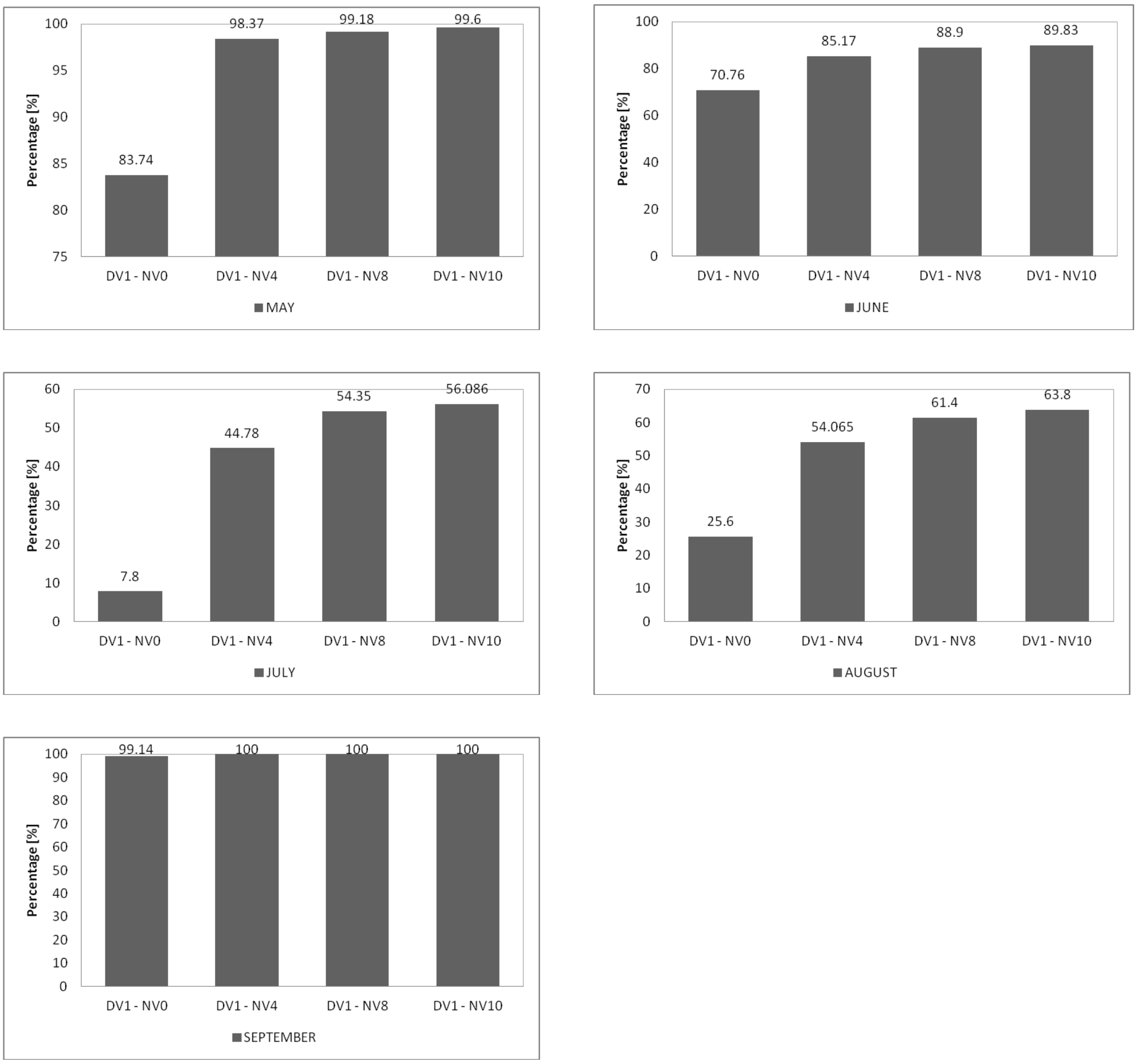

Figure 4.2.11: Monthly percentage of hourly temperature<26°C during the occupied hours in Vienna

As a conclusion, it is clearly seen in the Figure 4.2.12 and 4.2.13 below that the indoor temperature patterns in the period between May and September in both cities showed the same general tendencies.

As expected, the highest hourly peak temperatures were measured in base case. Hence, the rate of hours with indoor temperatures below 26°C was the lowest under the base case.

The lowest daily peak temperatures were found under Case 3 which in presumed 10 ACH night ventilation during night time period. As a result of that, the highest percentage of hours with indoor temperatures below 26°C was seen under Case 3.

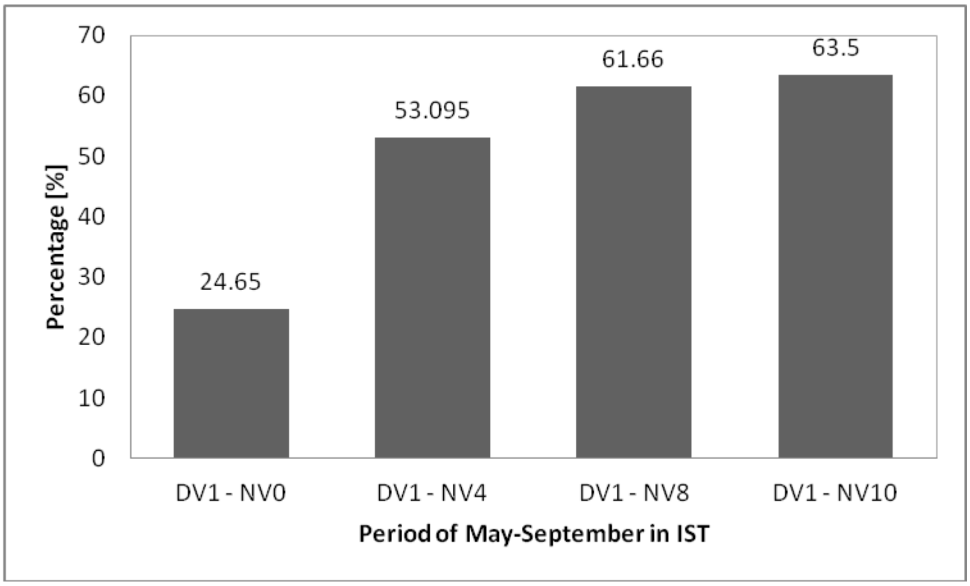

Figure 4.2.12: Percentage of hourly temperature < 26°C during the occupied hour in Istanbul

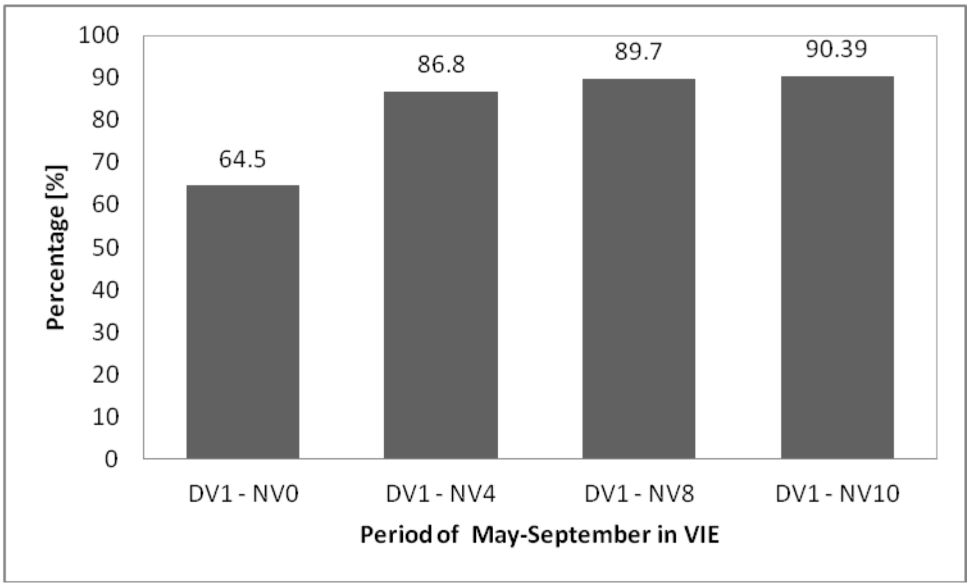

Figure 4.2.13: Percentage of hourly temperature < 26°C during the occupied hour in Vienna

In Figure 4.2.14, the results from two cities are compared. This chart shows that in each city the lowest percentages of hours with indoor temperatures below 26°C were found in base case. On the contrary, the percentages were the highest under Case 3.

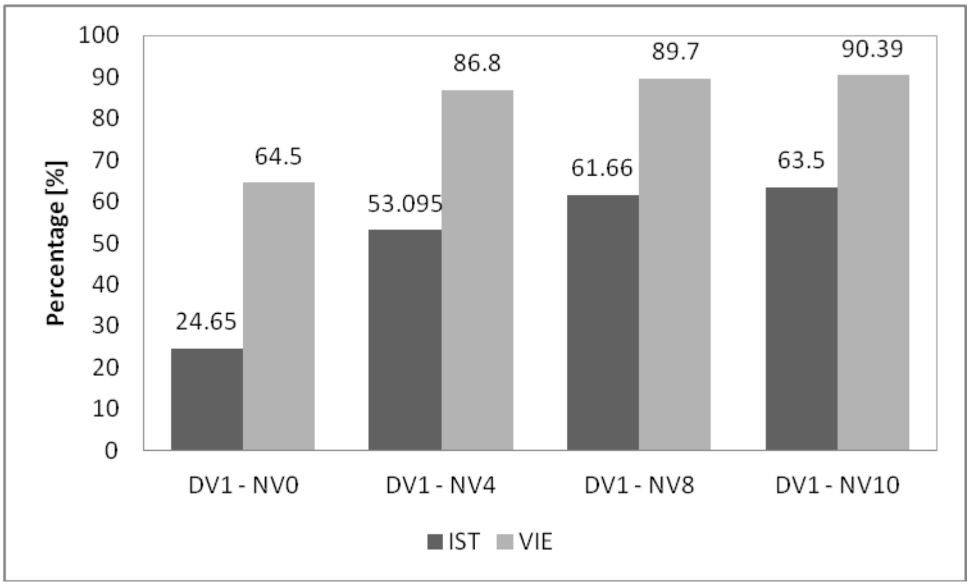

Figure 4.2.14: Comparison of percentage of hourly temperature<26°C during the occupied hours in Istanbul and Vienna

In addition, cumulative distribution graphs in Figure 4.2.15 and 4.2.16 also represented the same general results both in Istanbul and Vienna.

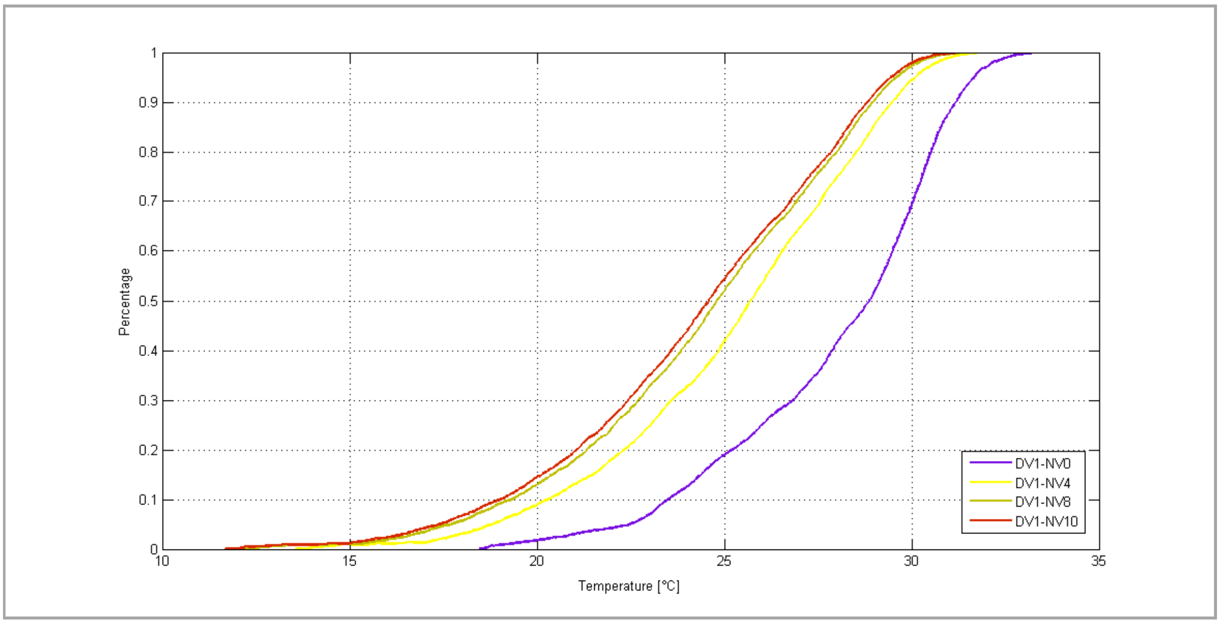

Figure 4.2.15: Probability of 26°C indoor temperature during the occupied hours in Istanbul

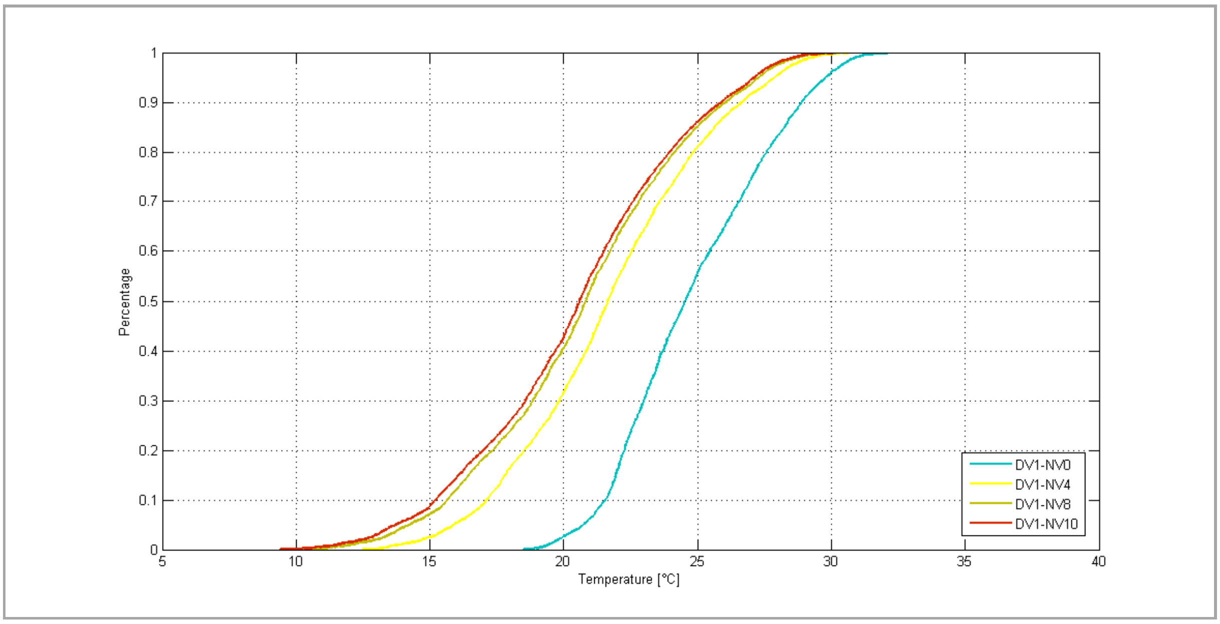

Figure 4.2.16: Probability of 26°C indoor temperature during the occupied hours in Vienna

4.2.3. Comparison of Scenarios with & without Shading

To study the impact of shading devices on building performance, two sets of scenarios with and without shading are compared below. When the results are examined, it is obviously seen that shading is one of the significant factor that affects the indoor temperature during the day.

Particularly in Istanbul, outdoor temperature is very high in summer period. In this regard, as is seen in results of ventilation scenarios without shading, night ventilation can be seen as a promising solution in order to decrease indoor temperature during the day in offices. However, the results of scenarios with shading showed that the thermal comfort can be improved with the help of shading devices.

Figure 4.2.17 and 4.2.18 presented the percentage of hours with indoor temperature below 26°C in Istanbul and Vienna for two cases: the windows have or don't have external blinds. In the case which has shading system, it is assumed that the external blinds are on if the solar radiation is higher than 150 W/m^2 on windows. The figures showed that in both cities, shading devices helped to decrease the indoor temperature during the day. The rate of hours with indoor temperature below 26°C was higher in both cities in the case of shading devices were applied to the windows.

Furthermore, Figure 4.2.19 and 4.2.20 proved that in both cities, the lowest probability of indoor temperatures less than 26°C during the occupied hours was under the base ventilation case without shading devices.

However, the highest cumulative probability of 26°C indoor temperature during the occupied hours was under Case 3 when the shading devices are applied.

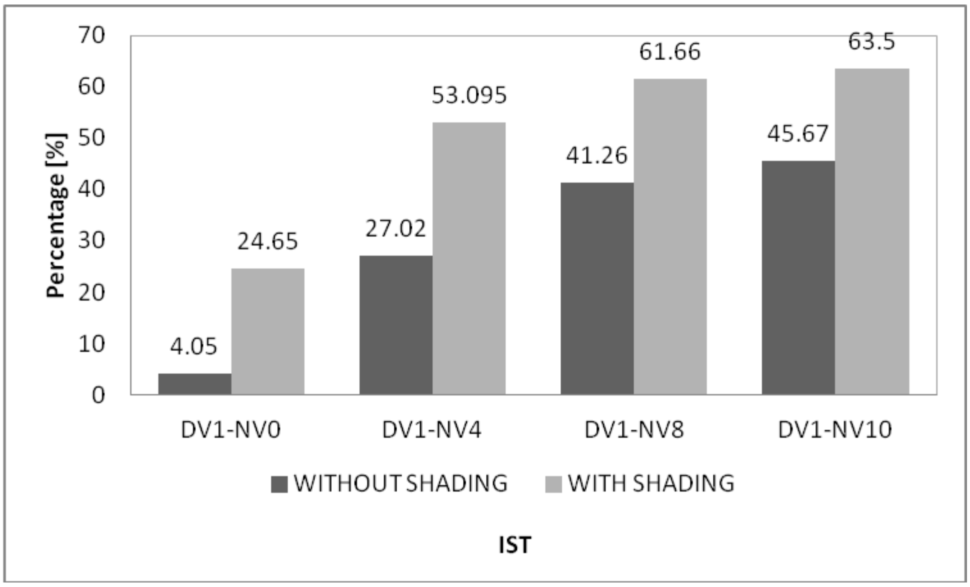

Figure 4.2.17: Comparison of ‘percentage of hourly temperature < 26°C during the occupied hour with/without shading devices in Istanbul

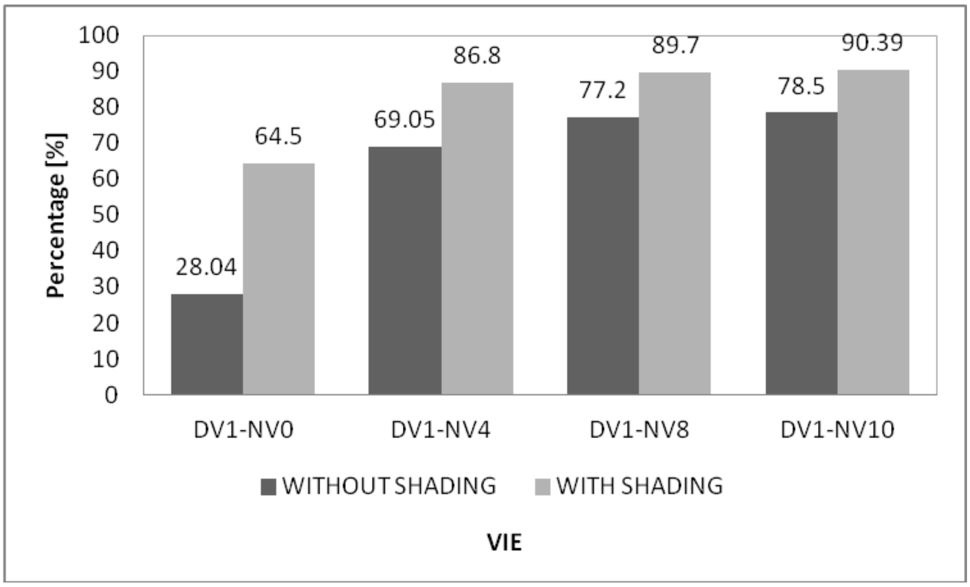

Figure 4.2.18: Comparison of ‘percentage of hourly temperature < 26°C during the occupied hour with/without shading devices in Vienna

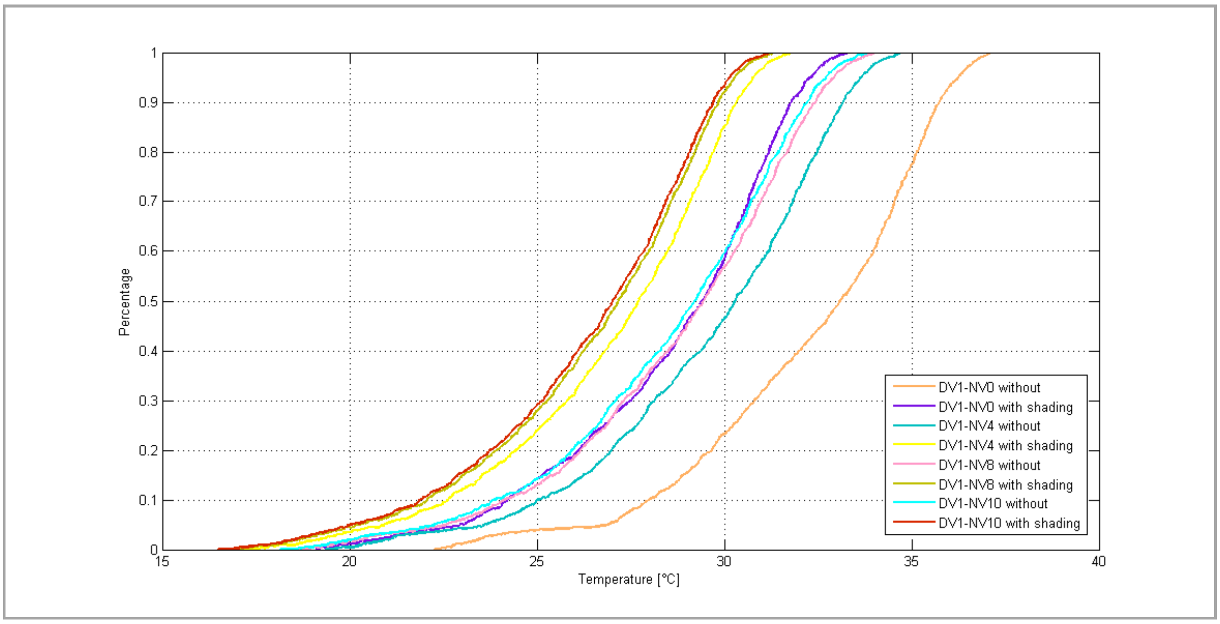

Figure 4.2.19: Comparison of indoor mean hourly dry-bulb temperatures during the occupied hours with/without shading devices in Istanbul

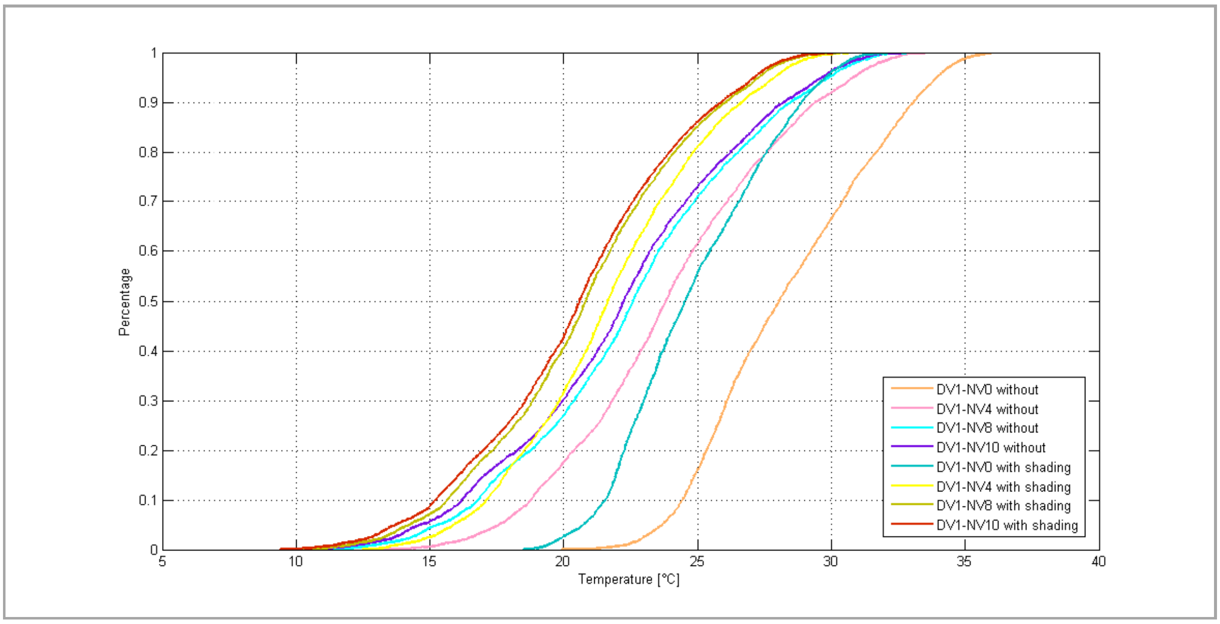

Figure 4.2.20: Comparison of indoor mean hourly dry-bulb temperatures during the occupied hours with/without shading devices in Vienna

Table 4.2.1 and 4.2.2 summarized the results numerically for both scenarios.

In both cities, the highest number of occupied hours lower than 26°C was found under Case 3 where night ventilation was presumed with the highest air change rate and the lowest values were under the base case where it was assumed that the offices were not ventilated during the night time.

When two scenarios are compared both in Istanbul and Vienna, the ‘number of occupied hours lower than 26°C’ was higher under ventilation scenario with shading than without shading.

	SCENARIO 1	Number of hours>26	Number of hours<26
IST	DV1 – NV0	3542	110
	DV1 – NV4	2845	807
	DV1 – NV8	2370	1282
	DV1 – NV10	2204	1448
VIE	DV1 – NV0	3116	536
	DV1 – NV4	1459	2193
	DV1 – NV8	1095	2557
	DV1 – NV10	1015	2637

Table 4.2.1: Comparison of ‘number of total occupied hours higher/lower than 26°C’ in Istanbul / Vienna for Scenario 1

	SCENARIO 2	Number of hours>26	Number of hours<26
IST	DV1 – NV0	2752	900
	DV1 – NV4	1713	1939
	DV1 – NV8	1400	2252
	DV1 – NV10	1334	2318
VIE	DV1 – NV0	1293	2359
	DV1 – NV4	479	3173
	DV1 – NV8	376	3276
	DV1 – NV10	351	3301

Table 4.2.2: Comparison of ‘number of total occupied hours higher/lower than 26°C’ in Istanbul / Vienna for Scenario 2

4.3. Cooling Loads Results

4.3.1. Ventilation Scenarios without Shading

After simulation process, as explained in the previous chapter, firstly monthly cooling load results were calculated for each city.

Figure 4.3.1 shows the changing of total cooling loads in each case for Istanbul. As it can be seen in Figure 4.3.1, the total cooling load was calculated 52.33 kWh/m^2 in base case (Base case was assumed without night time cooling). However, this value decreased to 36.93 kWh/m^2 in Case 1 (In Case 1, 4 ACH night ventilation was presumed). Following that, the total cooling load decreased as follows; 31.89 kWh/m^2 in Case 2(8 ACH night ventilation was presumed) and lastly 30.48 in Case 3(10 ACH night ventilation was presumed).

Figure 4.3.2 presents the total cooling load results for Vienna. As it was investigated above for Istanbul, also in Vienna the cooling loads were decreased from base case to Case 3. In Vienna, the total cooling loads were recorded as follows: 24.24 kWh/m^2 in base case (Base case was assumed without night time cooling), 13.16 kWh/m^2 in Case 1 (In Case 1, 4 ACH night ventilation was presumed).10.25 kWh/m^2 in Case 2(8 ACH night ventilation was presumed) and lastly 9.5 in Case 3(10 ACH night ventilation was presumed).

Consequently, the total cooling load in the period between May and September dropped off from base case to Case 3 in both cities. In Istanbul, reduction of total cooling loads was calculated as follows: 15.4 kWh/m^2 from base case to Case 1, 20.44 kWh/m^2 from base case to Case 2, 21.85 kWh/m^2 from base case to Case 3. Additionally, reduction of total cooling loads was seen in Vienna as follows: from base case to Case 1, 11.08 kWh/m^2, from base case to Case 2, 13.99 kWh/m^2 and finally from base case to Case 3, 14.74 kWh/m^2.

In conclusion, the monthly cooling load results in each city proved the same fact. It is clearly seen that night ventilation helps to decrease the cooling loads in summer period in Istanbul and Vienna. Nevertheless, as the results show, if the air change rate of night ventilation is higher, the reduction increases. Hence, the highest amount of reduction was seen between base case and Case 3 and the lowest amount of reduction was between base case and Case 1 in both cities.

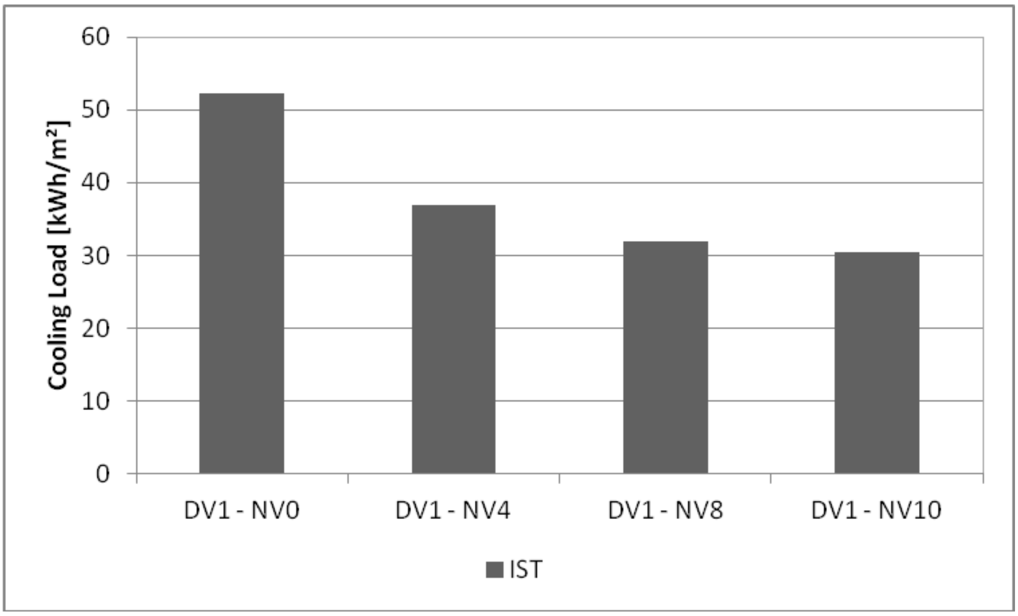

Figure 4.3.1: Total cooling loads between May-September in Istanbul

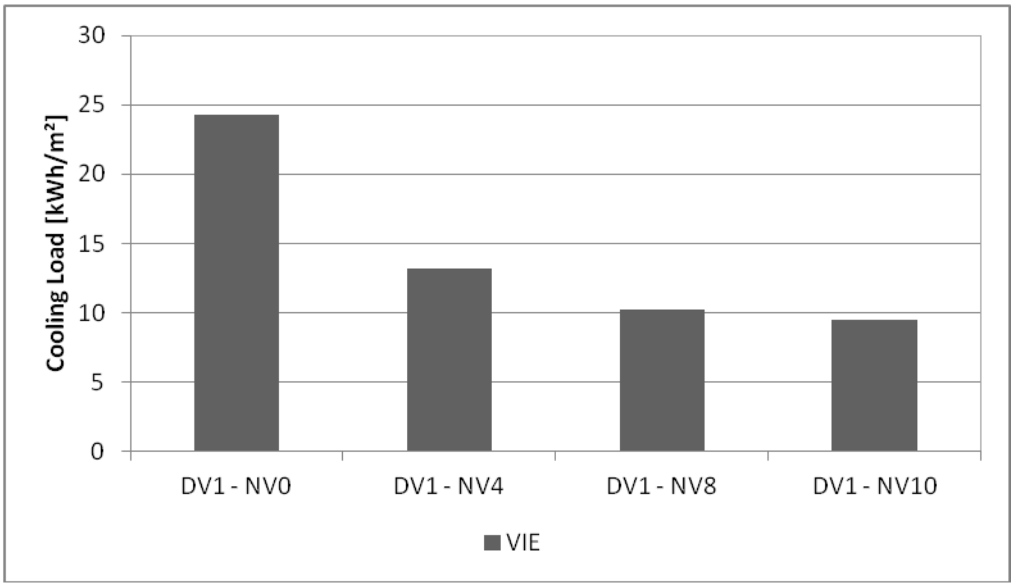

Figure 4.3.2: Total cooling loads between May-September in Vienna

Figure 4.3.3 shows the total cooling load between May and September for Istanbul and Vienna. As it was investigated in the previous chapter, the mean outdoor temperature values in Istanbul were higher than Vienna. As a result of that, in summer period, the cooling demand in Istanbul was also higher than Vienna. Additionally, it can be observed that, as expected, the cooling loads in both cities reached the lowest peak values under Case 3 and the highest peak values under the base case.

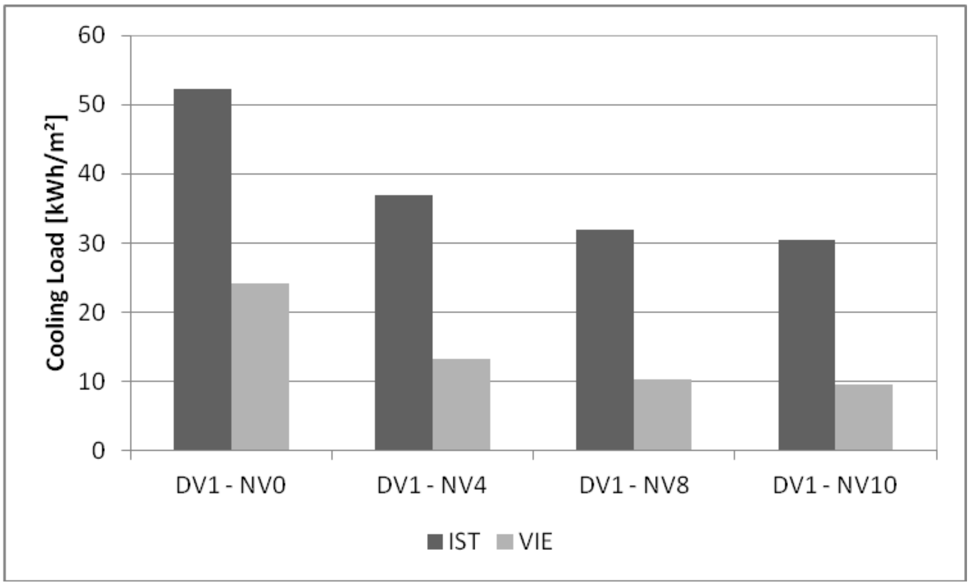

Figure 4.3.3: Comparison of cooling loads between May-September in Istanbul & Vienna

4.3.2. Ventilation Scenarios with Shading

In ventilation scenarios with shading, as it was explained in previous chapter, windows have external blinds that are on if the solar radiation is higher than 150 W/m^2 on windows.

Firstly, simulations were run in order to calculate total cooling loads in Istanbul and Vienna.

Figure 4.3.4 presents total cooling load results for Istanbul. As it is clearly seen in Figure 4.3.4, the cooling loads showed decrease from base case (DV1- NV0) to Case 3(DV1 – NV10). To give an example, the cooling load under base case (DV1- NV0) was recorded 20 kWh/m^2 in Istanbul. However, it decreased to 13.65 kWh/m^2 under Case 1(DV1- NV4), to 11.8 kWh/m^2 under Case 2(DV1- NV8) and lastly to 11.3 kWh/m^2 under Case 3(DV1- NV10).

It can be observed that the total cooling load results for Vienna showed the same general tendencies as Istanbul's. As Figure 4.3.5 shows that the reduction in cooling load from base case (DV1- NV0) to Case 3 (DV1 – NV10) was recorded also for Vienna. The cooling load under base case (DV1- NV0) was 6 kWh/m^2 in Vienna. On the other hand, it decreased to 2.93 kWh/m^2 under Case 1(DV1- NV4), to 2.25 kWh/m^2 under Case 2(DV1- NV8) and lastly to 2.083 kWh/m^2 under Case 3(DV1- NV10).

Consequently, the total cooling load in the period between May and September decreased from base case (DV1- NV0) to Case 3(DV1- NV10) in each city. In Istanbul, reduction of total cooling loads was calculated as follows: 6.35 kWh/m^2 from base case (DV1- NV0) to Case 1(DV1-NV4), 8.2 kWh/m^2 from base case to Case 2(DV1- NV8), 8.7kWh/m^2 from base case to Case 3(DV1-NV10). Additionally, reduction of total cooling loads was seen in Vienna as follows: from base case (DV1- NV0) to Case 1(DV1- NV4),3.07 kWh/m^2; from base case to Case 2(DV1- NV8), 3.75 kWh/m^2 and finally from base case to Case 3(DV1- NV10), 3.917 kWh/m^2.

In conclusion, the cooling load results in ventilation scenarios with shading also showed that night ventilation helps to decrease the cooling loads in summer period in Istanbul and Vienna. If the air change rate of night ventilation is higher, the reduction increases. Nevertheless, it is clearly seen that besides night ventilation, shading system also helps to decrease the cooling load during summer period.

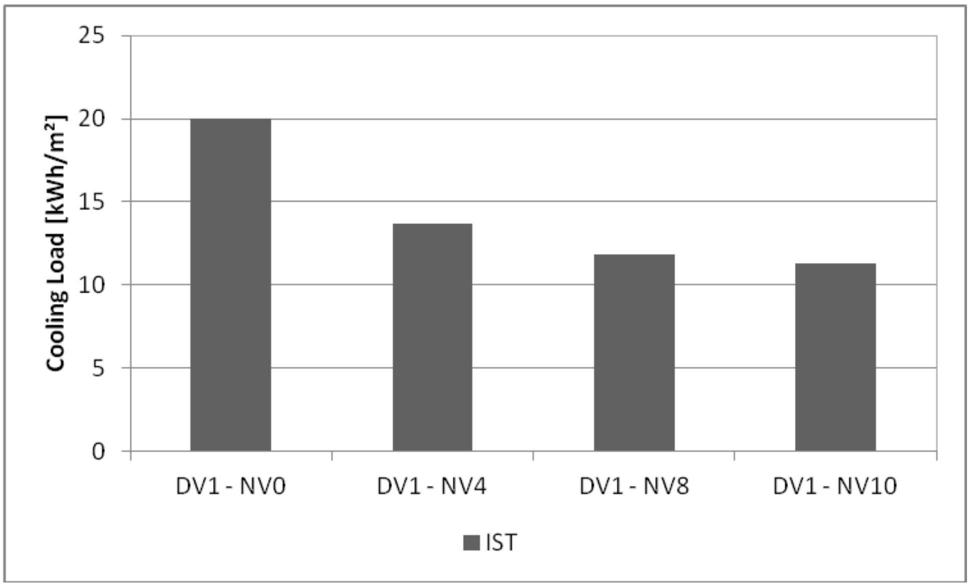

Figure 4.3.4: Total cooling loads between May-September in Istanbul

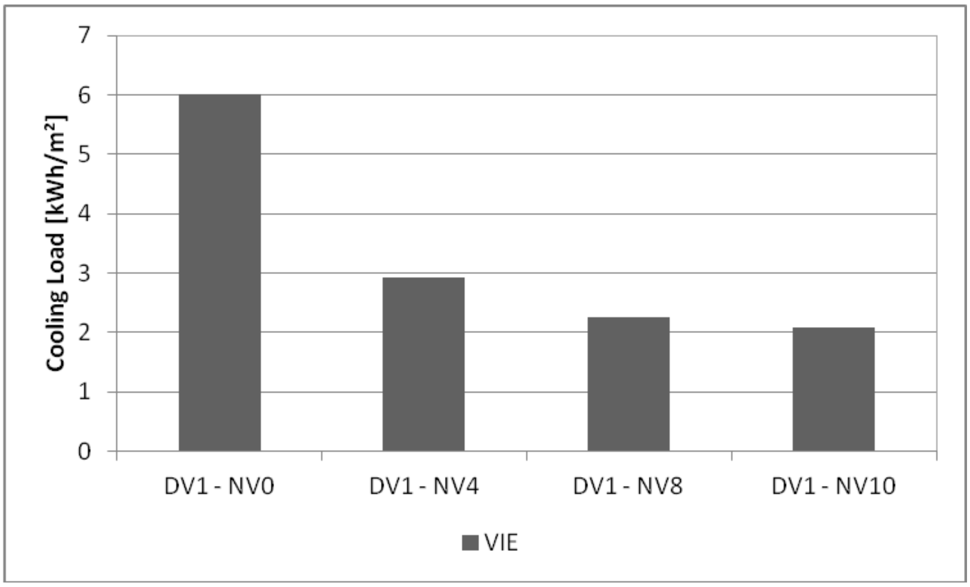

Figure 4.3.5: Total cooling loads between May-September in Vienna

Hence, the highest amount of reduction was seen between base case (DV1- NV0) and Case 3 (DV1- NV10) and the lowest amount of reduction was between base case (DV1- NV0) and Case 1(DV1- NV4) in both Istanbul and Vienna (Figure 4.3.6).

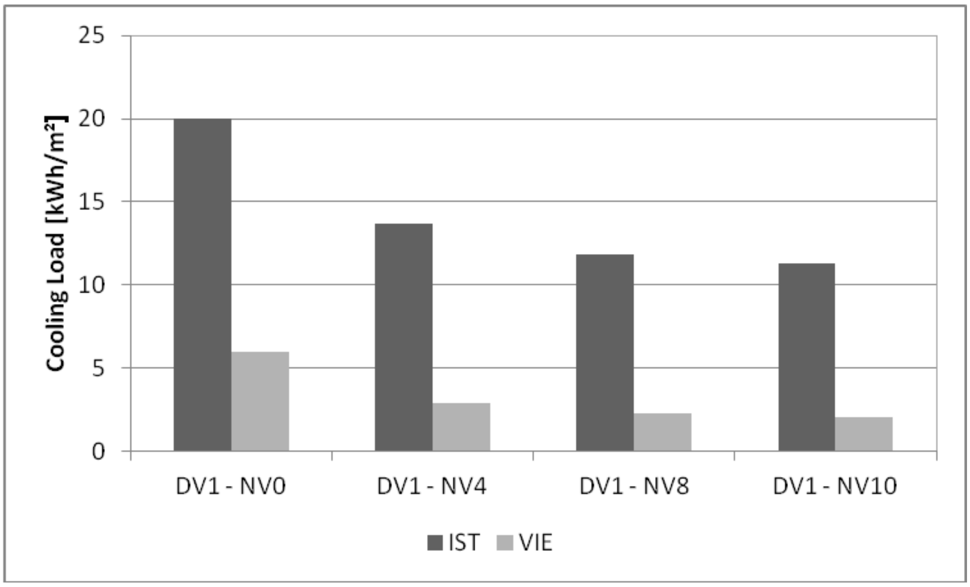

Figure 4.3.6: Comparison of cooling loads between May-September in Istanbul & Vienna

4.3.3. Comparison of Scenarios with & without Shading

In order to investigate the impact of shading system on building performance, ventilation scenarios with and without shading were compared below. Figure 4.3.7 and 4.3.8 proved that shading system has a sizeable impact on reduction of cooling load during the summer.

Figure 4.3.7 presents the comparison of two scenarios' results for Istanbul. As expected, the cooling load showed decrease from base case (DV1- NV0) to Case 3 (DV1- NV10) in each scenario due to night ventilation increase. Additionally, the cooling load was extremely low when shading system existed.

Figure 4.3.8 shows the cooling load results in Vienna for both scenarios: the windows have/ don't have shading devices. As Istanbul's results, also in Vienna the cooling load decreased from base case (DV1- NV0) to Case 3 (DV1- NV10) for both conditions. In Scenario 2 (with shading system), the cooling load was dropped to 3.32 kWh/m^2 under Case 3 when in Scenario 1 it was 15.92 kWh/m^2.

Consequently, shading is a considerable factor in order to reduce cooling load in summer period. Figure 4.3.7 and 4.3.8 show that in both cities, the lowest peak cooling load was recorded under Case 3 (DV1- NV10) with shading system conditions. On the other hand, the highest peak cooling load was recorded under base case (DV1- NV0) in case of without shading system.

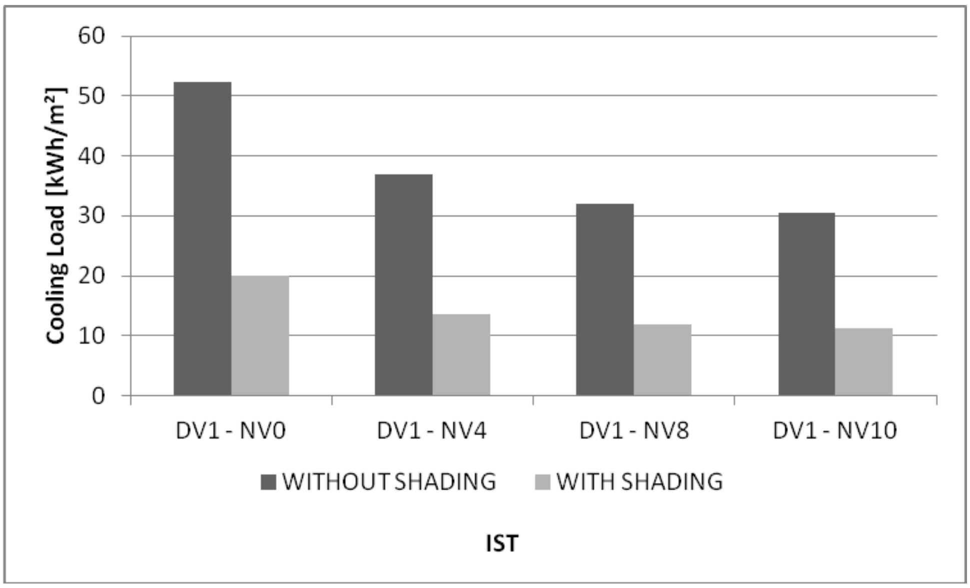

Figure 4.3.7: Comparison of 'cooling loads' during the occupied hour with/without shading devices in Istanbul

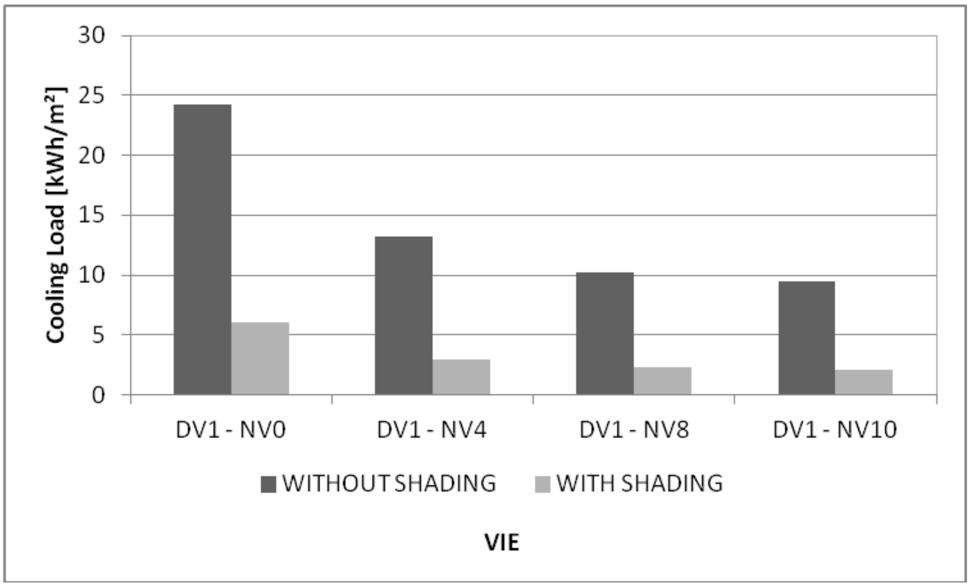

Figure 4.3.8: Comparison of 'cooling loads' during the occupied hour with/without shading devices in Vienna

Furthermore, it is expected that shading also has an effect on electric lighting usage. As it can be seen below in Figure 4.3.9 and 4.3.10, lights total heating energy was increased when shading system was applied. In other saying, using shading devices leads to increase of electric lighting usage in both cities.

In Istanbul, for ventilation scenarios without shading, lights total heating energy was 1.72 kWh/m^2. However, in ventilation scenarios with shading, it was reached to 2.4 kWh/m^2 due to the fact that using shading leads to increase of electric lighting usage.

In Vienna, lights total heating energy was calculated 2.02 kWh/m^2 for scenarios without shading. This value increased to 2.65 in ventilation scenarios with shading due to the existing of shading system.

However, the increase in lighting electricity use due to the use of shading devices is very low compared to the reduction of solar heat gains. Therefore, shading devices have decreased the building cooling loads noticeably (Figure 4.3.9 and 4.3.10).

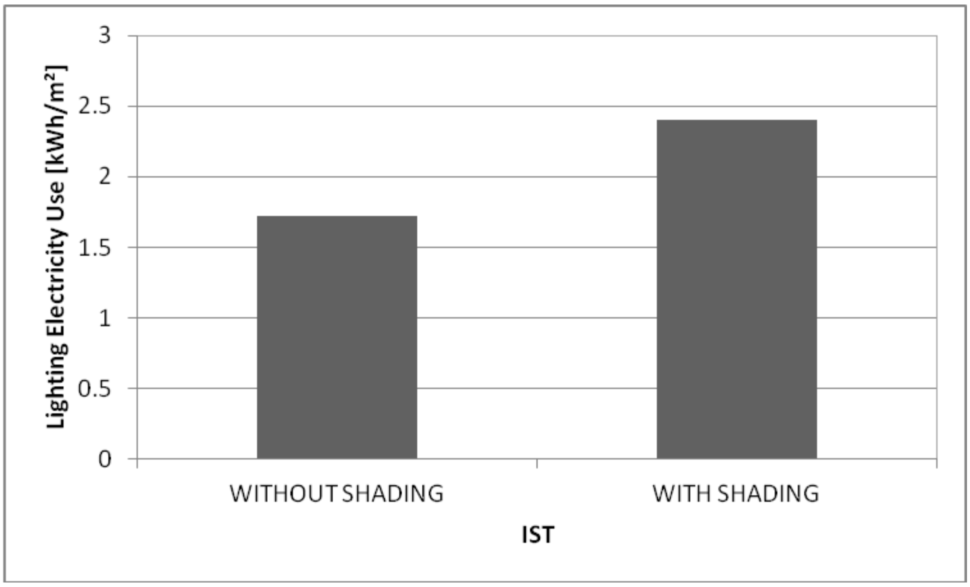

Figure 4.3.9: Comparison of 'lighting electricity use' during the occupied hour with/without shading devices in Istanbul

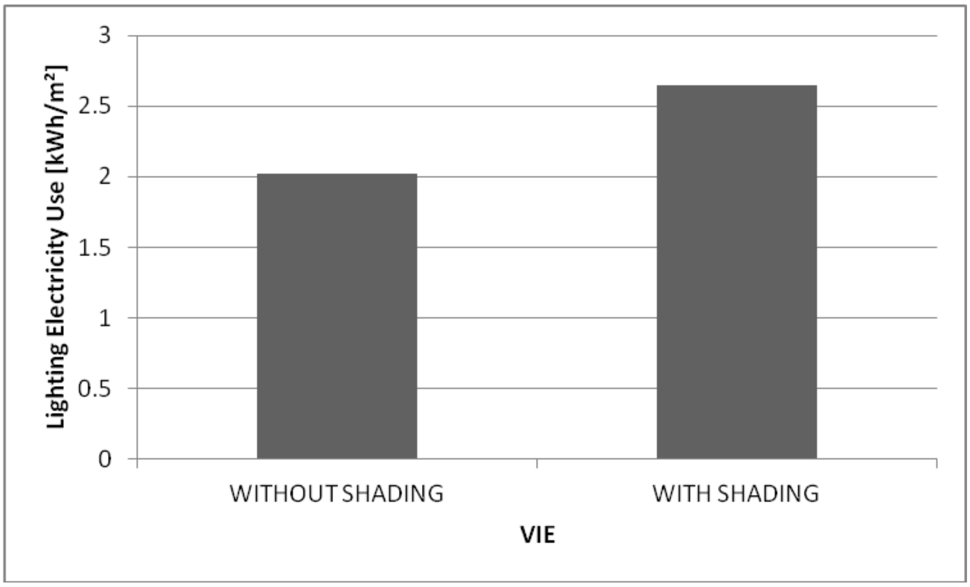

Figure 4.3.10: Comparison of 'lighting electricity use' during the occupied hour with/without shading devices in Vienna

5. CONCLUSION

This thesis was aimed to find out the impact of night ventilation on indoor thermal comfort in different climatic zones during the summer months. Within this scope, the typical five-story office building was created and the main factors that had an influence on thermal performance characteristics of this reference building were investigated by simulation studies.

The simulations were evaluated based on two benchmarks; indoor temperature during the occupied hour and cooling load during the five warmest months of the year (between May and September) in Istanbul and Vienna.

As a conclusion, it was found out that;

1. Night ventilation had an important role in order to decrease daytime indoor temperature during the summer in both cities. Due to the fact that outdoor mean temperature in Istanbul is higher than Vienna's temperature in that period, night ventilation became more crucial strategy in Istanbul to supply thermal comfort in offices.

2. Following this, the air change rate of night ventilation had a clear positive effect on decreasing indoor temperature during the day. The higher air change rate of night ventilation was assumed, the lower indoor temperature during the occupied hours in Istanbul and Vienna was achieved.

3. Moreover, night ventilation had an influence on reducing cooling load during the summer. In Istanbul, by help of night ventilation, the cooling load was reduced approximately 30%. This reduction was reached to 42% if the night ventilation air change rate was increased. In Vienna, the cooling demand was decreased in the ratio of 45% thanks to night cooling. This value reached to 60% when the air change rate of night ventilation was increased.

4. It was found out that shading had an important role to improve thermal comfort during the warmest summer months in Istanbul and Vienna. In case that the windows had exterior blinds as a shading device, the indoor temperature decreased during the summer in both cities. Due to the fact that, the reference building had high glazing area (Glazed Area/Façade Area Ratio: 60%), the shading had such a crucial effect on indoor temperature.

5. Shading had a considerable role in reducing cooling load. It helped to reduce cooling energy the period between May and September in both cities. Even though, it caused

increasing of electric lighting usage during the day, thermal advantages of shading was more dominant than electric energy disadvantages. To give an example, because of shading, the cooling energy was 20 kWh/m² reduced. However, in the same case, the lights heating energy was about 1-1.5 kWh/m² increased.

Lastly, this research is based only on computer simulations that were done for a reference building model. Nonetheless, the results demonstrated the potential of night ventilation for building performance.

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Appendix

The Initial EnergyPlus Model

```
!-Generator IDFEditor 1.44
!-Option SortedOrder UseSpecialFormat

!-NOTE: All comments with '!-' are ignored by the IDFEditor and are generated automatically.
!-      Use '!' comments if they need to be retained when using the IDFEditor.

!-   ===========  ALL OBJECTS IN CLASS: VERSION ===========

Version,
8.1;                                     !- Version Identifier

!-   ===========  ALL OBJECTS IN CLASS: SIMULATIONCONTROL ===========

SimulationControl,
    No,                                  !- Do Zone Sizing Calculation
    No,                                  !- Do System Sizing Calculation
    No,                                  !- Do Plant Sizing Calculation
    No,                                  !- Run Simulation for Sizing Periods
    Yes;                                 !- Run Simulation for Weather File Run Periods


!-   ===========  ALL OBJECTS IN CLASS: BUILDING ===========

Building,
    Medium Office-1,                     !- Name
    -0,                                  !- North Axis {deg}
    City,                                !- Terrain
    0.04,                                !- Loads Convergence Tolerance Value
    0.4,                                 !- Temperature Convergence Tolerance Value {deltaC}
    FullExterior,                        !- Solar Distribution
    25,                                  !- Maximum Number of Warmup Days
    6;                                   !- Minimum Number of Warmup Days


!-   ===========  ALL OBJECTS IN CLASS: TIMESTEP ===========

Timestep,
    4;                                   !- Number of Timesteps per Hour

!-   ===========  ALL OBJECTS IN CLASS: RUNPERIOD ===========

RunPeriod,
    Run Period 1,                        !- Name
    4,                                   !- Begin Month
    1,                                   !- Begin Day of Month
    10,                                  !- End Month
    31,                                  !- End Day of Month
    UseWeatherFile,                      !- Day of Week for Start Day
    Yes,                                 !- Use Weather File Holidays and Special Days
    Yes,                                 !- Use Weather File Daylight Saving Period
    No,                                  !- Apply Weekend Holiday Rule
    Yes,                                 !- Use Weather File Rain Indicators
    Yes,                                 !- Use Weather File Snow Indicators
    1,                                   !- Number of Times Runperiod to be Repeated
    Yes;                                 !- Increment Day of Week on repeat
```

```
!-   ===========  ALL OBJECTS IN CLASS: SCHEDULETYPELIMITS ===========

ScheduleTypeLimits,
    Any Number;                                  !- Name
ScheduleTypeLimits,
    Fraction,                                    !- Name
    0,                                           !- Lower Limit Value
    1,                                           !- Upper Limit Value
    CONTINUOUS;                                  !- Numeric Type

ScheduleTypeLimits,
    On/Off,                                      !- Name
    0,                                           !- Lower Limit Value
    1,                                           !- Upper Limit Value
    DISCRETE;                                    !- Numeric Type


!-   ===========  ALL OBJECTS IN CLASS: SCHEDULE:COMPACT ===========

Schedule:Compact,
    Night Ventilation,                           !- Name
    Fraction,                                    !- Schedule Type Limits Name
    Through: 12/31,                              !- Field 1
    For: Weekdays,                               !- Field 2
    Until: 07:00,                                !- Field 3
    1,                                           !- Field 4
    Until: 21:00,                                !- Field 5
    0,                                           !- Field 6
    Until: 24:00,                                !- Field 7
    1,                                           !- Field 8
    For: Saturday,                               !- Field 9
    Until: 07:00,                                !- Field 10
    1,                                           !- Field 11
    Until: 21:00,                                !- Field 12
    0,                                           !- Field 13
    Until: 24:00,                                !- Field 14
    1,                                           !- Field 15
    For: Allotherdays,                           !- Field 16
    Until: 24:00,                                !- Field 17
    0;                                           !- Field 18

Schedule:Compact,
    Constant,                                    !- Name
    on/off,                                      !- Schedule Type Limits Name
    Through: 12/31,                              !- Field 1
    For: AllDays,                                !- Field 2
    Until: 24:00,                                !- Field 3
    1.0;                                         !- Field 4

Schedule:Compact,
    Office Lighting,                             !- Name
    Fraction,                                    !- Schedule Type Limits Name
    Through: 12/31,                              !- Field 1
    For: Weekdays SummerDesignDay,               !- Field 2
    Until: 05:00,                                !- Field 3
    0.05,                                        !- Field 4
    Until: 07:00,                                !- Field 5
    0.1,                                         !- Field 6
    Until: 08:00,                                !- Field 7
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```
    0.3,                                !- Field 8
    Until: 17:00,                       !- Field 9
    0.9,                                !- Field 10
    Until: 18:00,                       !- Field 11
    0.5,                                !- Field 12
    Until: 20:00,                       !- Field 13
    0.3,                                !- Field 14
    Until: 22:00,                       !- Field 15
    0.2,                                !- Field 16
    Until: 23:00,                       !- Field 17
    0.1,                                !- Field 18
    Until: 24:00,                       !- Field 19
    0.05,                               !- Field 20
    For: Saturday WinterDesignDay,      !- Field 21
    Until: 06:00,                       !- Field 22
    0.05,                               !- Field 23
    Until: 08:00,                       !- Field 24
    0.1,                                !- Field 25
    Until: 12:00,                       !- Field 26
    0.3,                                !- Field 27
    Until: 17:00,                       !- Field 28
    0.15,                               !- Field 29
    Until: 24:00,                       !- Field 30
    0.05,                               !- Field 31
    For: Sunday Holidays AllOtherDays,  !- Field 32
    Until: 24:00,                       !- Field 33
    0.05;                               !- Field 34

  Schedule:Compact,
    Office Occupancy,                   !- Name
    Fraction,                           !- Schedule Type Limits Name
    Through: 12/31,                     !- Field 1
    For: Weekdays SummerDesignDay,      !- Field 2
    Until: 06:00,                       !- Field 3
    0.0,                                !- Field 4
    Until: 07:00,                       !- Field 5
    0.1,                                !- Field 6
    Until: 08:00,                       !- Field 7
    0.2,                                !- Field 8
    Until: 12:00,                       !- Field 9
    0.95,                               !- Field 10
    Until: 13:00,                       !- Field 11
    0.5,                                !- Field 12
    Until: 17:00,                       !- Field 13
    0.95,                               !- Field 14
    Until: 18:00,                       !- Field 15
    0.3,                                !- Field 16
    Until: 22:00,                       !- Field 17
    0.1,                                !- Field 18
    Until: 24:00,                       !- Field 19
    0.05,                               !- Field 20
    For: Saturday WinterDesignDay,      !- Field 21
    Until: 06:00,                       !- Field 22
    0.0,                                !- Field 23
    Until: 08:00,                       !- Field 24
    0.1,                                !- Field 25
    Until: 12:00,                       !- Field 26
    0.3,                                !- Field 27
    Until: 17:00,                       !- Field 28
    0.1,                                !- Field 29
```

```
    Until: 19:00,                          !- Field 30
    0.05,                                  !- Field 31
    Until: 24:00,                          !- Field 32
    0.0,                                   !- Field 33
    For: Sunday Holidays AllOtherDays,     !- Field 34
    Until: 06:00,                          !- Field 35
    0.0,                                   !- Field 36
    Until: 18:00,                          !- Field 37
    0.05,                                  !- Field 38
    Until: 24:00,                          !- Field 39
    0.0;                                   !- Field 40

Schedule:Compact,
    act,                                   !- Name
    Any Number,                            !- Schedule Type Limits Name
    Through: 12/31,                        !- Field 1
    For: AllDays,                          !- Field 2
    Until: 24:00,                          !- Field 3
    117;                                   !- Field 4

Schedule:Compact,
    reporting,                             !- Name
    on/off,                                !- Schedule Type Limits Name
    Through: 4/30,                         !- Field 1
    For: AllDays,                          !- Field 2
    Until: 24:00,                          !- Field 3
    0,                                     !- Field 4
    Through: 9/30,                         !- Field 5
    For: AllDays,                          !- Field 6
    Until: 24:00,                          !- Field 7
    1,                                     !- Field 8
    Through: 12/31,                        !- Field 9
    For: AllDays,                          !- Field 10
    Until: 24:00,                          !- Field 11
    0;                                     !- Field 12

Schedule:Compact,
    CoolingSchedule,                       !- Name
    Any Number,                            !- Schedule Type Limits Name
    Through: 12/31,                        !- Field 1
    For: Weekdays,                         !- Field 2
    Until: 08:00,                          !- Field 3
    100,                                   !- Field 4
    Until: 18:00,                          !- Field 5
    26,                                    !- Field 6
    Until: 24:00,                          !- Field 7
    100,                                   !- Field 8
    For: Saturday,                         !- Field 9
    Until: 08:00,                          !- Field 10
    100,                                   !- Field 11
    Until: 12:00,                          !- Field 12
    26,                                    !- Field 13
    Until: 24:00,                          !- Field 14
    100,                                   !- Field 15
    For: Allotherdays,                     !- Field 16
    Until: 24:00,                          !- Field 17
    100;                                   !- Field 18

Schedule:Compact,
    occupied,                              !- Name
```

```
    Fraction,                            !- Schedule Type Limits Name
    Through: 12/31,                      !- Field 1
    For: Weekdays,                       !- Field 2
    Until: 08:00,                        !- Field 3
    0,                                   !- Field 4
    Until: 18:00,                        !- Field 5
    1,                                   !- Field 6
    Until: 24:00,                        !- Field 7
    0,                                   !- Field 8
    For: Saturday,                       !- Field 9
    Until: 08:00,                        !- Field 10
    0,                                   !- Field 11
    Until: 12:00,                        !- Field 12
    1,                                   !- Field 13
    Until: 24:00,                        !- Field 14
    0,                                   !- Field 15
    For: Allotherdays,                   !- Field 16
    Until: 24:00,                        !- Field 17
    0;                                   !- Field 18

Schedule:Compact,
    Day Ventilation,                     !- Name
    Fraction,                            !- Schedule Type Limits Name
    Through: 12/31,                      !- Field 1
    For: Weekdays,                       !- Field 2
    Until: 08:00,                        !- Field 3
    0,                                   !- Field 4
    Until: 18:00,                        !- Field 5
    1,                                   !- Field 6
    Until: 24:00,                        !- Field 7
    0,                                   !- Field 8
    For: Saturday,                       !- Field 9
    Until: 08:00,                        !- Field 10
    0,                                   !- Field 11
    Until: 12:00,                        !- Field 12
    1,                                   !- Field 13
    Until: 24:00,                        !- Field 14
    0,                                   !- Field 15
    For: Allotherdays,                   !- Field 16
    Until: 24:00,                        !- Field 17
    0;                                   !- Field 18

!-   ===========  ALL OBJECTS IN CLASS: MATERIAL ===========

Material,
    000 F08 Metal surface,               !- Name
    Smooth,                              !- Roughness
    0.0008,                              !- Thickness {m}
    45.28,                               !- Conductivity {W/m-K}
    7824,                                !- Density {kg/m3}
    500,                                 !- Specific Heat {J/kg-K}
    0.9,                                 !- Thermal Absorptance
    0.7,                                 !- Solar Absorptance
    0.7;                                 !- Visible Absorptance

Material,
    000 F16 Acoustic tile,               !- Name
    MediumSmooth,                        !- Roughness
    0.03,                                !- Thickness {m}
    1.1,                                 !- Conductivity {W/m-K}
```

```
    2100,                               !- Density {kg/m3}
    837,                                !- Specific Heat {J/kg-K}
    0.9,                                !- Thermal Absorptance
    0.7,                                !- Solar Absorptance
    0.7;                                !- Visible Absorptance
Material,
    000 G01a 19mm gypsum board,         !- Name
    MediumSmooth,                       !- Roughness
    0.019,                              !- Thickness {m}
    0.7,                                !- Conductivity {W/m-K}
    1400,                               !- Density {kg/m3}
    1090,                               !- Specific Heat {J/kg-K}
    0.9,                                !- Thermal Absorptance
    0.7,                                !- Solar Absorptance
    0.7;                                !- Visible Absorptance

Material,
    000 G05 25mm wood,                  !- Name
    MediumSmooth,                       !- Roughness
    0.0254,                             !- Thickness {m}
    0.15,                               !- Conductivity {W/m-K}
    608,                                !- Density {kg/m3}
    1630,                               !- Specific Heat {J/kg-K}
    0.9,                                !- Thermal Absorptance
    0.7,                                !- Solar Absorptance
    0.7;                                !- Visible Absorptance

Material,
    000 I01 25mm insulation board,      !- Name
    MediumRough,                        !- Roughness
    0.0254,                             !- Thickness {m}
    0.03,                               !- Conductivity {W/m-K}
    43,                                 !- Density {kg/m3}
    1210,                               !- Specific Heat {J/kg-K}
    0.9,                                !- Thermal Absorptance
    0.7,                                !- Solar Absorptance
    0.7;                                !- Visible Absorptance

Material,
    000 M11 100mm lightweight concrete, !- Name
    MediumRough,                        !- Roughness
    0.2,                                !- Thickness {m}
    1.1,                                !- Conductivity {W/m-K}
    2000,                               !- Density {kg/m3}
    1110,                               !- Specific Heat {J/kg-K}
    0.9,                                !- Thermal Absorptance
    0.7,                                !- Solar Absorptance
    0.7;                                !- Visible Absorptance

Material,
    1/2IN Gypsum,                       !- Name
    Smooth,                             !- Roughness
    0.0127,                             !- Thickness {m}
    0.16,                               !- Conductivity {W/m-K}
    784.9,                              !- Density {kg/m3}
    830,                                !- Specific Heat {J/kg-K}
    0.9,                                !- Thermal Absorptance
    0.92,                               !- Solar Absorptance
    0.92;                               !- Visible Absorptance
```

```
Material,
    MAT-CC05 4 HW CONCRETE,          !- Name
    Rough,                           !- Roughness
    0.2,                             !- Thickness {m}
    1,                               !- Conductivity {W/m-K}
    1800,                            !- Density {kg/m3}
    1110,                            !- Specific Heat {J/kg-K}
    0.9,                             !- Thermal Absorptance
    0.7,                             !- Solar Absorptance
    0.7;                             !- Visible Absorptance

Material,
    Metal Decking,                   !- Name
    MediumSmooth,                    !- Roughness
    0.0015,                          !- Thickness {m}
    45.006,                          !- Conductivity {W/m-K}
    7680,                            !- Density {kg/m3}
    418.4,                           !- Specific Heat {J/kg-K}
    0.9,                             !- Thermal Absorptance
    0.7,                             !- Solar Absorptance
    0.3;                             !- Visible Absorptance

Material,
    Roof Insulation [21],            !- Name
    MediumRough,                     !- Roughness
    0.2105,                          !- Thickness {m}
    0.049,                           !- Conductivity {W/m-K}
    265,                             !- Density {kg/m3}
    836.8,                           !- Specific Heat {J/kg-K}
    0.9,                             !- Thermal Absorptance
    0.7,                             !- Solar Absorptance
    0.7;                             !- Visible Absorptance

Material,
    Roof Membrane,                   !- Name
    VeryRough,                       !- Roughness
    0.0095,                          !- Thickness {m}
    0.16,                            !- Conductivity {W/m-K}
    1121.29,                         !- Density {kg/m3}
    1460,                            !- Specific Heat {J/kg-K}
    0.9,                             !- Thermal Absorptance
    0.7,                             !- Solar Absorptance
    0.7;                             !- Visible Absorptance

Material,
    Wall Insulation [39],            !- Name
    MediumRough,                     !- Roughness
    0.1,                             !- Thickness {m}
    0.03,                            !- Conductivity {W/m-K}
    70,                              !- Density {kg/m3}
    840,                             !- Specific Heat {J/kg-K}
    0.9,                             !- Thermal Absorptance
    0.7,                             !- Solar Absorptance
    0.7;                             !- Visible Absorptance

Material,
    OS:Material:AirWall 1,           !- Name
    MediumSmooth,                    !- Roughness
    0.01,                            !- Thickness {m}
    0.6,                             !- Conductivity {W/m-K}
```

```
    800,                                !- Density {kg/m3}
    1000,                               !- Specific Heat {J/kg-K}
    0.95,                               !- Thermal Absorptance
    0.7,                                !- Solar Absorptance
    0.7;                                !- Visible Absorptance

Material,
    M15 200mm heavyweight concrete,     !- Name
    MediumRough,                        !- Roughness
    0.2032,                             !- Thickness {m}
    1.95,                               !- Conductivity {W/m-K}
    2240,                               !- Density {kg/m3}
    1110;                               !- Specific Heat {J/kg-K}


!-   ===========  ALL OBJECTS IN CLASS: MATERIAL:NOMASS ===========

Material:NoMass,
    CP02 CARPET PAD,                    !- Name
    VeryRough,                          !- Roughness
    0.2165,                             !- Thermal Resistance {m2-K/W}
    0.9,                                !- Thermal Absorptance
    0.7,                                !- Solar Absorptance
    0.8;                                !- Visible Absorptance

Material:NoMass,
    MAT-SHEATH,                         !- Name
    Rough,                              !- Roughness
    0.3626,                             !- Thermal Resistance {m2-K/W}
    0.9,                                !- Thermal Absorptance
    0.7,                                !- Solar Absorptance
    0.7;                                !- Visible Absorptance


!-   ===========  ALL OBJECTS IN CLASS: MATERIAL:AIRGAP ===========

Material:AirGap,
    000 F04 Wall air space resistance,  !- Name
    0.15;                               !- Thermal Resistance {m2-K/W}

Material:AirGap,
    000 F05 Ceiling air space resistance,  !- Name
    0.18;                               !- Thermal Resistance {m2-K/W}


!-   ===========  ALL OBJECTS IN CLASS: WINDOWMATERIAL:GLAZING ===========

WindowMaterial:Glazing,
    000 Clear 3mm,                      !- Name
    SpectralAverage,                    !- Optical Data Type
    ,                                   !- Window Glass Spectral Data Set Name
    0.003,                              !- Thickness {m}
    0.837,                              !- Solar Transmittance at Normal Incidence
    0.075,                              !- Front Side Solar Reflectance at Normal Incidence
    0.075,                              !- Back Side Solar Reflectance at Normal Incidence
    0.898,                              !- Visible Transmittance at Normal Incidence
    0.081,                              !- Front Side Visible Reflectance at Normal Incidence
    0.081,                              !- Back Side Visible Reflectance at Normal Incidence
    0,                                  !- Infrared Transmittance at Normal Incidence
    0.84,                               !- Front Side Infrared Hemispherical Emissivity
```

```
    0.84,                                  !- Back Side Infrared Hemispherical Emissivity
    0.9;                                   !- Conductivity {W/m-K}

WindowMaterial:Glazing,
    Theoretical Glass [207],               !- Name
    SpectralAverage,                       !- Optical Data Type
    ,                                      !- Window Glass Spectral Data Set Name
    0.003,                                 !- Thickness {m}
    0.3311,                                !- Solar Transmittance at Normal Incidence
    0.6189,                                !- Front Side Solar Reflectance at Normal Incidence
    0.6189,                                !- Back Side Solar Reflectance at Normal Incidence
    0.44,                                  !- Visible Transmittance at Normal Incidence
    0.51,                                  !- Front Side Visible Reflectance at Normal Incidence
    0.51,                                  !- Back Side Visible Reflectance at Normal Incidence
    0,                                     !- Infrared Transmittance at Normal Incidence
    0.9,                                   !- Front Side Infrared Hemispherical Emissivity
    0.9,                                   !- Back Side Infrared Hemispherical Emissivity
    0.0133,                                !- Conductivity {W/m-K}
    1,                                     !- Dirt Correction Factor for Solar and Visible Transmittance
    No;                                    !- Solar Diffusing


!-   ===========  ALL OBJECTS IN CLASS: WINDOWMATERIAL:GAS ===========

WindowMaterial:Gas,
    000 Air 13mm,                          !- Name
    Air,                                   !- Gas Type
    0.0127;                                !- Thickness {m}
!-   ===========  ALL OBJECTS IN CLASS: CONSTRUCTION ===========

Construction,
    000 Exterior Door,                     !- Name
    000 F08 Metal surface,                 !- Outside Layer
    000 I01 25mm insulation board;         !- Layer 2

Construction,
    000 Exterior Window,                   !- Name
    000 Clear 3mm,                         !- Outside Layer
    000 Air 13mm,                          !- Layer 2
    000 Clear 3mm;                         !- Layer 3

Construction,
    000 ExtSlabCarpet 4in ClimateZone 1-8,  !- Name
    MAT-CC05 4 HW CONCRETE,                !- Outside Layer
    CP02 CARPET PAD;                       !- Layer 2

Construction,
    000 Interior Ceiling,                  !- Name
    M15 200mm heavyweight concrete,        !- Outside Layer
    000 I01 25mm insulation board,         !- Layer 2
    000 F16 Acoustic tile;                 !- Layer 3

Construction,
    000 Interior Door,                     !- Name
    000 G05 25mm wood;                     !- Outside Layer

Construction,
    000 Interior Floor,                    !- Name
    000 F16 Acoustic tile,                 !- Outside Layer
    000 I01 25mm insulation board,         !- Layer 2
```

```
    M15 200mm heavyweight concrete;         !- Layer 3

Construction,
    000 Interior Wall,                      !- Name
    000 G01a 19mm gypsum board,             !- Outside Layer
    000 M11 100mm lightweight concrete,     !- Layer 2
    000 G01a 19mm gypsum board;             !- Layer 3

Construction,
    000 Interior Window,                    !- Name
    000 Clear 3mm;                          !- Outside Layer

Construction,
    ASHRAE 189.1-2009 ExtRoof IEAD ClimateZone 2-5,          !- Name
    Roof Membrane,                          !- Outside Layer
    Roof Insulation [21],                   !- Layer 2
    Metal Decking;                          !- Layer 3

Construction,
    ASHRAE 189.1-2009 ExtWall SteelFrame ClimateZone 4-8,    !- Name
    1/2IN Gypsum,                           !- Outside Layer
    M15 200mm heavyweight concrete,         !- Layer 2
    Wall Insulation [39],                   !- Layer 3
    M15 200mm heavyweight concrete,         !- Layer 4
    1/2IN Gypsum;                           !- Layer 5

Construction,
    ASHRAE 189.1-2009 ExtWindow ClimateZone 4-5,             !- Name
    000 Clear 3mm,                          !- Outside Layer
    000 Air 13mm,                           !- Layer 2
    000 Clear 3mm;                          !- Layer 3

!-   ===========  ALL OBJECTS IN CLASS: GLOBALGEOMETRYRULES ===========

GlobalGeometryRules,
    UpperLeftCorner,                        !- Starting Vertex Position
    Counterclockwise,                       !- Vertex Entry Direction
    Relative,                               !- Coordinate System
    Relative,                               !- Daylighting Reference Point Coordinate System
    Relative;                               !- Rectangular Surface Coordinate System


!-   ===========  ALL OBJECTS IN CLASS: ZONE ===========

Zone,
    atrium_zone,                            !- Name
    -0,                                     !- Direction of Relative North {deg}
    10,                                     !- X Origin {m}
    10,                                     !- Y Origin {m}
    0;                                      !- Z Origin {m}

Zone,
    N_1st,                                  !- Name
    180,                                    !- Direction of Relative North {deg}
    36,                                     !- X Origin {m}
    30,                                     !- Y Origin {m}
    3;                                      !- Z Origin {m}

Zone,
    N_2nd,                                  !- Name
```

```
    180,                                  !- Direction of Relative North {deg}
    36,                                   !- X Origin {m}
    30,                                   !- Y Origin {m}
    6;                                    !- Z Origin {m}

Zone,
    N_3rd,                                !- Name
    180,                                  !- Direction of Relative North {deg}
    36,                                   !- X Origin {m}
    30,                                   !- Y Origin {m}
    9;                                    !- Z Origin {m}

Zone,
    N_4th,                                !- Name
    180,                                  !- Direction of Relative North {deg}
    36,                                   !- X Origin {m}
    30,                                   !- Y Origin {m}
    12;                                   !- Z Origin {m}

Zone,
    N_ground,                             !- Name
    -0,                                   !- Direction of Relative North {deg}
    36,                                   !- X Origin {m}
    30,                                   !- Y Origin {m}
    0;                                    !- Z Origin {m}

Zone,
    S_1st,                                !- Name
    -0,                                   !- Direction of Relative North {deg}
    0,                                    !- X Origin {m}
    2.88764567812905e-015,                !- Y Origin {m}
    3;                                    !- Z Origin {m}

Zone,
    S_2nd,                                !- Name
    -0,                                   !- Direction of Relative North {deg}
    0,                                    !- X Origin {m}
    5.77529135625809e-015,                !- Y Origin {m}
    6;                                    !- Z Origin {m}

Zone,
    S_3rd,                                !- Name
    -0,                                   !- Direction of Relative North {deg}
    0,                                    !- X Origin {m}
    5.77529135625809e-015,                !- Y Origin {m}
    9;                                    !- Z Origin {m}

Zone,
    S_4th,                                !- Name
    -0,                                   !- Direction of Relative North {deg}
    0,                                    !- X Origin {m}
    5.77529135625809e-015,                !- Y Origin {m}
    12;                                   !- Z Origin {m}

Zone,
    S_ground,                             !- Name
    -0,                                   !- Direction of Relative North {deg}
    0,                                    !- X Origin {m}
    0,                                    !- Y Origin {m}
    0;                                    !- Z Origin {m}
```

```
Zone,
    Z1_1st,                  !- Name
    -0,                      !- Direction of Relative North {deg}
    10,                      !- X Origin {m}
    20,                      !- Y Origin {m}
    3;                       !- Z Origin {m}

Zone,
    Z1_2nd,                  !- Name
    -0,                      !- Direction of Relative North {deg}
    10,                      !- X Origin {m}
    20,                      !- Y Origin {m}
    6;                       !- Z Origin {m}

Zone,
    Z1_ground,               !- Name
    -0,                      !- Direction of Relative North {deg}
    10,                      !- X Origin {m}
    20,                      !- Y Origin {m}
    0;                       !- Z Origin {m}

Zone,
    Z2_1st,                  !- Name
    -0,                      !- Direction of Relative North {deg}
    26,                      !- X Origin {m}
    10,                      !- Y Origin {m}
    3;                       !- Z Origin {m}

Zone,
    Z2_2nd,                  !- Name
    -0,                      !- Direction of Relative North {deg}
    26,                      !- X Origin {m}
    10,                      !- Y Origin {m}
    6;                       !- Z Origin {m}

Zone,
    Z2_3rd,                  !- Name
    -0,                      !- Direction of Relative North {deg}
    26,                      !- X Origin {m}
    10,                      !- Y Origin {m}
    9;                       !- Z Origin {m}

Zone,
    Z2_4th,                  !- Name
    -0,                      !- Direction of Relative North {deg}
    26,                      !- X Origin {m}
    10,                      !- Y Origin {m}
    12;                      !- Z Origin {m}

Zone,
    Z2_ground,               !- Name
    -0,                      !- Direction of Relative North {deg}
    26,                      !- X Origin {m}
    10,                      !- Y Origin {m}
    0;                       !- Z Origin {m}

Zone,
    Z_3rd,                   !- Name
    -0,                      !- Direction of Relative North {deg}
```

```
    10,                                    !- X Origin {m}
    20,                                    !- Y Origin {m}
    9;                                     !- Z Origin {m}


Zone,
    Z_4th,                                 !- Name
    -0,                                    !- Direction of Relative North {deg}
    10,                                    !- X Origin {m}
    20,                                    !- Y Origin {m}
    12;                                    !- Z Origin {m}

!-   ===========  ALL OBJECTS IN CLASS: PEOPLE ===========

People,
    ASHRAE 189.1-2009 ClimateZone 4-8 MediumOffice PeopInst,                !- Name
    Offices,                               !- Zone or ZoneList Name
    Office Occupancy,                      !- Number of People Schedule Name
    People/Area,                           !- Number of People Calculation Method
    ,                                      !- Number of People
    0.1,                                   !- People per Zone Floor Area {person/m2}
    ,                                      !- Zone Floor Area per Person {m2/person}
    0.3,                                   !- Fraction Radiant
    autocalculate,                         !- Sensible Heat Fraction
    act;                                   !- Activity Level Schedule Name


!-   ===========  ALL OBJECTS IN CLASS: LIGHTS ===========

Lights,
    ASHRAE 189.1-2009 ClimateZone 4-8 MediumOffice LightsInst,              !- Name
    allZonesExceptAtrium,                  !- Zone or ZoneList Name
    Office Lighting,                       !- Schedule Name
    Watts/Area,                            !- Design Level Calculation Method
    ,                                      !- Lighting Level {W}
    10,                                    !- Watts per Zone Floor Area {W/m2}
    ,                                      !- Watts per Person {W/person}
    ,                                      !- Return Air Fraction
    ,                                      !- Fraction Radiant
    ,                                      !- Fraction Visible
    ,                                      !- Fraction Replaceable
    Lights;                                !- End-Use Subcategory


!-   ===========  ALL OBJECTS IN CLASS: ELECTRICEQUIPMENT ===========

ElectricEquipment,
    ASHRAE 189.1-2009 ClimateZone 4-8 MediumOffice ElecInst,                !- Name
    Offices,                               !- Zone or ZoneList Name
    Office Occupancy,                      !- Schedule Name
    Watts/Area,                            !- Design Level Calculation Method
    ,                                      !- Design Level {W}
    6,                                     !- Watts per Zone Floor Area {W/m2}
    ,                                      !- Watts per Person {W/person}
    ,                                      !- Fraction Latent
    ,                                      !- Fraction Radiant
    ,                                      !- Fraction Lost
    ElectricEquipment;                     !- End-Use Subcategory
```

```
!-   ===========  ALL OBJECTS IN CLASS: DAYLIGHTING:CONTROLS

Daylighting:Controls,
    N_1st,                  !- Zone Name
    1,                      !- Total Daylighting Reference Points
    18,                     !- X-Coordinate of First Reference Point {m}
    5,                      !- Y-Coordinate of First Reference Point {m}
    0.8,                    !- Z-Coordinate of First Reference Point {m}
    ,                       !- X-Coordinate of Second Reference Point {m}
    ,                       !- Y-Coordinate of Second Reference Point {m}
    ,                       !- Z-Coordinate of Second Reference Point {m}
    1,                      !- Fraction of Zone Controlled by First Reference Point
    ,                       !- Fraction of Zone Controlled by Second Reference Point
    500,                    !- Illuminance Setpoint at First Reference Point {lux}
    ,                       !- Illuminance Setpoint at Second Reference Point {lux}
    3,                      !- Lighting Control Type
    180,                    !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
    22,                     !- Maximum Allowable Discomfort Glare Index
    0.3,                    !- Minimum Input Power Fraction for Continuous Dimming Control
    0.2,                    !- Minimum Light Output Fraction for Continuous Dimming Control
    0,                      !- Number of Stepped Control Steps
    1;                      !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

Daylighting:Controls,
    N_2nd,                  !- Zone Name
    1,                      !- Total Daylighting Reference Points
    18,                     !- X-Coordinate of First Reference Point {m}
    5,                      !- Y-Coordinate of First Reference Point {m}
    0.8,                    !- Z-Coordinate of First Reference Point {m}
    ,                       !- X-Coordinate of Second Reference Point {m}
    ,                       !- Y-Coordinate of Second Reference Point {m}
    ,                       !- Z-Coordinate of Second Reference Point {m}
    1,                      !- Fraction of Zone Controlled by First Reference Point
    ,                       !- Fraction of Zone Controlled by Second Reference Point
    500,                    !- Illuminance Setpoint at First Reference Point {lux}
    ,                       !- Illuminance Setpoint at Second Reference Point {lux}
    3,                      !- Lighting Control Type
    180,                    !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
    22,                     !- Maximum Allowable Discomfort Glare Index
    0.3,                    !- Minimum Input Power Fraction for Continuous Dimming Control
    0.2,                    !- Minimum Light Output Fraction for Continuous Dimming Control
    0,                      !- Number of Stepped Control Steps
    1;                      !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

Daylighting:Controls,
    N_3rd,                  !- Zone Name
    1,                      !- Total Daylighting Reference Points
    18,                     !- X-Coordinate of First Reference Point {m}
    5,                      !- Y-Coordinate of First Reference Point {m}
    0.8,                    !- Z-Coordinate of First Reference Point {m}
    ,                       !- X-Coordinate of Second Reference Point {m}
    ,                       !- Y-Coordinate of Second Reference Point {m}
    ,                       !- Z-Coordinate of Second Reference Point {m}
    1,                      !- Fraction of Zone Controlled by First Reference Point
    ,                       !- Fraction of Zone Controlled by Second Reference Point
    500,                    !- Illuminance Setpoint at First Reference Point {lux}
```

```
    ,                        !- Illuminance Setpoint at Second Reference Point {lux}
    3,                       !- Lighting Control Type
    180,                     !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
    22,                      !- Maximum Allowable Discomfort Glare Index
    0.3,                     !- Minimum Input Power Fraction for Continuous Dimming Control
    0.2,                     !- Minimum Light Output Fraction for Continuous Dimming Control
    0,                       !- Number of Stepped Control Steps
    1;                       !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

Daylighting:Controls,
    N_4th,                   !- Zone Name
    1,                       !- Total Daylighting Reference Points
    18,                      !- X-Coordinate of First Reference Point {m}
    5,                       !- Y-Coordinate of First Reference Point {m}
    0.8,                     !- Z-Coordinate of First Reference Point {m}
    ,                        !- X-Coordinate of Second Reference Point {m}
    ,                        !- Y-Coordinate of Second Reference Point {m}
    ,                        !- Z-Coordinate of Second Reference Point {m}
    1,                       !- Fraction of Zone Controlled by First Reference Point
    ,                        !- Fraction of Zone Controlled by Second Reference Point
    500,                     !- Illuminance Setpoint at First Reference Point {lux}
    ,                        !- Illuminance Setpoint at Second Reference Point {lux}
    3,                       !- Lighting Control Type
    180,                     !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
    22,                      !- Maximum Allowable Discomfort Glare Index
    0.3,                     !- Minimum Input Power Fraction for Continuous Dimming Control
    0.2,                     !- Minimum Light Output Fraction for Continuous Dimming Control
    0,                       !- Number of Stepped Control Steps
    1;                       !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

Daylighting:Controls,
    N_ground,                !- Zone Name
    1,                       !- Total Daylighting Reference Points
    -18,                     !- X-Coordinate of First Reference Point {m}
    -5,                      !- Y-Coordinate of First Reference Point {m}
    0.8,                     !- Z-Coordinate of First Reference Point {m}
    ,                        !- X-Coordinate of Second Reference Point {m}
    ,                        !- Y-Coordinate of Second Reference Point {m}
    ,                        !- Z-Coordinate of Second Reference Point {m}
    1,                       !- Fraction of Zone Controlled by First Reference Point
    ,                        !- Fraction of Zone Controlled by Second Reference Point
    500,                     !- Illuminance Setpoint at First Reference Point {lux}
    ,                        !- Illuminance Setpoint at Second Reference Point {lux}
    3,                       !- Lighting Control Type
    0,                       !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
    22,                      !- Maximum Allowable Discomfort Glare Index
    0.3,                     !- Minimum Input Power Fraction for Continuous Dimming Control
    0.2,                     !- Minimum Light Output Fraction for Continuous Dimming Control
    0,                       !- Number of Stepped Control Steps
    1;                       !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

Daylighting:Controls,
    S_1st,                   !- Zone Name
    1,                       !- Total Daylighting Reference Points
```

```
   18,                              !- X-Coordinate of First Reference Point {m}
   5,                               !- Y-Coordinate of First Reference Point {m}
   0.8,                             !- Z-Coordinate of First Reference Point {m}
   ,                                !- X-Coordinate of Second Reference Point {m}
   ,                                !- Y-Coordinate of Second Reference Point {m}
   ,                                !- Z-Coordinate of Second Reference Point {m}
   1,                               !- Fraction of Zone Controlled by First Reference Point
   ,                                !- Fraction of Zone Controlled by Second Reference Point
   500,                             !- Illuminance Setpoint at First Reference Point {lux}
   ,                                !- Illuminance Setpoint at Second Reference Point {lux}
   3,                               !- Lighting Control Type
   180,                             !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
   22,                              !- Maximum Allowable Discomfort Glare Index
   0.3,                             !- Minimum Input Power Fraction for Continuous Dimming Control
   0.2,                             !- Minimum Light Output Fraction for Continuous Dimming Control
   0,                               !- Number of Stepped Control Steps
   1;                               !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

Daylighting:Controls,
   S_2nd,                           !- Zone Name
   1,                               !- Total Daylighting Reference Points
   18,                              !- X-Coordinate of First Reference Point {m}
   5,                               !- Y-Coordinate of First Reference Point {m}
   0.8,                             !- Z-Coordinate of First Reference Point {m}
   ,                                !- X-Coordinate of Second Reference Point {m}
   ,                                !- Y-Coordinate of Second Reference Point {m}
   ,                                !- Z-Coordinate of Second Reference Point {m}
   1,                               !- Fraction of Zone Controlled by First Reference Point
   ,                                !- Fraction of Zone Controlled by Second Reference Point
   500,                             !- Illuminance Setpoint at First Reference Point {lux}
   ,                                !- Illuminance Setpoint at Second Reference Point {lux}
   3,                               !- Lighting Control Type
   180,                             !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
   22,                              !- Maximum Allowable Discomfort Glare Index
   0.3,                             !- Minimum Input Power Fraction for Continuous Dimming Control
   0.2,                             !- Minimum Light Output Fraction for Continuous Dimming Control
   0,                               !- Number of Stepped Control Steps
   1;                               !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

Daylighting:Controls,
   S_3rd,                           !- Zone Name
   1,                               !- Total Daylighting Reference Points
   18,                              !- X-Coordinate of First Reference Point {m}
   5,                               !- Y-Coordinate of First Reference Point {m}
   0.8,                             !- Z-Coordinate of First Reference Point {m}
   ,                                !- X-Coordinate of Second Reference Point {m}
   ,                                !- Y-Coordinate of Second Reference Point {m}
   ,                                !- Z-Coordinate of Second Reference Point {m}
   1,                               !- Fraction of Zone Controlled by First Reference Point
   ,                                !- Fraction of Zone Controlled by Second Reference Point
   500,                             !- Illuminance Setpoint at First Reference Point {lux}
   ,                                !- Illuminance Setpoint at Second Reference Point {lux}
   3,                               !- Lighting Control Type
   180,                             !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
   22,                              !- Maximum Allowable Discomfort Glare Index
```

```
    0.3,                     !- Minimum Input Power Fraction for Continuous Dimming Control
    0.2,                     !- Minimum Light Output Fraction for Continuous Dimming Control
    0,                       !- Number of Stepped Control Steps
    1;                       !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

Daylighting:Controls,
    S_4th,                   !- Zone Name
    1,                       !- Total Daylighting Reference Points
    18,                      !- X-Coordinate of First Reference Point {m}
    5,                       !- Y-Coordinate of First Reference Point {m}
    0.8,                     !- Z-Coordinate of First Reference Point {m}
    ,                        !- X-Coordinate of Second Reference Point {m}
    ,                        !- Y-Coordinate of Second Reference Point {m}
    ,                        !- Z-Coordinate of Second Reference Point {m}
    1,                       !- Fraction of Zone Controlled by First Reference Point
    ,                        !- Fraction of Zone Controlled by Second Reference Point
    500,                     !- Illuminance Setpoint at First Reference Point {lux}
    ,                        !- Illuminance Setpoint at Second Reference Point {lux}
    3,                       !- Lighting Control Type
    180,                     !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
    22,                      !- Maximum Allowable Discomfort Glare Index
    0.3,                     !- Minimum Input Power Fraction for Continuous Dimming Control
    0.2,                     !- Minimum Light Output Fraction for Continuous Dimming Control
    0,                       !- Number of Stepped Control Steps
    1;                       !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

Daylighting:Controls,
    S_ground,                !- Zone Name
    1,                       !- Total Daylighting Reference Points
    18,                      !- X-Coordinate of First Reference Point {m}
    5,                       !- Y-Coordinate of First Reference Point {m}
    0.8,                     !- Z-Coordinate of First Reference Point {m}
    ,                        !- X-Coordinate of Second Reference Point {m}
    ,                        !- Y-Coordinate of Second Reference Point {m}
    ,                        !- Z-Coordinate of Second Reference Point {m}
    1,                       !- Fraction of Zone Controlled by First Reference Point
    ,                        !- Fraction of Zone Controlled by Second Reference Point
    500,                     !- Illuminance Setpoint at First Reference Point {lux}
    ,                        !- Illuminance Setpoint at Second Reference Point {lux}
    3,                       !- Lighting Control Type
    180,                     !- Glare Calculation Azimuth Angle of View Direction Clockwise
from Zone y-Axis {deg}
    22,                      !- Maximum Allowable Discomfort Glare Index
    0.3,                     !- Minimum Input Power Fraction for Continuous Dimming Control
    0.2,                     !- Minimum Light Output Fraction for Continuous Dimming Control
    0,                       !- Number of Stepped Control Steps
    1;                       !- Probability Lighting will be Reset When Needed in Manual
Stepped Control

!-   ==========  ALL OBJECTS IN CLASS: ZONEINFILTRATION:DESIGNFLOWRATE ==========

ZoneInfiltration:DesignFlowRate,
    inf1,                    !- Name
    allZonesExceptAtrium,    !- Zone or ZoneList Name
    Constant,                !- Schedule Name
    AirChanges/Hour,         !- Design Flow Rate Calculation Method
    ,                        !- Design Flow Rate {m3/s}
```

```
    ,                                      !- Flow per Zone Floor Area {m3/s-m2}
    ,                                      !- Flow per Exterior Surface Area {m3/s-m2}
    0.5,                                   !- Air Changes per Hour {1/hr}
    ,                                      !- Constant Term Coefficient
    ,                                      !- Temperature Term Coefficient
    ,                                      !- Velocity Term Coefficient
    ;                                      !- Velocity Squared Term Coefficient

ZoneInfiltration:DesignFlowRate,
    inf2,                                  !- Name
    atrium_zone,                           !- Zone or ZoneList Name
    Constant,                              !- Schedule Name
    AirChanges/Hour,                       !- Design Flow Rate Calculation Method
    ,                                      !- Design Flow Rate {m3/s}
    ,                                      !- Flow per Zone Floor Area {m3/s-m2}
    ,                                      !- Flow per Exterior Surface Area {m3/s-m2}
    2,                                     !- Air Changes per Hour {1/hr}
    ,                                      !- Constant Term Coefficient
    ,                                      !- Temperature Term Coefficient
    ,                                      !- Velocity Term Coefficient
    ;                                      !- Velocity Squared Term Coefficient


!-   ===========  ALL OBJECTS IN CLASS: ZONEVENTILATION:DESIGNFLOWRATE ===========

ZoneVentilation:DesignFlowRate,
    DailyVentilation,                      !- Name
    Offices,                               !- Zone or ZoneList Name
    Day Ventilation,                       !- Schedule Name
    AirChanges/Hour,                       !- Design Flow Rate Calculation Method
    ,                                      !- Design Flow Rate {m3/s}
    ,                                      !- Flow Rate per Zone Floor Area {m3/s-m2}
    ,                                      !- Flow Rate per Person {m3/s-person}
    1,                                     !- Air Changes per Hour {1/hr}
    Natural,                               !- Ventilation Type
    ,                                      !- Fan Pressure Rise {Pa}
    1,                                     !- Fan Total Efficiency
    1,                                     !- Constant Term Coefficient
    ,                                      !- Temperature Term Coefficient
    ,                                      !- Velocity Term Coefficient
    ,                                      !- Velocity Squared Term Coefficient
    -100,                                  !- Minimum Indoor Temperature {C}
    ,                                      !- Minimum Indoor Temperature Schedule Name
    100,                                   !- Maximum Indoor Temperature {C}
    ,                                      !- Maximum Indoor Temperature Schedule Name
    -100,                                  !- Delta Temperature {deltaC}
    ,                                      !- Delta Temperature Schedule Name
    -100,                                  !- Minimum Outdoor Temperature {C}
    ,                                      !- Minimum Outdoor Temperature Schedule Name
    100,                                   !- Maximum Outdoor Temperature {C}
    ,                                      !- Maximum Outdoor Temperature Schedule Name
    40;                                    !- Maximum Wind Speed {m/s}

ZoneVentilation:DesignFlowRate,
    OfficeNightVent,                       !- Name
    Offices,                               !- Zone or ZoneList Name
    Night Ventilation,                     !- Schedule Name
    AirChanges/Hour,                       !- Design Flow Rate Calculation Method
    ,                                      !- Design Flow Rate {m3/s}
    ,                                      !- Flow Rate per Zone Floor Area {m3/s-m2}
```

```
    ,                                   !- Flow Rate per Person {m3/s-person}
    4,                                  !- Air Changes per Hour {1/hr}
    Natural,                            !- Ventilation Type
    ,                                   !- Fan Pressure Rise {Pa}
    1,                                  !- Fan Total Efficiency
    1,                                  !- Constant Term Coefficient
    ,                                   !- Temperature Term Coefficient
    ,                                   !- Velocity Term Coefficient
    ,                                   !- Velocity Squared Term Coefficient
    -100,                               !- Minimum Indoor Temperature {C}
    ,                                   !- Minimum Indoor Temperature Schedule Name
    100,                                !- Maximum Indoor Temperature {C}
    ,                                   !- Maximum Indoor Temperature Schedule Name
    -100,                               !- Delta Temperature {deltaC}
    ,                                   !- Delta Temperature Schedule Name
    -100,                               !- Minimum Outdoor Temperature {C}
    ,                                   !- Minimum Outdoor Temperature Schedule Name
    100,                                !- Maximum Outdoor Temperature {C}
    ,                                   !- Maximum Outdoor Temperature Schedule Name
    40;                                 !- Maximum Wind Speed {m/s}
!
!
!-   ===========  ALL OBJECTS IN CLASS: HVACTEMPLATE:THERMOSTAT ===========
!
! HVACTemplate:Thermostat,
!    thermostat1,                       !- Name
!    ,                                  !- Heating Setpoint Schedule Name
!    -100,                              !- Constant Heating Setpoint {C}
!    CoolingSchedule,                   !- Cooling Setpoint Schedule Name
!    26;                                !- Constant Cooling Setpoint {C}
!
!
!-   ======= ALL OBJECTS IN CLASS: HVACTEMPLATE:ZONE:IDEALLOADSAIRSYSTEM ========
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    N_1st,                             !- Zone Name
!    thermostat1,                       !- Template Thermostat Name
!    ,                                  !- System Availability Schedule Name
!    ,                                  !- Maximum Heating Supply Air Temperature {C}
!    ,                                  !- Minimum Cooling Supply Air Temperature {C}
!    ,                                  !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                  !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                  !- Heating Limit
!    ,                                  !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                  !- Maximum Sensible Heating Capacity {W}
!    ,                                  !- Cooling Limit
!    ,                                  !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                  !- Maximum Total Cooling Capacity {W}
!    ,                                  !- Heating Availability Schedule Name
!    ,                                  !- Cooling Availability Schedule Name
!    ,                                  !- Dehumidification Control Type
!    ,                                  !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                  !- Dehumidification Setpoint {percent}
!    ,                                  !- Humidification Control Type
!    ,                                  !- Humidification Setpoint {percent}
!    ,                                  !- Outdoor Air Method
!    ,                                  !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                  !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
```

```
!    ,                                   !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                   !- Design Specification Outdoor Air Object Name
!    ;                                   !- Demand Controlled Ventilation Type
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    N_2nd,                              !- Zone Name
!    thermostat1,                        !- Template Thermostat Name
!    ,                                   !- System Availability Schedule Name
!    ,                                   !- Maximum Heating Supply Air Temperature {C}
!    ,                                   !- Minimum Cooling Supply Air Temperature {C}
!    ,                                   !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                   !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                   !- Heating Limit
!    ,                                   !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                   !- Maximum Sensible Heating Capacity {W}
!    ,                                   !- Cooling Limit
!    ,                                   !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                   !- Maximum Total Cooling Capacity {W}
!    ,                                   !- Heating Availability Schedule Name
!    ,                                   !- Cooling Availability Schedule Name
!    ,                                   !- Dehumidification Control Type
!    ,                                   !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                   !- Dehumidification Setpoint {percent}
!    ,                                   !- Humidification Control Type
!    ,                                   !- Humidification Setpoint {percent}
!    ,                                   !- Outdoor Air Method
!    ,                                   !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                   !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
!    ,                                   !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                   !- Design Specification Outdoor Air Object Name
!    ;                                   !- Demand Controlled Ventilation Type
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    N_3rd,                              !- Zone Name
!    thermostat1,                        !- Template Thermostat Name
!    ,                                   !- System Availability Schedule Name
!    ,                                   !- Maximum Heating Supply Air Temperature {C}
!    ,                                   !- Minimum Cooling Supply Air Temperature {C}
!    ,                                   !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                   !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                   !- Heating Limit
!    ,                                   !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                   !- Maximum Sensible Heating Capacity {W}
!    ,                                   !- Cooling Limit
!    ,                                   !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                   !- Maximum Total Cooling Capacity {W}
!    ,                                   !- Heating Availability Schedule Name
!    ,                                   !- Cooling Availability Schedule Name
!    ,                                   !- Dehumidification Control Type
!    ,                                   !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                   !- Dehumidification Setpoint {percent}
!    ,                                   !- Humidification Control Type
!    ,                                   !- Humidification Setpoint {percent}
!    ,                                   !- Outdoor Air Method
!    ,                                   !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                   !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
```

```
!    ,                                        !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                        !- Design Specification Outdoor Air Object Name
!    ;                                        !- Demand Controlled Ventilation Type
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    N_4th,                                   !- Zone Name
!    thermostat1,                             !- Template Thermostat Name
!    ,                                        !- System Availability Schedule Name
!    ,                                        !- Maximum Heating Supply Air Temperature {C}
!    ,                                        !- Minimum Cooling Supply Air Temperature {C}
!    ,                                        !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                        !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                        !- Heating Limit
!    ,                                        !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                        !- Maximum Sensible Heating Capacity {W}
!    ,                                        !- Cooling Limit
!    ,                                        !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                        !- Maximum Total Cooling Capacity {W}
!    ,                                        !- Heating Availability Schedule Name
!    ,                                        !- Cooling Availability Schedule Name
!    ,                                        !- Dehumidification Control Type
!    ,                                        !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                        !- Dehumidification Setpoint {percent}
!    ,                                        !- Humidification Control Type
!    ,                                        !- Humidification Setpoint {percent}
!    ,                                        !- Outdoor Air Method
!    ,                                        !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                        !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
!    ,                                        !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                        !- Design Specification Outdoor Air Object Name
!    ;                                        !- Demand Controlled Ventilation Type
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    N_ground,                                !- Zone Name
!    thermostat1,                             !- Template Thermostat Name
!    ,                                        !- System Availability Schedule Name
!    ,                                        !- Maximum Heating Supply Air Temperature {C}
!    ,                                        !- Minimum Cooling Supply Air Temperature {C}
!    ,                                        !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                        !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                        !- Heating Limit
!    ,                                        !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                        !- Maximum Sensible Heating Capacity {W}
!    ,                                        !- Cooling Limit
!    ,                                        !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                        !- Maximum Total Cooling Capacity {W}
!    ,                                        !- Heating Availability Schedule Name
!    ,                                        !- Cooling Availability Schedule Name
!    ,                                        !- Dehumidification Control Type
!    ,                                        !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                        !- Dehumidification Setpoint {percent}
!    ,                                        !- Humidification Control Type
!    ,                                        !- Humidification Setpoint {percent}
!    ,                                        !- Outdoor Air Method
!    ,                                        !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                        !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
```

```
!    ,                                    !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                    !- Design Specification Outdoor Air Object Name
!    ;                                    !- Demand Controlled Ventilation Type
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    S_1st,                               !- Zone Name
!    thermostat1,                         !- Template Thermostat Name
!    ,                                    !- System Availability Schedule Name
!    ,                                    !- Maximum Heating Supply Air Temperature {C}
!    ,                                    !- Minimum Cooling Supply Air Temperature {C}
!    ,                                    !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                    !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                    !- Heating Limit
!    ,                                    !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                    !- Maximum Sensible Heating Capacity {W}
!    ,                                    !- Cooling Limit
!    ,                                    !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                    !- Maximum Total Cooling Capacity {W}
!    ,                                    !- Heating Availability Schedule Name
!    ,                                    !- Cooling Availability Schedule Name
!    ,                                    !- Dehumidification Control Type
!    ,                                    !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                    !- Dehumidification Setpoint {percent}
!    ,                                    !- Humidification Control Type
!    ,                                    !- Humidification Setpoint {percent}
!    ,                                    !- Outdoor Air Method
!    ,                                    !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                    !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
!    ,                                    !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                    !- Design Specification Outdoor Air Object Name
!    ;                                    !- Demand Controlled Ventilation Type
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    S_2nd,                               !- Zone Name
!    thermostat1,                         !- Template Thermostat Name
!    ,                                    !- System Availability Schedule Name
!    ,                                    !- Maximum Heating Supply Air Temperature {C}
!    ,                                    !- Minimum Cooling Supply Air Temperature {C}
!    ,                                    !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                    !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                    !- Heating Limit
!    ,                                    !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                    !- Maximum Sensible Heating Capacity {W}
!    ,                                    !- Cooling Limit
!    ,                                    !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                    !- Maximum Total Cooling Capacity {W}
!    ,                                    !- Heating Availability Schedule Name
!    ,                                    !- Cooling Availability Schedule Name
!    ,                                    !- Dehumidification Control Type
!    ,                                    !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                    !- Dehumidification Setpoint {percent}
!    ,                                    !- Humidification Control Type
!    ,                                    !- Humidification Setpoint {percent}
!    ,                                    !- Outdoor Air Method
!    ,                                    !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                    !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
```

```
!    ,                                    !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                    !- Design Specification Outdoor Air Object Name
!    ;                                    !- Demand Controlled Ventilation Type
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    S_3rd,                               !- Zone Name
!    thermostat1,                         !- Template Thermostat Name
!    ,                                    !- System Availability Schedule Name
!    ,                                    !- Maximum Heating Supply Air Temperature {C}
!    ,                                    !- Minimum Cooling Supply Air Temperature {C}
!    ,                                    !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                    !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                    !- Heating Limit
!    ,                                    !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                    !- Maximum Sensible Heating Capacity {W}
!    ,                                    !- Cooling Limit
!    ,                                    !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                    !- Maximum Total Cooling Capacity {W}
!    ,                                    !- Heating Availability Schedule Name
!    ,                                    !- Cooling Availability Schedule Name
!    ,                                    !- Dehumidification Control Type
!    ,                                    !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                    !- Dehumidification Setpoint {percent}
!    ,                                    !- Humidification Control Type
!    ,                                    !- Humidification Setpoint {percent}
!    ,                                    !- Outdoor Air Method
!    ,                                    !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                    !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
!    ,                                    !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                    !- Design Specification Outdoor Air Object Name
!    ;                                    !- Demand Controlled Ventilation Type
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    S_4th,                               !- Zone Name
!    thermostat1,                         !- Template Thermostat Name
!    ,                                    !- System Availability Schedule Name
!    ,                                    !- Maximum Heating Supply Air Temperature {C}
!    ,                                    !- Minimum Cooling Supply Air Temperature {C}
!    ,                                    !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                    !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                    !- Heating Limit
!    ,                                    !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                    !- Maximum Sensible Heating Capacity {W}
!    ,                                    !- Cooling Limit
!    ,                                    !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                    !- Maximum Total Cooling Capacity {W}
!    ,                                    !- Heating Availability Schedule Name
!    ,                                    !- Cooling Availability Schedule Name
!    ,                                    !- Dehumidification Control Type
!    ,                                    !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                    !- Dehumidification Setpoint {percent}
!    ,                                    !- Humidification Control Type
!    ,                                    !- Humidification Setpoint {percent}
!    ,                                    !- Outdoor Air Method
!    ,                                    !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                    !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
```

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!    ,                                   !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                   !- Design Specification Outdoor Air Object Name
!    ;                                   !- Demand Controlled Ventilation Type
!
! HVACTemplate:Zone:IdealLoadsAirSystem,
!    S_ground,                           !- Zone Name
!    thermostat1,                        !- Template Thermostat Name
!    ,                                   !- System Availability Schedule Name
!    ,                                   !- Maximum Heating Supply Air Temperature {C}
!    ,                                   !- Minimum Cooling Supply Air Temperature {C}
!    ,                                   !- Maximum Heating Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                   !- Minimum Cooling Supply Air Humidity Ratio
{kgWater/kgDryAir}
!    ,                                   !- Heating Limit
!    ,                                   !- Maximum Heating Air Flow Rate {m3/s}
!    ,                                   !- Maximum Sensible Heating Capacity {W}
!    ,                                   !- Cooling Limit
!    ,                                   !- Maximum Cooling Air Flow Rate {m3/s}
!    ,                                   !- Maximum Total Cooling Capacity {W}
!    ,                                   !- Heating Availability Schedule Name
!    ,                                   !- Cooling Availability Schedule Name
!    ,                                   !- Dehumidification Control Type
!    ,                                   !- Cooling Sensible Heat Ratio {dimensionless}
!    ,                                   !- Dehumidification Setpoint {percent}
!    ,                                   !- Humidification Control Type
!    ,                                   !- Humidification Setpoint {percent}
!    ,                                   !- Outdoor Air Method
!    ,                                   !- Outdoor Air Flow Rate per Person {m3/s}
!    ,                                   !- Outdoor Air Flow Rate per Zone Floor Area {m3/s-m2}
!    ,                                   !- Outdoor Air Flow Rate per Zone {m3/s}
!    ,                                   !- Design Specification Outdoor Air Object Name
!    ;                                   !- Demand Controlled Ventilation Type
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