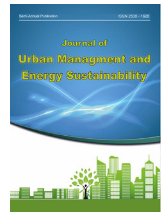
International Journal of Urban Management and Energy Sustainability (JUMES)

Homepage: http://www.ijumes.com



CASE STUDY RESEARCH PAPER

Thermal performance of smart canopy and natural ventilation in atriums in Tehran

Ahmadreza Keshtkar Ghalati[1*] , Maryam Farahkhiz[2]

1 Department of Architecture, Faculty of Art and Architecture, Kharazmi University, Tehran, Iran*
2 Department of Architecture, Faculty of Art and Architecture, Rassam Institute of Higher Education, Karaj, Iran

ARTICLE INFO

Article History:
Received 2024-05-27
Revised 2025-01-21
Accepted 2025-06-11

Keywords:
Atrium, Daylight Performance, Energy Consumption, Intelligent Canopy, Natural Ventilation.

ABSTRACT

Atriums are central glass-roofed spaces that are usually considered closed and controlled spaces in multi-story buildings. This research aims to compare the effectiveness of adding an intelligent canopy and natural ventilation in the efficiency of atriums. For this purpose, an atrium has been selected in the educational space in Tehran. In this regard, Design Builder software has been simulated and EnergyPlus engine has been used for calculations. The results showed that the energy consumption in the building with the atrium in the form of a circular plan and a flat cap is equal to 207.1 (MWh). Also, with the integration of the smart canopy in the atrium, the energy consumption of the building was 201.33 (MWh), which decreased by 5.77 (MWh). This means that with the integration of the smart canopy in the atrium, the energy consumption of the building has been reduced by about 3%. In the conditions of using natural ventilation, the energy consumption of the building was 173.39 (MWh), compared to the integration of the canopy without natural ventilation, the energy consumption of the building decreased to a significant amount of 27.94 (MWh), which seems to be a proper option considering the low cost of using natural ventilation.

DOI: 10.22034/ijumes.2025.2030424.1218

Running Title: Thermal performance of smart canopy and natural ventilation in atriums

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
70	07	14

*Corresponding Author:
Email: *a.keshtkar@khu.ac.ir*
Phone: +989123188201
ORCID: https://orcid.org/0000-0001-6916-380x

INTRODUCTION

The development process of human life after the industrial revolution has led to an increase in the use of various types of energy, most of which are non-renewable. Optimum use of energy resources, according to architectural design guidelines, is a priority to contribute to the sustainability of contemporary cities (Verma, 2017; Danesh Pajouh et al., 2020; Keshtkar Ghalati & Amiri, 2022). In general, the energy demand for building lighting is about 30-40% (Chow et al., 2013; Eiraji & Elmkhah, 2021). In dense urban areas, buildings with wide plans have high energy costs to provide permanent lighting (Rezaei et al., 2019; Esquivias et al., 2011). In addition, lighting spaces have a transitional role in the organization of spaces, and at the same time, they improve the quality of the interior space (Pitts & Bin Saleh, 2007; Keshtkar Ghalati & Ahmadian, 2023; Keshtkar Ghalati & Taromsari, 2023). As a bioclimatic strategy, atriums can reduce the cost of artificial lighting and improve the energy efficiency of the building by receiving natural light and controlling the internal temperature (Danielski et al., 2016; Mahlabani et al., 2019). With the proper design of the atrium ventilation system, the energy consumption of the building can be reduced. On the other hand, an atrium with a poor design causes a loss of thermal comfort and increases the energy consumption for cooling the building. In these cases, an energy-modulating technology may be considered a passive cooling system (Hussain & Oosthuizen, 2011; Karamouzian et al., 2021). A ventilation system can be used as a mechanical and Natural cooling system or a combination of both at different conditions (Hussain & Oosthuizen, 2012; Hessari & Seyf shojaee, 2021). Today, automatic and intelligent systems are considered effective tools for saving energy and building. The intelligent atrium sunshade systems include manual and automatic control types.

This research aims to compare the effectiveness of adding an intelligent canopy and natural ventilation in the efficiency of atriums. For this purpose, an atrium has been selected in the educational space in Tehran. To calculate the energy consumption, the amount of energy consumed for cooling, heating, and general lighting of an educational building in Tehran has been used. Light spaces include open or closed spaces in the building, which are mainly used to solve the problem of light in large-plan buildings. Atriums are central glass-roofed spaces that are usually considered closed and controlled spaces in multi-story buildings. For the proper design of the atrium in such a way that natural light spreads in the space without energy loss, it is necessary to identify the variables affecting the thermal performance, the most important of which include the geometry of the atrium, the angle of the sun, the type of covering, the form of the roof, and the percentage of the window-to-wall ratio (Littlefair, 2002; Sharples & Lash, 2006). Various studies have evaluated these variables using scale models, analytical equations, field measurements, and software simulation (Omrany et al., 2020). Atriums, as the passive light-absorbing solution, may cause the space to overheat in hot seasons and increase the cost of cooling if there is no ventilation and shading (Cheshmehnour et al., 2018). Therefore, atriums should be measured with standards and patterns of energy consumption reduction, otherwise, they will impose a significant thermal load on the building. (Tab. 1).

The main characteristics of atriums can be categorized into three parts:

(1) Skylight system (skylight height, shape, scale).
(2) Form of the atrium (well height, shape, scale).
(3) Surrounding interface (corridors, windows, etc.).

Many studies have investigated the daylighting of atriums and have shown that the lighting performance of an atrium largely depends on its geometrical characteristics (Tab. 2).

As shown in Table 2, most of the research carried out is in the field of administrative, commercial, and educational users, which is due to the amount of energy consumption and the load

Table 1: Types of light-emitting spaces

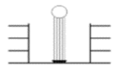
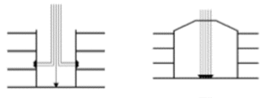
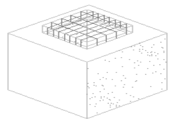
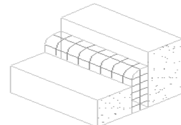
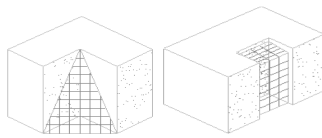
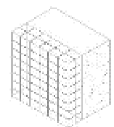
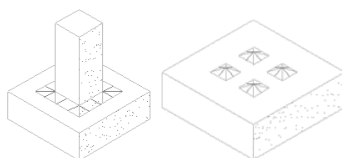
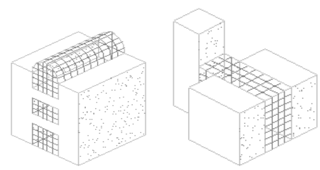
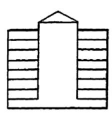
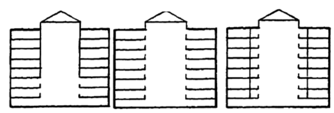
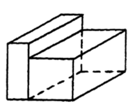
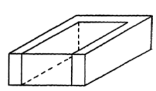
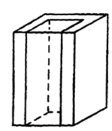
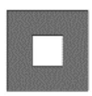
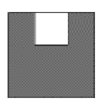
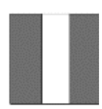
Reference	Base	Types			
(Farahkhiz, & Kashtkar Ghalati, 2021)	Section				
		Open Area	Atrium	Light Wells	
(Eqbali et al., 2016)	Form				
		Central		Linear	
	connection				
		Enclosed		Unenclosed	
	Expanse				
		Continuous and Individual Central Form		A Linear Form Connecting Buildings	
(Bajracharya, 1997)	Function				
		Close	Open		
(Yoshino et al., 1995)	Dimensions				
		Adjunct	Short and Wide	High Tower	
(Bendar, 1986)	Form				

Table 2: Review of the atrium daylight studies

Number	Author(s)	Function	Indicators and objectives
1	(Du & Sharples, 2012)	-	Atrium scale (dimension ratio in section 2 and dimension ratio in plan), height; Direction of surface reflection
2	(Kazemzadeh et al., 2014)	Official	Atrium roof form and skylight height
3	(Mohsenin & Hu, 2015)	-	Atrium scale (well index), skylight roof form
4	(Ghasemi et al., 2016)	Official	Atrium scale (dimension ratio in section and dimension ratio in plan); Skylight ceiling height, number of floors
5	(Nasrollahi et al., 2016)	Official	Peripheral effects of the atrium
6	(Tourani et al., 2016)	Educational	The inclination angles of the atrium based on the orientation towards the solar diagram
7	(Sudan et al., 2017)	-	Atrium scale (well index and well depth index), surface reflection
8	(Cheshmehnour et al., 2018)	Official	Spatial positioning
8	(Li et al., 2019)	Commercial	Atrium form (dimension scale in the plan), building height, skylight roof size
9	(Taghipour Mizani et al., 2019)	Educational	Changes in the shape of the roof, the dimensions of the atrium plan and the surface of the roof glass
10	(Zeinolabdinzadeh et al., 2020)	Commercial	Type of atrium skylight glass
11	(Rastegari et al., 2021)	Official	Atrium scale (width to height ratio)
12	(Wu et al., 2021)	Library	Atrium scale (dimension ratio in section and dimension ratio in plan), height of atrium
113	(Zeinolabdinzadeh et al., 2021)	Commercial	The shape and height of the skylight ceiling
14	(Dong et al., 2022)	Commercial	The shape and number of atriums, the angle and deviation 6, the ratio of the skylight height of the ceiling
15	(Xue & Liu, 2022)	Commercial	Form and height of the atrium
16	(Ibrahim et al., 2022)	Educational	Atrium form
17	(Piraei et al., 2022)	Cultural Heritage	Form and number of atria

of their use during the day. The research about the form of the atrium has mainly focused on the dimensions of the plan and height. In addition, most of this research is related to the scale of the atrium (ratio of the dimensions in the section and the ratio of the dimensions in the plan), the height of the skylight ceiling, the form of the atrium (the scale of the dimensions in the plan) and the size of the skylight ceiling. A natural ventilation system may not support the building's thermal comfort range as well as a mechanical ventilation system (De Dear & Gail, 2002). However, natural ventilation can improve a building's energy efficiency by up to 60% (Chan et al., 2010).

There are four types of the atrium as shown in Figure 1 below. Each shape of the vestibule has its advantage according to the environmental conditions, ventilation, and daylight performance. In cold conditions, the efficiency of atriums is obvious as they act as solar space (Hawkes & Baker, 1983; Nelson, 1984). Although, in hot seasons, they increase the temperature of the building and destroy the thermal comfort conditions (Douvlou & Pitts, 2001; Edmonds & Greenup, 2002). Providing comfortable conditions in glass buildings without considering a complex system becomes very uncomfortable (ASHRAE, 2009). However, the high heat of the atrium can be removed by natural ventilation.

The ambient air flows into the floors through the windows, and after being heated, it goes into the atrium and exits through the vent above.

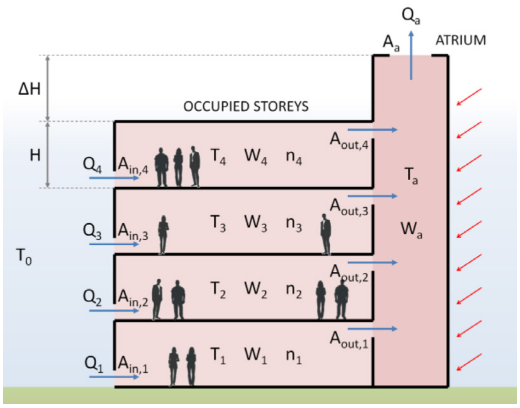


Figure 1: Schematic of a naturally ventilated atrium (Hunt & Acred, 2013)

In addition to aesthetic benefits, atriums provide daylight in adjacent indoor spaces and increase social interactions (Pfafferott et al., 2004). In addition, atriums provide fresh air in the entire building by creating air circulation between different floors (Laouadi et al., 2002). This architectural element can be considered an environmental technology, especially in modern buildings with glass walls, where environmental potentials are ignored (Encinas, 2004). Despite the excessive solar heat gain from the large glass walls (Göçer et al., 2006), the energy consumption of this type of building with optimal design is estimated to be less than 150 kWh/m2 (Voeltzel et al., 2001). Natural ventilation in such buildings provides thermal comfort without using mechanical systems such as heating, ventilation, and air conditioning (HVAC) (Thirugnanasambandam et al., 2010). Therefore, more than 60% of the total energy consumption of the building is saved (Chan et al., 2010).

Atriums and courtyards improve the quality of adjacent indoor spaces (Olsen & Chen, 2003) by providing natural ventilation and sunlight (Khan et al., 2008). In terms of energy efficiency, although in tall buildings, atriums are more efficient (Aldawoud & Clark, 2008), in low-rise houses, courtyards, like atriums, help to balance the building's energy consumption (Taleghani et al., 2014). Figure 3 shows a list of variables, ventilation techniques and other design parameters of atriums.

Natural ventilation in the building creates acceptable environmental comfort conditions. Ventilation in the building occurs due to the pressure difference in the internal and external environments, and as a result, it causes the air to move throughout the building. Increasing the temperature difference inside the building and the outside environment can increase the passive ventilation of the building. Because the stack effect relies on internal heat, it is more controllable and predictable than wind flow (Lomas, 2007). While wind power is more effective, but less predictable and less controllable. In areas where the difference between outside and inside temperatures is small, the flow is considered the main factor of ventilation (Gan, 2010).

When the ambient air temperature is higher than 35 degrees Celsius, natural ventilation should not be used and the penetration of hot air inside should be prevented (Wang et al.,

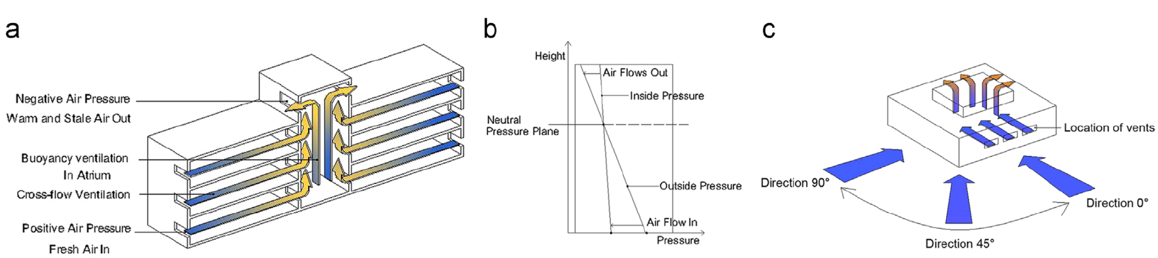


Figure 2: Natural ventilation flow through the atrium (Moosavi et al., 2014)

2009). Thermal layering in atriums mainly occurs by solar radiation on skylights (Pan et al., 2010). Preventing the reception of solar radiation can reduce up to 75% of the heat absorbed by the building (Rojas, 2013). The use of internal curtains and external canopies can be effective in this regard (Abdullah et al., 2009).

Although the force of the wind flow can help the ventilation, but in some cases, it may interfere with the ventilation of the atriums. When the wind enters in the direction opposite to the vertical force of ventilation, it causes the reverse downward flow of air in the atrium (Ray et al., 2014). Today, automatic and intelligent systems are considered effective tools for saving energy and building. The intelligent atrium sunshade systems include manual and automatic control types.

Intelligent or automatic control systems allow each sunshade panel to be moved individually. The temperature curve created in the Design-Builder software is the most important algorithm of the intelligent control system, which enables the system to control the temperature of the atrium by determining the opening value of the solar panels.

MATERIALS AND METHODS

The aim of this study is to compare the effect of intelligent canopy and natural ventilation on the energy performance of the atrium in educational spaces. For this purpose, the modeling method has been used using Design Builder software to simulate and analyze the data, as well as the Energy Plus engine for calculations. According to the type and method of research, the independent variables include the change in the use of ventilation technology and intelligent canopy, and the dependent variables include the amount of thermal absorption and annual energy consumption (MWh) as well as the amount of thermal comfort. The materials of components are considered fixed in calculations. In the process of simulation, all the specifications: including the number of people and equipment, schedule, performance, and properties of materials and materials are modeled according to ASHREA standards and national building regulations.

The study sample is located in District 7, Region 2 of Tehran. To the north of the site is Iran Zamin Street, to the west is Khovardin Boulevard, and to the southwest is San'at Square (Figure 6).

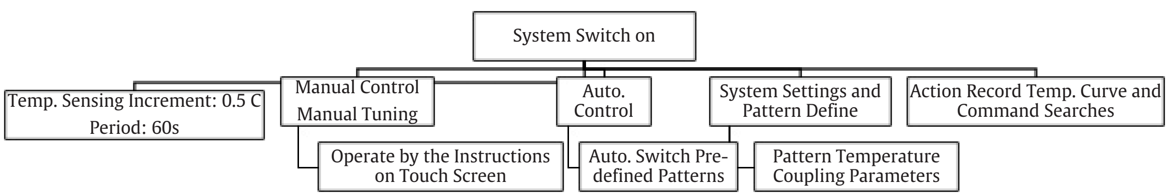


Figure 3: Intelligent sunshade control system process (Ni et al., 2017)

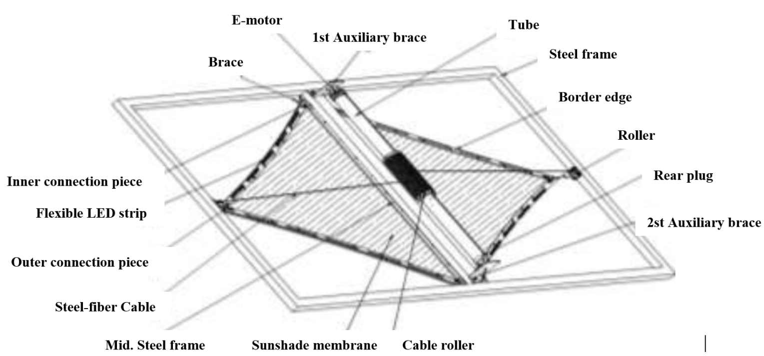


Figure 4: Tech. Details of the typical sunshade panel (Ni et al., 2017)

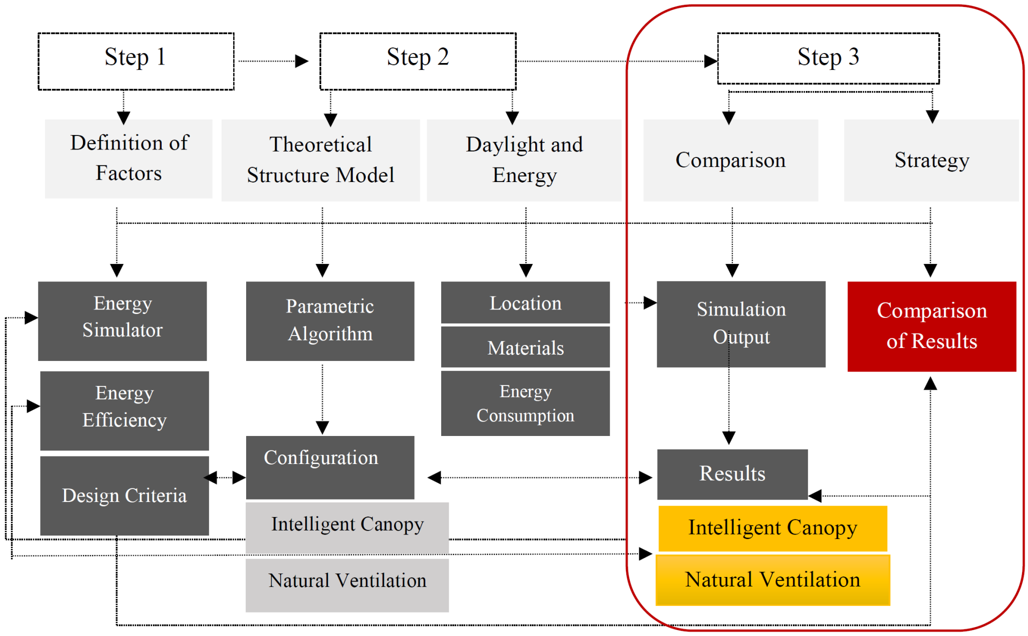


Figure 5: Research framework

Figure 6: The basic plan

This location was chosen due to its distinctive urban features. The variety in the size and orientation of these atriums provides a comprehensive understanding of the thermal performance of smart canopies and natural ventilation systems under diverse conditions, making it an ideal setting for this study.

A case example is a one-story educational building in Tehran, where educational spaces are arranged around it and the dimensions of the plans are considered to have the same area (Figure 7).

The input data of the software includes information related to the location and climatic

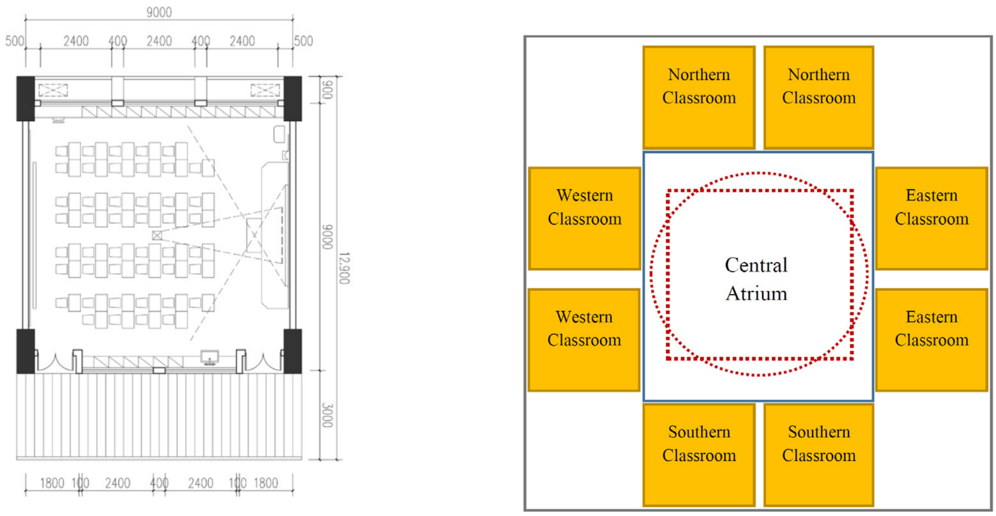


Figure 7: The basic plan

conditions of Tehran city in terms of latitude and longitude. These data also include dry bulb temperature, humidity, dew point temperature, wind speed and direction, air pressure and the amount of solar radiation energy (W/m2). All thermal zones and their characteristics such as usage schedule, number of occupants, lighting system, and equipment are determined based on ASHREA standards. The input data of the software includes the number of people in each class, operating hours, students' coverage level, students' activity level, heating regulation temperature, cooling regulation temperature, lighting level, coefficient of performance of the cooling and heating system, coefficient Heat transfer of external wall, roof, and window, the amount of air penetration, and natural ventilation rate. (Tab. 3).

Table 3: Input Data (ASHRAE, 2009)

Data	Number/ amount	Data	Number/ amount
The number of people in each class	35 people	Cooling Coefficient of Performance (COP)	0.5
Operating hours	8:00-13:00	Heating Coefficient of Performance (COP)	0.6
Students' coverage level	0.75 CLO	Heat Transfer Coefficient of the External Wall	1.9 W/m2K
The level of students' activity	0.9 met	Heat Transfer Coefficient of the Roof	0.43 W/m2K
Heating regulation temperature	22 °C	Heat Transfer Coefficient of the Window	2,7 W/m2K
The temperature of the cooling system	27°C	Air Penetration Rate	1,8 ACH
Light level	300 Lux	Natural ventilation rate	3 ACH

DISCUSSION AND FINDINGS

In the first step of the research, the circular plan of the atrium including the cylindrical skylight is simulated and the energy consumption of the building is calculated. (Tab. 4).

Table 4: Building with a circular plan and cylindrical skylight

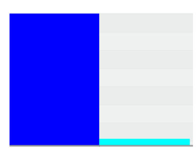
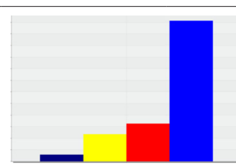
Energy		Amount
Fuel total	Gas MWh	40.70
	Electricity MWh	174.80
Fuel break down	Heating MWh	40.70
	Cooling MWh	125.85
Internal gains + solar	Exterior MWh	213.78
Co2 production	kg	113.56

The amount of heat absorbed by the building includes different parts: The first part is the amount of heat that is created through artificial lighting. The second part is the energy consumed by equipment such as computers, etc. The second part is the energy consumed by equipment such as computers, etc. Receiving energy from external windows is the amount of heating that is absorbed in the building through the sun's radiation on the windows. The next two parts are the amount of heating requirement and the amount of cooling requirement, and the last component is related to latent heat. The energy received from the exterior windows is the amount of heating absorbed into the building through radiation to the windows. Energy consumption is evaluated separately. This energy is consumed by equipment, lighting, heating, cooling, and hot water of the building. In the atrium in the form of a circle and a cylindrical cap, the amount of heating that is absorbed through the sunlight on the windows in the building is equal to 213.78 megawatt hours. In a circular atrium with a cylindrical Skylight cap, the amount of heating absorbed through the sunlight on the windows in the building is 213.78 (MWh).

To check the validity of simulation software, different methods have been introduced, which are classified into three categories: analytical, comparative, and experimental (Zomorrodian & Tahsildoust, 2014). Among the reliability studies of energy software, experimental methods and comparisons are the most common reliability studies. In this research for validation, the results of two building energy modeling software, Design Builder and Energy Plus, have been compared. (Tab. 5).

According to the obtained results, the results obtained from the two software are not much different and the total annual energy consumption is about 7%, which is an acceptable number. Also, regardless of the building use type, the software results' generalizability can be generalized to compare the types of plans and the form of skylight caps. In addition, in order to validate the results of this research, the findings of similar studies are mentioned. (Tab. 6).

Table 5: Energy-Plus Output: The total energy of the building, separated by annual and monthly energy, in the atrium with a cylindrical skylight canopy

Energy Plus Output		Fuel Totals- Tehran Building		
Fuel (MWh)	180			
	160			
	140			
	120			
	100			
	80			
	60			
	40			
Electricity (MWh)		■	180.33	
Gas (MWh)		■	42.50	
Energy Plus Output		Fuel Breakdown- Tehran Building		
Fuel (MWh)	120			
	100			
	80			
	60			
	40			
	20			
Room Electricity (MWh)			■	15.74
Lighting (MWh)			■	33.37
Heating (Gas) (MWh)			■	42.50
Cooling	(Electricity)	(MWh)	■	131.22

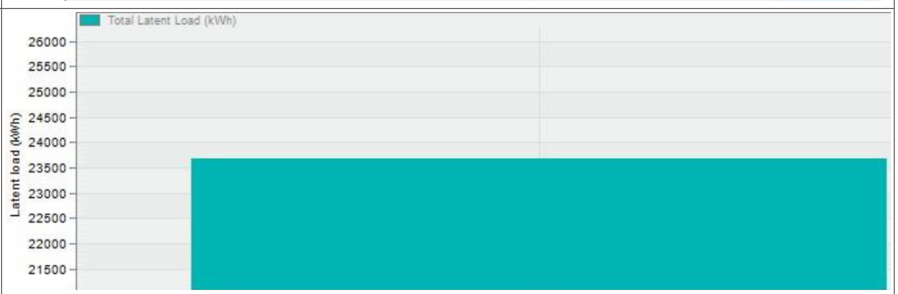
<table>
<tr><td colspan="2">Energy Plus Output</td><td colspan="2">Comfort- Tehran Building</td></tr>
<tr><td>Temperature (°C)</td><td>22
21
20
19
18
17</td><td colspan="2"></td></tr>
<tr><td colspan="2">Air Temperature (°C)</td><td>■</td><td>21.37</td></tr>
<tr><td colspan="2">Radiant Temperature (°C)</td><td>■</td><td>22.68</td></tr>
<tr><td colspan="2">Operative Temperature (°C)</td><td>■</td><td>22.03</td></tr>
<tr><td colspan="2">Outside Dry-Bulb Temperature(°C)</td><td>■</td><td>17.27</td></tr>
<tr><td colspan="2">Energy Plus Output</td><td colspan="2">Internal Gains +Solar</td></tr>
<tr><td>Heat Balance (MWh)</td><td colspan="3">
</td></tr>
<tr><td>Latent Load (KWh)</td><td colspan="3">
</td></tr>
<tr><td colspan="2">General Lighting (MWh)</td><td>■</td><td>33.26</td></tr>
<tr><td colspan="2">Computer + Equip (MWh)</td><td>■</td><td>15.68</td></tr>
<tr><td colspan="2">Occupancy (MWh)</td><td>■</td><td>48.83</td></tr>
<tr><td colspan="2">Solar Gains Interior Windows (MWh)</td><td>■</td><td>26.42</td></tr>
<tr><td colspan="2">Solar Gains Exterior Windows (MWh)</td><td>■</td><td>213.78</td></tr>
<tr><td colspan="2">Zone Sensible Heating (MWh</td><td>■</td><td>26.74</td></tr>
<tr><td colspan="2">Zone Sensible Cooling (MWh</td><td>■</td><td>-223.83</td></tr>
<tr><td colspan="2">Total Latent Load (KWh)</td><td>■</td><td>23680.85</td></tr>
</table>

Table 7 shows the Thermal absorption of the building annually and monthly in the atrium with a cylindrical skylight cap and an intelligent canopy. The data in the table is based on the output of Energy Plus. In this table, energy consumption is shown by general lighting (MWh), computer equipment (MWh), occupancy (MWh), solar gains interior windows (MWh), solar gains exterior windows (MWh), zone sensible heating (MWh), zone sensible cooling (MWh), and total latent load (KWh) in different months of the year. (Tab. 7).

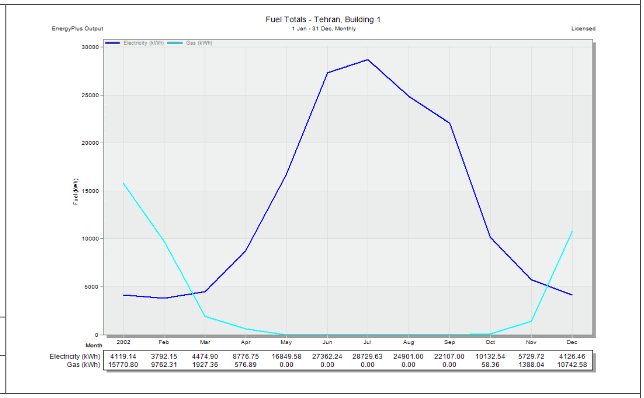
The total amount of energy consumption using the smart canopy is 210.33 (MWh). Then, by integrating the intelligent canopy into the atrium, energy consumption has been reduced by two percent. The energy efficiency impact of integrating the intelligent canopy into circular Atrium, can be seen in Table 8. (Tab. 8).

Table 6: Energy-Plus Output: The total energy of the building, separated by annual and monthly energy, in the atrium with a cylindrical skylight cap, and an intelligent canopy

Fuel Totals- Tehran Building

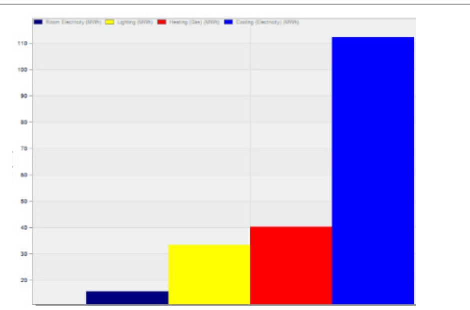
Fuel (MWh)

Electricity (MWh)	■ (blue)	161.10
Gas (MWh)	■ (cyan)	40.23

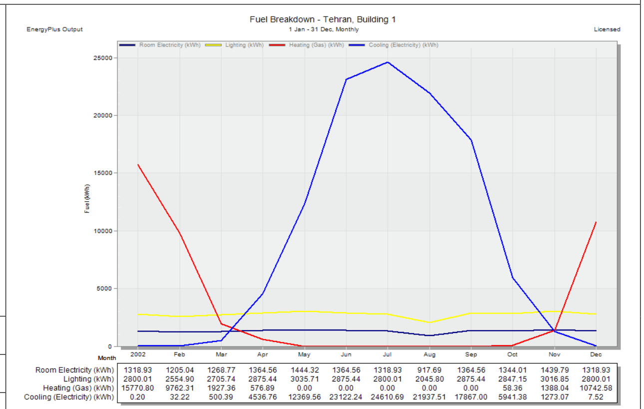


Fuel Breakdown- Tehran Building

Fuel (MWh)



Room Electricity (MWh)	■ (navy)	15.67
Lighting (MWh)	■ (yellow)	33.23
Heating (Gas) (MWh)	■ (red)	40.23
Cooling (Electricity) (MWh)	■ (blue)	112.20



In the next step, the natural ventilation process is calculated. The amount of fresh air entering the building includes two options: (1) Air enters unintentionally through window gaps, thermal bridge openings, and doors. (2) Natural ventilation: Air enters as desired, thereby reducing energy consumption.

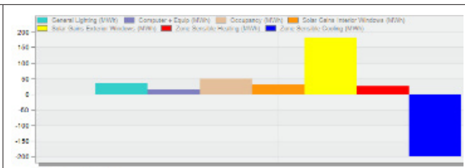
In the next step, the role of natural ventilation in the efficiency of the studied atrium is investigated. Natural air enters through the side wall openings of the stairs. If the temperature of the incoming air is lower than the temperature inside and exits from the flue above the atrium; this natural ventilation process cools the space by several degrees. The amount of opening in the roof is 100% and the amount of opening in the windows is 50%. Natural ventilation is done in spring and summer. Natural ventilation includes effective air flow to reduce the cooling load of the building in the hot seasons of the year. (Tab. 9).

Fresh air entering the building includes two options: The first is that air enters unintentionally through window gaps, openings in thermal bridges, and doors. The second option is natural ventilation, that is, the air entering as desired, which reduces the energy consumption of the building.

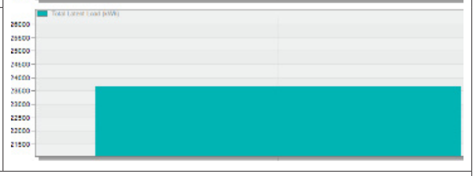
Table 10 shows the fuel consumption of the building, separated by annual and monthly energy, in the atrium with a cylindrical skylight cap, and natural ventilation. (Tab. 10).

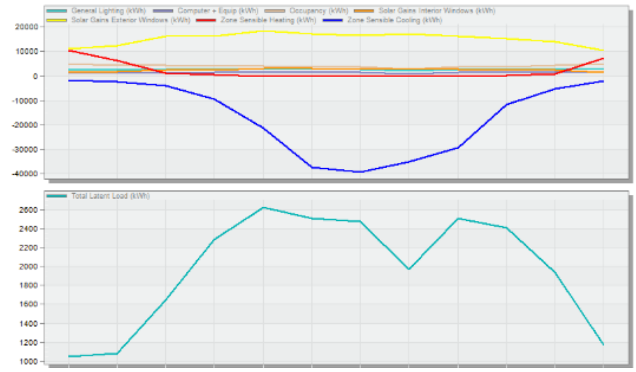
Table 7: Energy-Plus Output: Thermal absorption of the building annually and monthly in the atrium with a cylindrical skylight cap and an intelligent canopy

Heat Balance (MWh)



Latent Load (KWh)





General Lighting (MWh)	■	33.23
Computer + Equip (MWh)	■	15.67
Occupancy (MWh)	■	48.78
Solar Gains Interior Windows (MWh)	■	29.19
Solar Gains Exterior Windows (MWh)	■	180.70
Zone Sensible Heating (MWh)	■	26.17
Zone Sensible Cooling (MWh	■	-199.11
Total Latent Load (KWh)	■	23009.32

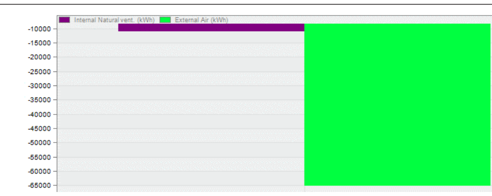
Table 8: Comparison of total energy consumption in the optimal form of atrium with and without intelligent canopy

	Fuel total		Fuel break down		Internal gains + solar	Co2 production
	Gas MWh	Electricity MWh	Healing MWh	Cooling MWh	Exterior MWh	kg
Normal Atrium without Intelligent Canopy Integration	40.23	166.87	40.23	117.98	196.45	108.67
Integration of Intelligent Canopy into the Atrium	40.23	161.10	40.23	112.20	180.70	105.17

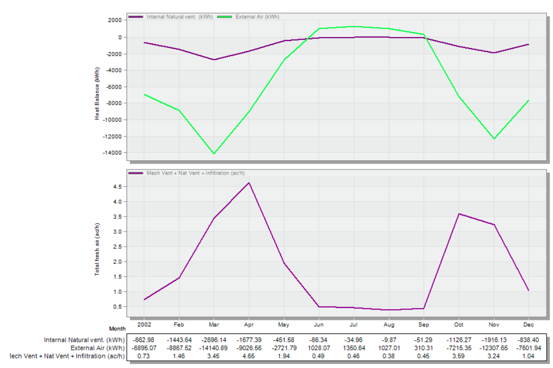
Table 9: Fabric and Ventilation: The amount of fresh air entering the building

Fabric and Ventilation - Tehran Building

Heat Balance (KWh)



Total Fresh Air (ac/h)



Internal Natural Ventilation (KWh)	■	-10974.99
External Air Ventilation (KWh)	■	-65060.75
Mechanical Vent +Natural Vent + Infiltration (ac/h)		1.82

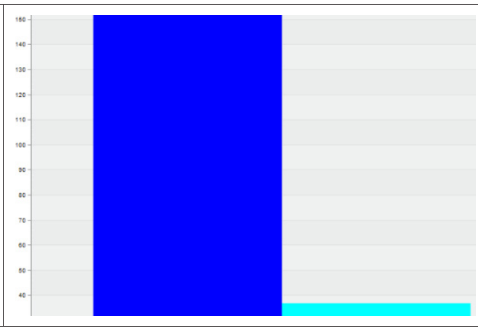
Table 11 shows the total energy of the building, separated by annual and monthly energy, in the atrium with a cylindrical skylight cap, and with natural ventilation. In this table, energy consumption is shown by room Electricity (MWh), lighting (MWh), heating (Gas) (MWh), and cooling (Electricity) (MWh) in different months of the year. (Tab. 11).

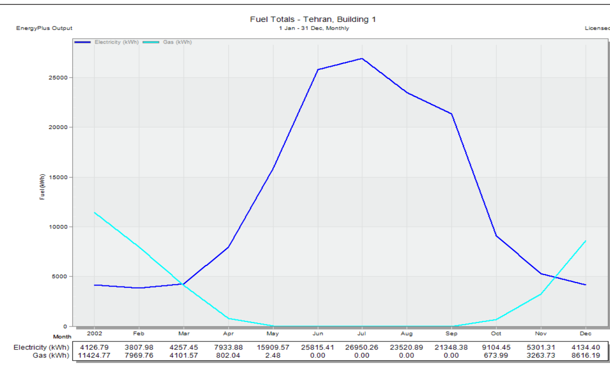
As can be seen, the total energy consumption of the building in the case of using natural ventilation is 189.06 (MWh). So it can be seen that natural ventilation in the building has reduced energy consumption. As can be seen in the figures, the increase of fresh air entering the building and the flow of internal natural ventilation causes an increase of 1.5 times, and a 7% reduction in energy consumption. Then A 6% reduction in energy consumption can be observed when natural ventilation is used in the atrium compared to the previous state. Table 12 shows the thermal absorption of the building annually and monthly in the atrium with a cylindrical skylight cap, and with natural ventilation. (Tab. 12).

Table 10: Energy-Plus Output: The total fuel consumption of the building, separated by annual and monthly energy, in the atrium with a cylindrical skylight cap, and natural ventilation

Fuel Totals- Tehran Building

Fuel (MWh)



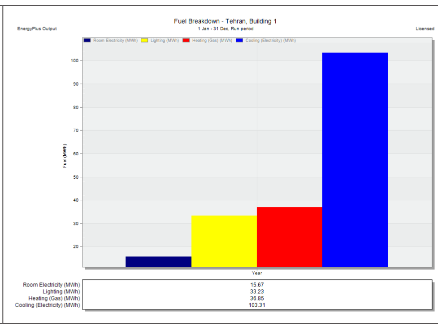


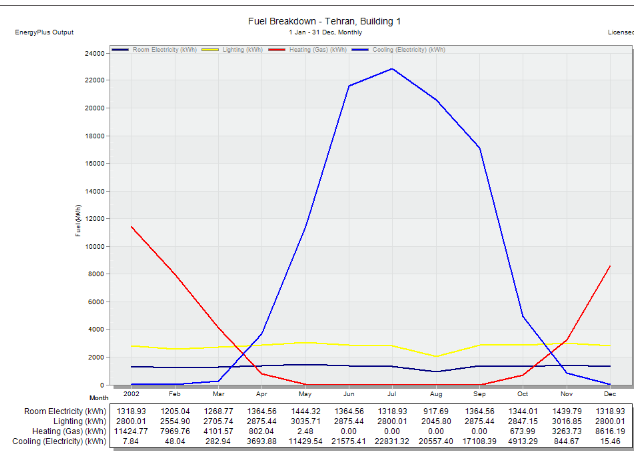
Electricity (MWh)	■	152.21
Gas (MWh)	■	36.85

Table 11: Energy-Plus Output: The total energy of the building, separated by annual and monthly energy, in the atrium with a cylindrical skylight cap, and with natural ventilation

Fuel Breakdown- Tehran Building

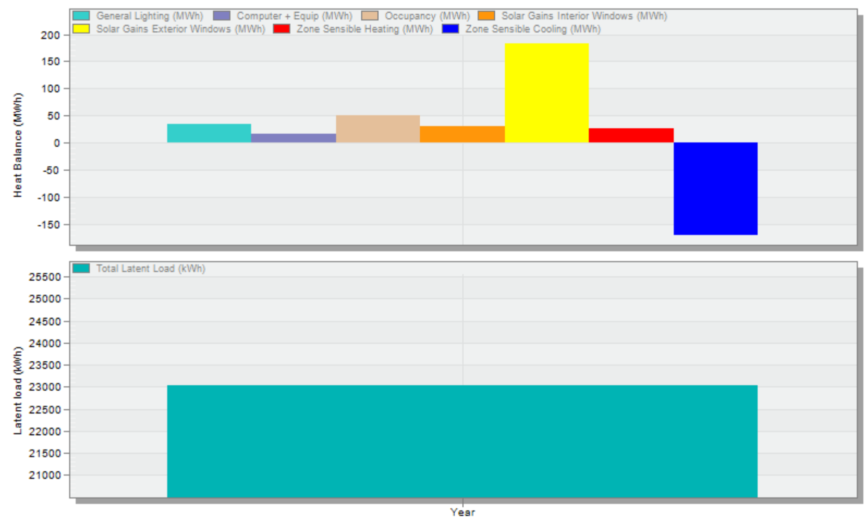
Fuel (MWh)





Room Electricity (MWh)	■	15.67
Lighting (MWh)	■	33.23
Heating (Gas) (MWh)	■	36.85
Cooling (Electricity) (MWh)	■	103.31

Table 12: Thermal absorption of the building annually and monthly in the atrium with a cylindrical skylight cap, and with natural ventilation

Energy Plus Output		Internal Gains +Solar
Heat Balance (MWh) / Latent Load (KWh)		
General Lighting (MWh)		33.23
Computer + Equip (MWh)		15.67
Occupancy (MWh)		49.41
Solar Gains Interior Windows (MWh)		29.19
Solar Gains Exterior Windows (MWh)		180.70
Zone Sensible Heating (MWh)		25.17
Zone Sensible Cooling (MWh)		-169.48
Total Latent Load (KWh)		23034.13

In table 12, energy consumption is shown by general lighting (MWh), computer equipment (MWh), occupancy (MWh), solar gains interior windows (MWh), solar gains exterior windows (MWh), zone sensible heating (MWh), zone sensible cooling (MWh), and total latent load (KWh) in different months of the year. Table 13 shows the thermal comfort of the building, separated by annual and monthly energy, in the atrium with a cylindrical skylight cap, and with natural ventilation. (Tab. 13).

In table 14, Thermal comfort of the building is shown by Air Temperature (°C), Radiant Temperature (°C), Operative Temperature (°C), and Outside Dry-Bulb Temperature (°C). (Tab. 14).

The total energy consumption in the state of receiving natural ventilation was 189.06 MWh. According to the results, a reduction in energy consumption is observed using ventilation.

RESULT AND CONCLUSION

This study aimed to evaluate the thermal performance of smart canopies and natural ventilation in atriums within Tehran. By investigating the energy consumption in buildings with different atrium designs, we sought to determine the effectiveness of these passive cooling strategies.

Our research found that integrating a smart canopy into an atrium with a circular plan and a flat cap reduced energy consumption from 207.1 MWh to 201.33 MWh, achieving a 3% reduction. Furthermore, utilizing natural ventilation decreased energy consumption significantly to 173.39 MWh, compared to the canopy integration without ventilation, which resulted in a reduction of 27.94 MWh. These results highlight the potential of natural ventilation as a cost-effective solution to enhance thermal efficiency in buildings. Comparing our findings with existing

Table 13: Energy-Plus Output: Thermal comfort of the building, separated by annual and monthly energy, in the atrium with a cylindrical skylight cap, and with natural ventilation

Energy Plus Output		Comfort- Tehran Building
Temperature (°C)		
Air Temperature (°C)	■	**21.20**
Radiant Temperature (°C)	■	**22.37**
Operative Temperature (°C)	■	**21.79**
Outside Dry-Bulb Temperature(°C)	■	**17.27**

Table 14: Energy-Plus Output: Comparison of air conditioning and smart canopies in the atrium with a cylindrical skylight cap

	Fuel total		Fuel break down	Fabric &Ventilation		
	Gas (MWh)	Electricity (MWh)	Cooling (MWh)	Internal Natural Ventilation	External Air	Natural Ventilation + Infiltration
Integration of Intelligent Canopy into the Atrium	40.23	161.10	112.20	2286.62	25947.93	0.70
Natural Ventilation	36.85	152.21	103.31	10974.99	65060.75	1.82

studies, we note that similar research has also demonstrated the benefits of natural ventilation in reducing energy consumption

Future studies could explore the long-term impact of smart canopies and natural ventilation on occupant comfort and building energy performance. Additionally, investigating the integration of these systems in different climatic zones and building types would provide a broader understanding of their applicability and effectiveness.

REFERENCES

Abdullah, A. H., Meng, Q., Zhao, L., Wang, F. (2009). Field study on indoor thermal environment in an atrium in tropical climates. Build Environ; 44: 431–6. https://doi.org/10.1016/j.buildenv.2008.02.011

Aldawoud A, Clark R. (2008). Comparative analysis of energy performance between courtyard and atrium in buildings. Energy Build; 40: 209–14. https://doi.org/10.1016/j.enbuild.2007.02.017

ASHRAE. (2009). The ASHRAE guide for buildings in hot and humid climate (2nd Ed.). Atlanta: W. Stephen Constock.

Bajracharya, S. (1997). Computer simulation of thermal behavior of atriums (Unpublished master's thesis). University of Calgary.

Bendar, M.J. (1986), The New Atrium, New York: McGraw-Hill, Inc "Field Study on Indoor Thermal Environment in an Atrium in Tropical

Chan H-Y, Riffat S.B, Zhu J. (2010). Review of passive solar heating and cooling technologies. Renew Sustain Energy Rev; 14: 781–9. https://doi.org/10.1016/j.rser.2009.10.030

Cheshmehnour, M., Mehdizadeh Seraj, F., and Yazdanfar, S.A. (2018). The influence of placement of the interior spaces adjacent to the atrium in terms of the distribution of light and heat received (case study: office building of Niro Research Institute). Architecture and Sustainable Urbanism, 7(2): 119-134. (In Persian)

Chow, S.K.H.; Li, D.H.W.; Lee, E.W.M.; Lam, J.C. (2013). Analysis and prediction of daylighting and energy performance in atrium spaces using daylight-linked lighting controls. Appl. Energy, 112, 1016–1024. https://doi.org/10.1016/j.apenergy.2012.12.033

Danesh Pajouh, H., Majedi, H., & Zarabadi, Z. (2020). Explanation of Urban Morphology Evaluation methods and Tool in Sustainable Energies Approach. Journal of Urban Management and Energy Sustainability, 1(3), 62-75. https://doi.org/10.22034/ijumes.2017.18.12.023

Danielski, I.; Nair, G.; Joelsson, A.; Fröling, M. (2016). Heated atrium in multi-storey apartment buildings, a design with potential to enhance energy efficiency and to facilitate social interactions. Build. Environ. 106, 352–364. https://doi.org/10.1016/j.buildenv.2016.06.038

De Dear, R. J., Gail S. B. (2002). "Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55." Energy and buildings 34, no. 6: 549-561. https://doi.org/10.1016/S0378-7788(02)00005-1.

Dong, L.; He, Y.; Qi, Q.; Wang, W. (2022). Optimization of Daylight in Atrium in Underground Commercial Spaces: A Case Study in Chongqing, China. Energy Build. 256, 111739. https://doi.org/10.1016/j.enbuild.2021.111739

Douvlou, E. D. & Pitts, A. C. (2001). Glazed spaces in hot climates: The case of the atrium building in a mediterranean climate. In Proceedings 18th conference on passive and low energy architecture Florianópolis, Brazil.

Du, J.; Sharples, S (2012). The Assessment of Vertical Daylight Factors across the Walls of Atrium Buildings, Part 2: Rectangular Atria. Light. Res. Technol. 44, 124–138. https://doi.org/10.1177/1477153511412531.

Edmonds, I. R. & Greenup, P. J. (2002). Daylighting in the tropics. Solar Energy, 73(2), 111–121. https://doi.org/10.1016/S0038-092X(02)00039-7

Eiraji, J., & Elmkhah, S. (2021). Studying Energy Consumption in Built Educational Spaces with Approach of Sustainability and Optimization. Journal of Urban Management and Energy Sustainability, 2(4), 69-85. https://doi.org/10.22034/jumes.2021.560771.1083

Encinas F. (2004). The technology transferof double skin facades from Europeto Chile, an evaluation by means of Cfd simulations. Nottingham, UK: University of Nottingham.

Eqbali, F. Farrokhzad, M. and Pajohanfar, M. (2016), control of obtaining natural daylight in the middle atriums of buildings, the 5th International Congress on Civil Engineering, Architecture and Urban Development, Tehran. (In Persian)

Esquivias, P; Navarro, J; Muñoz, C (2011). Hacia la optimizacion del aprovechamiento de la luz natural; la Univ. Sevilla: Sevilla, España; pp. 229–274.

Farahkhiz, M., Kashtkar Ghalati, A. (2021). Analysis of the atrium pattern in optimizing energy consumption; The second international conference on architecture, civil engineering, urban planning, environment and horizons of Islamic art in the statement of the second step of the revolution; Islamic Art University of Tabriz; Tabriz. (In Persian)

Gan G. (2010). Interaction between wind and buoyancy effects in natural ventilation of buildings. Open Constr Build Technol J; 4: 134–45. http://dx.doi.org/10.2174/1874836801004010134

Ghasemi, M.; Kandar, M.Z.; Noroozi, M (2016). Investigating the Effect of Well Geometry on the Daylight Performance in the Adjoining Spaces of Vertical Top-Lit Atrium Buildings. Indoor Built Environ. 25, 934–948. https://doi.org/10.1177/1420326X15589121.

Göçer Ö., Tavil A., Özkan E. (2006). Thermal performance simulation of an atrium building. In: Proceedings of eSim building performance simulation conference. Faculty of architecture, landscape, and design. University of Toronto, Canada; p. 33–40.

Hawkes, D. & Baker, N. (1983). Atria and conservatories. The Architects Journals. May 11, 18 & 24.

Hessari, P., & Seyf shojaee, M. (2021). Evaluation of the optimal form of educational building based on energy consumption (Case study: Torbat Heydarieh city). Journal of Urban Management and Energy Sustainability, 2(4), 58-68. https://doi.org/10.22034/jumes.2021.558191.1081

Hunt, G. R., Acred, A. (2013). Passive ventilation in multi-storey atrium buildings: A first-order design guide. Conference: 34th AIVC ConferenceAt: Athens; September 2013.

Hussain, S., Oosthuizen, P. H. (2011). "Validation of numerical modeling of conditions in an atrium space with a hybrid ventilation system." Building and Environment 52: 152-161. https://doi.org/10.1016/j.buildenv.2011.12.016

Hussain, S., Oosthuizen, P. H. (2012). "Numerical investigations of buoyancy-driven natural ventilation in a simple atrium building and its effect on the thermal comfort conditions." Applied Thermal Engineering 40: 358-372. https://doi.org/10.1016/j.applthermaleng.2012.02.025

Ibrahim, I.; Al Badri, N.; Mushtaha, E.; Omar, O. (2022). Evaluating the Impacts of Courtyards on Educational Buildings, Case Study in the University of Sharjah. Sustainability. 14, 141. https://doi.org/10.3390/su14010141.

Karamouzian, H., Zanganeh Shahraki, S., & Farhoodi, R. (2021). Explanation of the energy consumption mechanism model-based in urban morphology context. Journal of Urban Management and Energy Sustainability, 2(3), 23-31. https://doi.org/10.22034/jumes.2021.249026

Kazemzadeh, M., Qabadian, V., and Tahbaz; M. (2014). Atrium and interior lighting of office buildings (investigating the effect of atrium roof form on receiving interior lighting). Volume 8, the second special issue of lighting, June 2014, 53-61. (In Persian)

Keshtkar Ghalati, A.K., Ahmadian, M. (2023). Effects of Window and Light Shelve Configurations on Energy Consumption and Daylight Illuminance in Classrooms, Renewable Energy Research and Applications, 5 (1), 107–119. https://doi.org/10.22044/rera.2023.12563.1194

Keshtkar Ghalati, A.K., Amiri, N. (2022). Urban Flood Management Using the Green Roof System (Case study: Tehran City); Urban Management and Energy Sustainability; 3 (1), 58–68. http://dx.doi.org/10.22034/jumes.2021.558168.1080

Keshtkar Ghalati, A.K., Taromsari, F.M. (2023). Integration of photovoltaic modules to optimize energy usage in residential buildings. Asian Journal of Civil Engineering; 24, 2179–2191. https://doi.org/10.1007/s42107-023-00634-0

Khan, N., Su, Y., Riffat, S.B. (2008). A review on wind driven ventilation techniques. Energy Build; 40: 1586–604. https://doi.org/10.1016/j.enbuild.2008.02.015

Laouadi, A., Atif, M., Galasiu, A. (2002). Towards developing skylight design tools for thermal and energy performance of atriums in cold climates. Build Environ; 37:1289–316. https://doi.org/10.1016/S0360-1323(02)00008-2

Li, J.; Ban, Q.; Chen, X.; Yao, J. (2019). Glazing Sizing in Large Atrium Buildings: A Perspective of Balancing Daylight Quantity and Visual Comfort. Energies 2019, 12, 701. https://doi.org/10.3390/en12040701.

Littlefair, P (2002). Daylight Prediction In Atrium Buildings. Sol. Energy. 73, 105–109. 12. https://doi.org/10.1016/S0038-092X(02)00038-5

Lomas KJ. (2007). Architectural design of an advanced naturally ventilated building form. Energy Build; 39: 166–81. https://doi.org/10.1016/j.enbuild.2006.05.004

Mahlabani, Y.G.; Araei, R.A.; Boushehri, A.M.; Alamuti, Z.M. (2019). A Study of Optimal Area of Atrium for Daylight Utilization (Case Study: Administrative Building in Qazvin, Iran). International Journal of Architectural Engineering & Urban Planning, 29, pp. 39–46. http://dx.doi.org/10.22068/ijaup.29.1.39

Mohsenin, M.; Hu, J (2015). Assessing Daylight Performance in Atrium Buildings by Using Climate Based Daylight Modeling. Sol. Energy, 119, 553–560. https://doi.org/10.1016/j.solener.2015.05.011.

Moosavi, L., Mahyuddin, N., Ab Ghafar, N., Ismail, M. A. (2014). Thermal performance of atria: An overview of natural ventilation effective designs. Renewable and Sustainable Energy Reviews 34: 654–670. http://dx.doi.org/10.1016/j.rser.2014.02.035

Nasrollahi, N., Abdullahzadeh, S., and Litkouhi, S. (2016). Investigating the effect of the atrium on the conditions of the indoor environment, the thermal comfort of the residents and the amount of energy consumption in office buildings, a case study: Tehran. Utopia architecture and urban planning. 10(21): 125-138. (In Persian)

Nelson, G. (1984). What's the use of Atria. The Architects Journal, (November), 73–76.

Ni, X., Jianhua, S., Wang, B. (2017). The adjustable intelligent atrium sunshade; International Symposium on Resource Exploration and Environmental Science; IOP Conference Series: Earth and Environmental Science: 64 (2017) 012065 http://dx.doi.org/10.1088/1755-1315/64/1/012065

Olsen, E.L., Chen, Q.Y. (2003). Energy consumption and comfort analysis for different low-energy cooling systems in a mild climate. Energy Build; 35: 560–71. https://doi.org/10.1016/S0378-7788(02)00164-0

Omrany, H., Ghaffarianhoseini, A.; Berardi, U.; Ghaffarianhoseini, A.; Li, D.H.W. (2020). Is atrium an ideal form for daylight in buildings? Archit. Sci. Rev. 2020, 63, 47–62. https://doi.org/10.1080/00038628.2019.1683508

Pan, Y., Li, Y., Huang, Z., Wu, G. (2010). Study on simulation methods of atrium building cooling load in hot and humid regions. Energy Build; 42: 1654–60. https://doi.org/10.1016/j.enbuild.2010.04.008

Pfafferott, J., Herkel, S., Wambsganß, M. (2004). Design, monitoring and evaluation of a low energy office building with passive cooling by night ventilation. Energy Build; 36: 455–65. https://doi.org/10.1016/j.enbuild.2004.01.041

Piraei, F.; Matusiak, B.; Lo Verso, V.R.M. (2022). Evaluation and Optimization of Daylighting in Heritage Buildings: A Case-Study at High Latitudes. Buildings. 12, 2045. https://doi.org/10.3390/buildings12122045.

Pitts, A.; Bin Saleh, J (2007). Potential for energy saving in building transition spaces. Energy Build. 39, 815– 822. https://doi.org/10.1016/j.enbuild.2007.02.006

Rastegari, M.; Pournaseri, S.; Sanaieian, H (2021). Daylight Optimization through Architectural Aspects in an Office Building Atrium in Tehran. J. Build. Eng. 33, 101718. https://doi.org/10.1016/j.jobe.2020.101718.

Ray, S. D., Gong, N-W., Glicksman, L. R., Paradiso, J. A. (2014). Experimental characterization of full-scale naturally ventilated atrium and validation of CFD simulations. Energy Build; 69: 285–91. https://doi.org/10.1016/j.enbuild.2013.11.018

Rezaei Rad, H., Rafieian, M., & Sozer, H. (2019). Evaluating the effects of increasing of building height on land surface temperature. Journal of Urban Management and Energy Sustainability, 1(1), 37-42. https://doi.org/10.22034/ijumes.2019.01.01.002.

Rojas, DP. (2013). Atrium building design: key aspects to improve their thermal performance on the Mediterranean climate of Santiago de Chile. Int J LowCarbon Technol; 8: 1–4. http://dx.doi.org/10.1093/ijlct/ctt009

Sharples, S.; Lash, D. (2006). Daylight in Atrium Buildings: A Critical Review. Archit. Sci. Rev. 50, 37–41. https://doi.org/10.3763/asre.2007.5037

Sudan, M.; Mistrick, R.G.; Tiwari, G.N (2017). Climate-Based Daylight Modeling (CBDM) for an Atrium: An Experimentally Validated Novel Daylight Performance. Sol. Energy, 158, 559–571. https://doi.org/10.1016/j.solener.2017.09.067.

Taghipour Mizani, E., Rashid Kalvir, H., and Akbari, H. (2019). Investigating the effect of the shape of the atrium ceiling on receiving the interior lighting of the atrium in the educational spaces of Tabriz city. Architecture and Urbanism Journal, 13(29): 111-97. (In Persian)

Taleghani M, Tenpierik M, van den Dobbelsteen A. (2014). Energy performance and thermal comfort of courtyard/atrium dwellings in the Netherlands in the light of climate change. Renew Energy; 63: 486–97. https://doi.org/10.1016/j.renene.2013.09.028

Thirugnanasambandam M, Iniyan S, Goic R. (2010). A review of solar thermal technologies. Renew Sustain Energy Rev; 14: 312–22. https://doi.org/10.1016/j.rser.2009.07.014

Tourani, A., Mofidi Shemirani, S.M., and Tahbaz, M. (2016). Measuring the effect of the atrium inclination angle on the visual comfort of students by daylight efficiency in educational buildings in Tehran (a field study and simulation). Scientific and research quarterly of research and urban planning, 8(31): 249-266. (In Persian)

Verma, A (2017). The Effect of an Atrium and Building Orientation on the Daylighting and Cooling Load of an Office Building. Sch. Archit. Built Environ. 6, 1–69.

Voeltzel A, Carrié FR, Guarracino G. (2001). Thermal and ventilation modelling of large highly-glazed spaces. Energy Build; 33: 121–32. https://doi.org/10.1016/S0378-7788(00)00074-8

Wang X, Huang C, Cao W. (2009). Mathematical modeling and experimental study on vertical temperature distribution of hybrid ventilation in an atrium building. Energy Build; 41: 907–14. https://doi.org/10.1016/j.enbuild.2009.03.002

Wu, P.; Zhou, J.; Li, N (2021). Influences of Atrium Geometry on the Lighting and Thermal Environments in summer: CFD Simulation Based on-Site Measurements for Validation. Build. Environ. 197, 107853. https://doi.org/10.1016/j.buildenv.2021.107853.

Xue, Y.; Liu, W. (2022). A Study on Parametric Design Method for Optimization of Daylight in Commercial Building's Atrium in Cold Regions. Sustainability, 14, 7667. https://doi.org/10.3390/su14137667.

Yoshino, H., Ito, K., & Aozasa, K. (1995). Trends in thermal environmental design of atrium buildings in Japan. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA (United States).

Zeinolabdinzadeh, S., Meddi, H., and Mafi, M. (2020). Analyzing the energy consumption performance of Almase-Sharq commercial complex based on the most suitable type of Atrium glass and azure blue color with the symbol of Islamic architecture. Quarterly Journal of Islamic Art Studies, 18 (42): 457-442. (In Persian)

Zeinolabdinzadeh, S., Meddi, H., and Mafi, M. (2021). Analyzing the performance of the form and the height of the central internal skylight ceiling of cold and dry climate commercial buildings (Mashhad city). Environmental Science and Technology Quarterly, Volume 23, Number 3 - Serial Number 106, 57-71. (In Persian)

Zomorrodian, Z., & Tahsildoust, M. (2014). Validation of energy simulation software in buildings: with an experimental and comparative approach. 4 (18): 115-132. (In Persian)

HOW TO CITE THIS ARTICLE
Keshtkar Ghalati, A. and Farahkhiz, M. (2025). Thermal performance of smart canopy and natural ventilation in atriums in Tehran. (e725280). International Journal of Urban Management and Energy Sustainability, (), e725280
DOI: 10.22034/ijumes.2025.2030424.1218