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A Survey of the Performance of Atrium Glass Type on Annual Energy Consumption of Commercial Complexes in Cold, Arid Climate, (Case Study of Almas-e Shargh Commercial Complex in Mashhad)

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Abstract--- *The present study focuses on the type of interior window skylight in commercial complexes of Mashhad due to its importance in cooling, heating, lighting, ventilation and indoor temperature. Based on this importance, the current study simulates the most appropriate type of glass in commercial complexes with internal skylight using comparative research method and Designer Builder software. This paper is aimed to find the best type of glass to reduce energy consumption and increase natural light and comfort for the residents. For this purpose, at first, the studied building was simulated in the software and then in order to determine the optimum glass of skylights in commercial complexes, in terms of impact on cooling, heating, lighting, ventilation and temperature in Almas-e Shargh Complex of Mashhad,5 glass types were selected. Then, after simulating them in the interior lighting of the commercial complex in two states (heating, ventilation and air conditioning) off and on, it was found that in the Almas-e Shargh Complex of Mashhad, the ventilation system in the off mode performs better than the ventilation system at on mode. Also, in terms of glass type, thermochromic glass is the most suitable type of glass to reduce temperature, cooling energy consumption by 10%, and increase the natural light entry in commercial complexes in cold arid areas of Mashhad both in the on and off modes of ventilation system.*

Keywords--- *Internal skylight, Glass, Thermal comfort, Climatic performance, Energy consumption simulation.*

I. INTRODUCTION

In the late twentieth century, following the energy and environmental crises, the necessity of reducing energy consumption and environmental pollutants was agreed by most countries. Buildings account for about 50 % of the world's energy consumption, of which 20 % is used in commercial buildings. In the past, the atrium was referred to as the central courtyard surrounding by the adjacent rooms [1]. In modern architecture, an atrium is a wide-open space with several stories, covered with glass roofs or large windows or both [2]. At the end of the 19th century, natural lighting was introduced to increase light, and atriums played a significant role in this regard. The atrium allows natural light to penetrate the center of the dark areas of adjacent rooms and reduces the need to use artificial lighting energy and maximizes the benefits of receiving direct solar energy. In addition to creating a link between the floors of building, it forms a suitable intermediate space between the interior and exterior environment [3]. Indeed, skylights actually act as a

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filter against the effects of inappropriate environmental factors such as rain, snow, wind, etc., while also allow the use of optimum environmental factors such as sunlight, fresh air and landscape and reduce heat dissipation from adjacent spaces [4]. Also, this space generates heat in the adjacent spaces as an intermediary space, providing the sun's heat to the adjacent spaces and such heat is highly efficient in the cold arid climate [5]. By creating an internal microclimate and providing thermal comfort in the cold seasons and in harsh climates, in provide uniform natural lighting and permanent interior green coverage, central skylights or atriums have been used widely in the contemporary architecture namely public, administrative and commercial buildings in the history [6]. Based on physical changes, these spaces are observed in all great civilizations around the world in the forms of Iranian central courtyard, arched yards, rooms without Roman ceiling , stores and interior green spaces of towers [7]. After the creation of greenhouse phenomenon in glass spaces and the heat accumulation in the enclosed space, some methods (static solar systems) have been developed to apply glass spaces in winter heating and summer ventilation for buildings without using mechanical utilities. The amount of energy received depends on the climatic conditions of building, the orientation of the building and the building physical characteristics [8]. But the land that is added to the skylight area by a variety of uses and functional requirements (with the same proportion of volume), and its wide glass surfaces potentially have adverse effects due to excessive heating, heat dissipation, lack of airlock, thermal stratification, chimney effect and the light dazzling[9]. In addition, the interplay between the physical and environmental conditions on skylights on the one hand, and the internal conditions of the adjacent skylight spaces, safety and utility issues, on the other hand, have faced designers with complex factors [10]. Since the energy consumption reduction and the use of environmental forces in an integrated design require comprehensive decisions, atriums have been studied from different perspectives and in different climatic conditions. Internal skylights affect the adjacent surfaces and spaces and are affected by external surfaces. Therefore, they show different thermal performance during the day and different seasons of the year, so it is necessary to evaluate its performance in terms of comfort and with minimal use of heating and cooling systems.

II. RESEARCH METHODOLOGY AND INSTRUMENT

The present study is an applied and simulation design. The research method of this study is based on an experimental process, field and comparative analysis. At first, a general study of the climatic conditions of the central area, cold arid climate and the installation of internal skylights in commercial complexes and the load of cooling, heating, lighting, ventilation and temperature were carried out in Mashhad. Then, Almas-e Shargh commercial complex, with an internal skylight in the center of the building (coated with green polycarbonate glass in the body of skylight and truss-shape structure) was selected as the study sample. Next, it was measured by the Design Builder simulator software, with an Energy Plus capable of analyzing and calculating the cooling, heating, lighting, comfort and supply loads of buildings; over a year with HVAC on and off modes. (To determine the amount of energy consumed in the building and the thermal comfort at both the time the HVAC systems are switched on and off.) The measurement is conducted from April to March 2018. The lighting is 400 LUX based on ASHRAE standard. The results are based on the software available in all commercial complexes with internal skylights located in cold arid climates in Mashhad. Given that all complexes are the same in terms of number of floors, the above results can be generalized to other complexes.

Research background

In the 1950s, John Portman, who is the first to use internal skylights in hotels and commercial spaces, examined atriums in commercial spaces and compared the open and extensive atriums allowing a proper view of the floors and surfaces of buildings. Atrium's capabilities in commercial complexes include: a place for green spaces and fountains, games, conferences, chatting and coffee shops. In this regard, Maria Wall used the term" glass-covered" buildings for all spaces with skylights and balconies greenhouses, porches and closed courtyards. She considered the reason for different interpretations of the thermal performance of internal skylights as the great dependence of these spaces on the outside climatic conditions and incompatibility of the physical characteristics of the skylight studied with environmental conditions [11]. At the Canadian Construction Research Center, centralized studies have be conducted on the thermal, acoustic and lighting performance of the internal skylights. The studies done by Morad Atif and Aziz Laouadi focus on behavioral calculations and thermal, ventilation and modeling and the amount of light received in internal skylight space in Canada's cold climate. In 1998, some researches have been performed on solar heat absorption and thermal stratification in two internal skylight samples and the relationship between static energy absorbed in skylight, thermal comfort, and the effect of HVAC[1] systems performance were determined. Evaluation of two internal skylights showed that the outdoor environmental changes have less impact on skylights in the performance of winter systems, but in summer, the sunlight is effective on thermal stratification and the increase in internal temperature. It was also found that a part of temperature of the skylights is due to the internal load of the building and electrical appliances [12]. Also in a study done by Gilani et al (2013) the thermal stratification of buildings was performed using CFDs. It was found that by reducing the air conditioning systems, it is possible to identify and control the thermal stratification in the interior of the building and achieve high efficiency and control of air conditioning [13]. Leila Mousavi et al., (2014) also carried out a study on thermal stratification of atriums using natural ventilation and its design approaches and found that providing fresh air using natural ventilation with passive systems can improve thermal stratification and ventilation of atriums [14]. Karlsen (2016) concluded that the possible advantages of some internal skylight geometries include that they can reduce the total surface area of the building. Since heat transfer is usually directly proportional to the surface of the building, this reduction can lead to energy saving [15].

Susan Bajracharya (2016) also simulated the thermal stratification in atria by confirming the appearance of the early models and found that a relatively stable ESP-r model can simulate the thermal stratification of atria accurately, because of this applies computer simulation software in addition to the initial heat transfer: a) The capacity to perform simulation with the time steps up to 10 minutes, b) Ability to model mass flow, c) Radiation transfer capacity from the first impact point. The model validation process Showed the thermal data value for the days with different climatic conditions. A simulation model that gives good results for one-day climatic data is not necessarily good for other-day climatic data. Therefore, validation studies for atrium modeling should be based on experimental data for at least two days with different climatic conditions [16]. Farhoudi (2016) explored how direct sunlight enters rectangular atriums, so that if the walls of adjacent rooms and windows are well designed, the difference in natural light penetration between the upper and middle floors can be minimized. This means that there is a relationship between cheaper construction and uniform natural lighting for areas close to the atrium’s floor [17]. Regarding the thermal stratification in atriums, Zhang et al., (2017) studied the atria and lighting problems in the current Iranian architecture and found that the optimal forms of atrium are: circular, square, and rectangular, respectively. They also showed that the atrium should be better designed as stair or inverse trapezoid, reducing the glazing surfaces in the upper floors (adjacent to the atrium ceiling) and are increased in the ground floors [18].

III. THEORETICAL BASICS

- **Climate investigation**

This study was conducted in Mashhad with coordinates (59.35º to 60. 35 º East longitude and 36.12º North latitude). The minimum altitude of this area is 750 meters above sea level and maximum value is 1800 meters and the average

[1] Heating, Ventilation and Air Conditioning

height of Mashhad is 943 meters above sea level. The maximum height of the mountains in two sides is 3,150 meters; thus the height of the mountains Drainage divide and the Thalweg of Kashfrood valley is 2400 meters, which has a great impact on the regulation of the surface water network [19]. Therefore, Mashhad has a cold arid climate. As shown in Figure 1, the coldest temperature in the region is between 1 and 5 ° C and the hottest day of the year is 38-35 ° C. The maximum relative humidity in Mashhad is 72% at the end of December and the minimum relative humidity in July is about 13.2 %, which reflects the fact that the climatic condition difference in hot and cold seasons is high and its design is difficult.

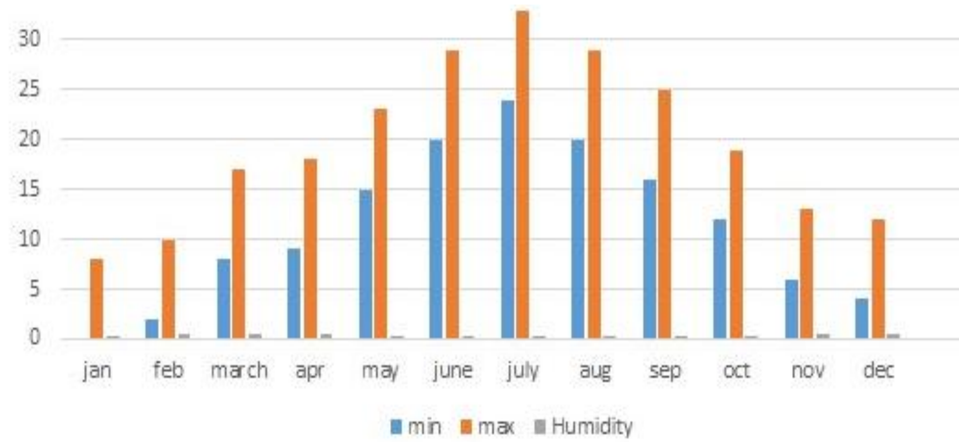

Chart 1- Annual minimum and maximum temperature and relative average humidity in Mashhad in 2018,(Source: Meteorological Organization of Iran.)

- **internal skylight in commercial complexes of Mashhad**

Generally, in commercial complexes of Mashhad, the model of internal skylights is O-shaped or oval-shaped on the floors. The skylights in commercial complexes start from the -1th floor, with corridors to the commercial booths in the -1 to +2 floors and in the upper floors (3 + and 4 +) a range of playground areas and coffee shops are located. These skylights provide the daylight for the mentioned spaces. In some commercial complexes, the skylights composition includes steel or aluminum structures with iron or aluminum frame with single-wall and double-wall glass. Normally, the skylights have problems with thermal insulation, air locking and sealing, and the air leakage, rainfall and water vapor condensation have been observed in these buildings and no shading systems have been used. Most of the skylights in the commercial complexes of Mashhad have no air conditioning ventilation. The adjoining wall and the body of the skylights are usually of stone or polymeric coatings with light color. The materials used in the wall of skylight are lightweight and there is only concrete structure in the floor and ceiling of the corridors. Also, the ceiling of the skylights is made of polycarbonate and sometimes, triple layer, two walled coating is used in this area.

In this study, first the length to width and average height ratios in internal skylights of commercial buildings were investigated through field inspections. Then, Design Builder software version 3.2.0.070 was used to model different aspects of the building such as: heating and cooling systems, lighting and energy consumption. Meanwhile, Almas-e Shargh commercial complex, which has an internal skylight, was simulated by the software to measure its validity as a true environmental simulation tool. The building's information such as cooling, heating and lighting systems was also used in the simulation.

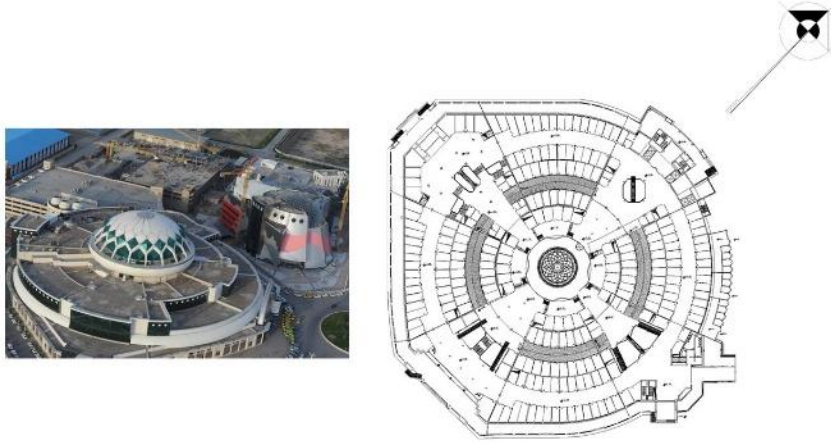

Figure 1- a) Right side photo: Ground floor plan of Almas-e Shargh b) Left side photo: The location of Almas-e Shargh commercial complex,(Source: Author).

Table 1- Description of Almas-e Shargh complex in Mashhad,(Source: Author).

Title	Features
Type of use	Commercial
Location	Mashhad (Iran)
Form	Circle
Number of floors	6 stories
Area of the land	About 5500 sq
Area of the complex	20000 sq
Height of each floor	About 5m
Glass surfaces	305 sq
Glass surface percentage	25%
Using hours	9 to 24

Almas-e Shargh commercial complex with 6 floors (not including parking) is located on Baharestan Square in Mashhad. The building has a 37 m high skylight with spherical shape. The diameter of the cylinder is 16 meters at the floor level. The skylight is enclosed by its adjacent spaces from the -1 th floor to the fourth floor and is spherical-shaped at the end with the light coming only from the body and the glass are made of green polycarbonate materials. The building structure is metal and the aluminum frames of the glazed wall are attached to the steel structure of skylight. There is no opening in the ceiling of the skylight. Therefore, skylight can not provide night ventilation and heat mitigation in the summer. On the other hand, there are no exterior shell insulation and shading equipment in the building. Skylights are installed in all floors with air conditioning channels and the interior wall of the skylight is coating with bright spraying colors. In addition to the spiral steel staircase and elevator, it also links floors.

- **Data validation analysis**

The results of this study were based on numerical and empirical simulation. The atrium of the mentioned commercial complex was investigated using dome geometry. The dimensions of the design model are as follows: Almas-e Shargh commercial complex is 136 × 146 m long and 29 m high under the atrium dome, and at its center, there is an atrium 16 × 16 m high with 36.97 m height (from the basement by including the height of atrium dome as 5.41m). Accordingly, after simulating the given building, the solar utilization rate, cooling load, heating load and annual building lighting rate for different window percentages are calculated for Almas-e Shargh commercial complexes. It should be noted that the cooling system of the complex is a direct flame absorption chiller and has a specific ignition. From the beginning of April and at temperature above 20 degrees, the cooling system is switched on, and most of the energy consumption is observed in the afternoon with the maximum attendance of the clients. From September to mid-November the cooling and heating systems are switched off. Also, the heating system is switched off or it is at its minimum degree at hot days due to the over crowdedness, internal skylight, lighting system, etc. According to the simulations in the on mode of HVAC: The total energy consumption of Almas-e Shargh commercial complex of Mashhad 5013326 kWh includes the energy consumed in the cooling section 474301 kWh, heating 3811765 kWh and the amount of lighting received is 3295 LUX. The energy consumption in each area of the whole building is 41460 kWh / m2 including 3811765 kWh / m2 in the heating section and 474301 kWh / m2 in the cooling section. Based on the data obtained from the gas and electricity bills of the commercial complex annually, the energy consumption of gas is about 752930 m3 (2785841 kWh) and the energy consumption in electricity section is 2776,000 kWh (gas consumption is higher in the hot seasons than the cold season), which indicates that the above results show the accuracy of the Design Builder software for modeling.

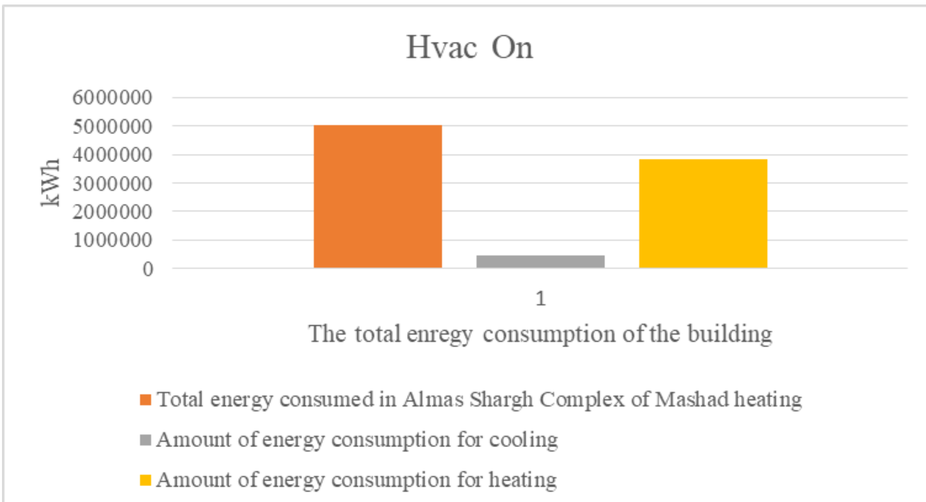

Chart 2- Annual features of total energy consumption of the building in the on mode of HVAC, (Author)

The above Chart (Chart with HVAC on) shows the outdoor temperature, which ranges between 5 ° to 32.49 ° C, in relation to the effective temperature of the building over a year, the amount of heat is shown in kWh. Thus, internal skylight windows let sunlight into the building, and the increase in the heat of indoors during the summer when the sun's penetration through external windows is greater than 55.41 kW; can increase the cooling load of the building. The cooling in the building starts with cooling devices in March and April and the peak time is in July when the maximum cooling energy consumption is 29/363kWh, and doesn't reduce cooling energy consumption before September. In this regard, the permeability of space during winter compared to summer (due to high temperature), causes more heat losses. It should be noted that artificial lights and engine room are also the main causes of increased heat throughout the year. However, compared to the windows, they are at the second level. Also, the cooling energy consisting the function of cooling devices in the summer, despite the existence of atrium and sunlight inside it, the higher floors receive more heat and they need much cooling energy to neutralize the heat received, but the the lower floors require less cooling energy due to receiving less sunlight. For this reason, as we move to the upper floors, the function of coolers increases. For this reason, the rate of functioning of the heating devices, which have the highest energy consumption in Almas-e Shargh complex, varies 10% to 12%. However, the rest of the energy consumed in the building comprises 10% to 90% of the heating energy, including indoor heater, lighting system, engine room, all interior surfaces including walls, ceilings, floors, windows, materials and other mass heat and heat production by customers and all heat generating factors in the commercial complex. By switching off HVAC systems; indoor temperature ranges from 20 to 42.33 °C and the indoor relative humidity within the year varies from 10% to 45%, the highest degree of which is dedicated in April and the lowest in July, because as the temperature in month is the highest (42.33). The amount of discomfort condition in summer with summer clothes ranges 1.98 to 12 and in winter with winter clothes 4.87 to 12. Therefore, generally, discomfort conditions range from a minimum of 0.48 hours in March to a maximum of 12 hours in April to September, whereas with HVAC on systems, discomfort conditions are 200 to 2600 hours per year, and thermal comfort based on the Fanger thermal comfort index (Pmv(Predicted MeanVote)) which should be -0.5 to +0.5; ranges from -0.41 to 5.14 (pmv) with the off systems which indicates the inability of this system to provide thermal comfort conditions. In this regard, architectural design by recognizing the best types of glass used on exterior surfaces and finding the best one using Design Builder simulator software can improve the interior conditions of commercial complexes as well as install some ventilations systems through some surfaces and walls in order to keep indoor conditions at a comfortable level based on the Fanger standard.

- **Improve the type of glass used in internal skylight**

Improvements to building heating load require reduced sunlight penetration, control of heat penetration and increased resistance. In this regard, improvement requires much attention to environmental, economic and social aspects to obtain practical solutions. The purpose of this study was to understand the importance of energy consumption in commercial buildings with internal skylights in cold arid climates. In summer, direct sunlight is from 6am to 7pm. In summer, the amount of sunlight entering the building increases by up to 10 kW in the interior space. Therefore, by replacing the other glass with the existing glass, one can find an efficient way to reduce sunlight penetration and summer heat exposure. Besides having visual aesthetics "Figure 2", these glass can regulated the heating, ventilation, temperature and lighting load inside the building and provide thermal comfort for the customers.

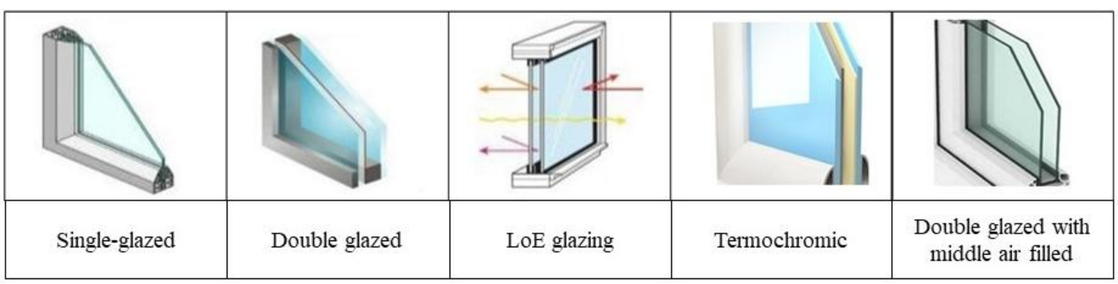

Figure 2- A schematic view of the alternative glass in the internal skylight of Almas-e Shargh commercial complex in Mashhad, Iran, (Author)

In the case study, the glass is made of polycarbonate with a thickness of 48.91000 mm, green and the heat transfer rate of the glass is about 0.222 W / (m-K). In this regard, the effect of using alternative glass related to heating, cooling, lighting, temperature and ventilation loads in both off and on modes in HVAC was investigated. Alternative glass strategies are: clear glass, green glass, 3 to 13 mm thickness filled with air gas in the middle layer, polycarbonate glass, THERMOCHROMIC glass, 3 mm thick green glass and LoE quadruple glazing. LoE glass has metallic coating with low-thickness in one or more layer s consisting of the following layers: 3 mm and 8 mm Krypton in the outer layer, 3 mm clear glass, Krypton 8 mm with 88% polyester coating with the transmission coefficient of 88% and the 3mm Krypton layer in the middle of the 8mm Krypton and the 3mm clear glass in the inner layer. In this regard, the proposed strategies are based on the following properties:

Table 2- Specifications of the studied glass according to ISO 10292 / EN673 standard, (Author)

Glass type	W/(m2-K)	SHGC	D.S	LT
Single- layer glass 3 mm	5/894	0/861	0/837	0/898
Green glass with the thickness of 3 to 13mm	2/556	0/616	0/534	0/743
THERMOCHROMIC glass	2/130	0/569	0/409	0/578
Double green 3mm air	1/960	0/691	0/624	0/744
Polycarbonate glass (sample)	1/252	0/511	0/287	0/295
Quadruple Leo glazing	0/781	0/466	0/338	0/624

In this respect, we have: W/(m2-K) (heat transfer coefficient) and SHGC (solar heat gain coefficient), D.S (direct solar energy transfer from window to inside the space) and LT(natural lighting of building). One can only reduce the heat transfer coefficient inside the building by increasing the thickness of the glass from 3 to 13 mm and double glazing, as in single-glazed clear glass, the heat transfer coefficient is 5.894 W/(m2-K). In double-glazed clear glass with a thickness of up to 13 mm, the heat transfer coefficient is 1.96 W/(m2-K). Among the alternative glass in the internal skylight of the Almas-e Shargh commercial complex, Quadruple Leo glazing has the lowest heat transfer coefficient (0.781 W/(m2-K)) and the lowest solar heat transfer rate (0.466) indoors. However, regarding the direct solar energy transfer from the window (D.S) to Indoor and natural lighting, polycarbonate glass with direct transfer 0.287 and the brightness 0.295 has the lowest direct heat transfer to indoor and lighting of the inside of the building. Therefore, by replacing these types of glass in the internal skylight of Almas-e Shargh commercial complex in Mashhad: They were calculated and simulated in Design Building software in two modes of one and off HVAC in terms of building energy (Cooling, heating, lighting, ventilation and temperature load) and the results are presented in Charts 4&5.

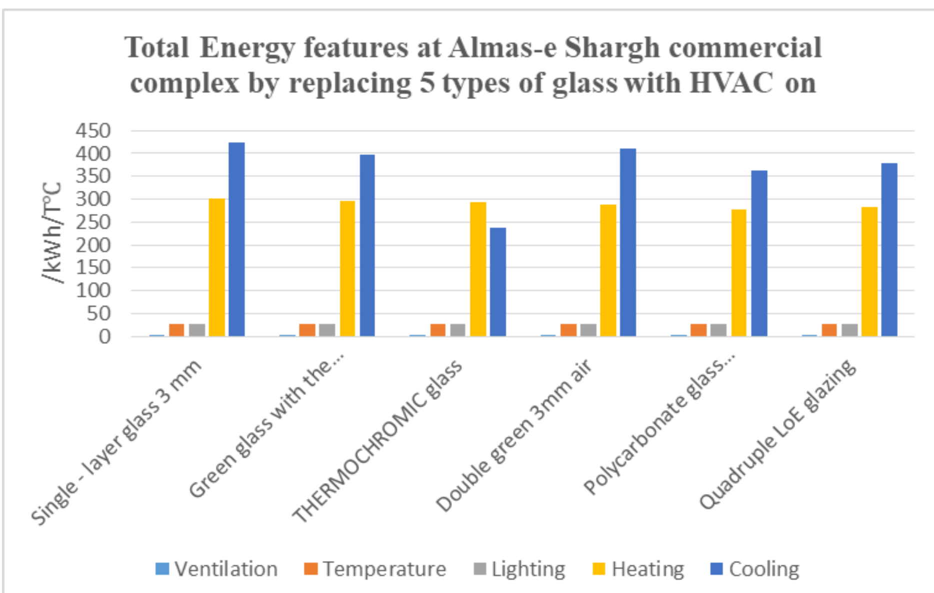

Chart 4- Total energy consumption features of Almas-e Shargh commercial complex by replacing 5 types of glass with HVAC on, (Author)

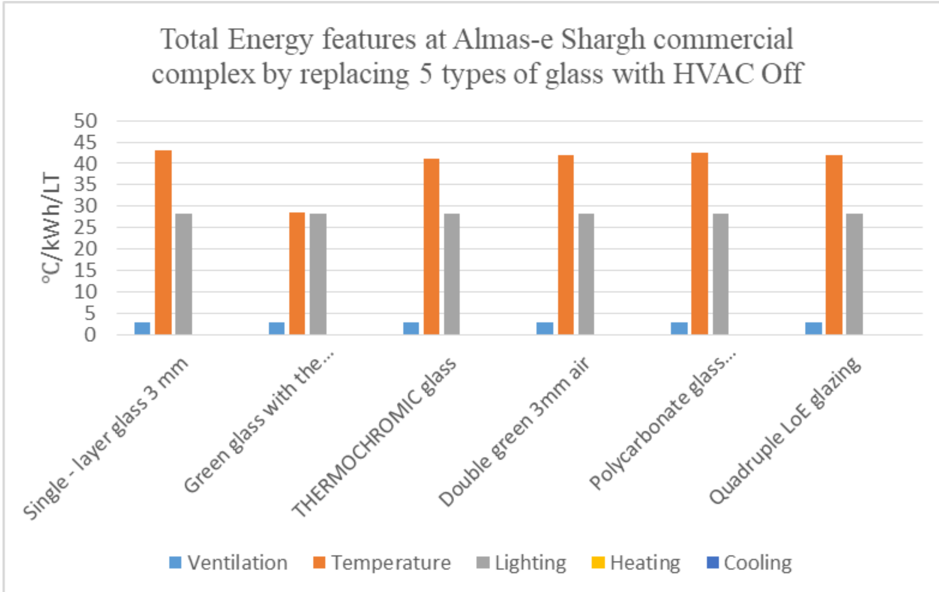

Figure 5- Specifications of heat, humidity and discomfort hours at Almas-e Shargh commercial complex by replacing 5 types of glass with HVAC Off, (Author)

IV. Conclusion

The present study focuses on the importance of energy consumption to reduce the energy consumption transmitted from windows into the atrium in Almas-e Shargh commercial complex of Mashhad. To achieve an optimal window type to provide the lowest energy consumption and maximum thermal comfort to customers at the commercial complex in the cold arid climate; annual solar gain, cooling, heating, lighting and ventilation rates were investigated. In this regard, considering the importance of optimizing energy consumption in commercial complexes of 5 types of glass (clear glass, green glass with 3 to 13 mm thickness filled with air gas in the middle layer, polycarbonate glass, THERMOCHROMIC glass, green glass with 3 mm thickness and quadruple LoE glazing) were selected and simulated in Design Builder software to replace the internal skylight glass of Almas-e Shargh commercial complex. It should be noted that all simulations of both HVAC on and off modes were performed and it was found that in HVAC off mode (despite the building's inability to provide thermal comfort), the building performs better than HVAC on. In HVAC on mode, all of the above-mentioned glass has the same natural ventilation and the least amount of natural brightness in the polycarbonate glass currently used in Almas-e Shargh commercial complex. While calculating the heating and cooling loads of glass, THERMOCHROMIC glass has the lowest cooling load in the building and polycarbonate glass has the lowest heating load in Almas-e Shargh commercial complex. In the same way, in the HVAC on mode, the THERMOCHROMIC glass has the lowest heat and the LoE glazing has the lowest relative humidity. Hence, the most suitable glass in commercial complexes in Mashhad is THERMOCHROMIC glass with a higher degree of ventilation and lighting, lower temperature and cooling energy consumption and a lower amount of heat energy consumption compared to other alternative glass and sample glass is polycarbonate. In addition, these types of glass are also used in from aesthetical and functional aspects.

The present research attempted to achieve the followings:

- Relationship between the type of internal skylight glass and energy consumption (heating, cooling, lighting and ventilation)

- Choosing the most appropriate type of glass to achieve thermal comfort and optimize energy consumption in cold arid climates in commercial complexes with internal skylight

- Guide designers, engineers and architects to improve the thermal performance of internal skylights in commercial complexes in cold arid climates, as well as energy efficiency and comfort for customers.

- Develop simple, low-cost solutions to reduce building energy consumption and general operating costs.

- Provide empirical measurements for future algorithms progress and validate existing simulation models.

The present study demonstrates the best type of glass to achieve optimization of energy consumption and thermal comfort in the internal skylight of commercial complexes in Mashhad with its cold arid climate . Also, the results obtained from this study can be applied to other commercial complexes with internal skylight in Mashhad. In addition, in order to measure energy consumption reduction, architectural capabilities including appropriate formwork and internal skylight dimensions must be considered.

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