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Optimal Atrium Configuration in Office for Thermal Comfort Enhancement (Case Study: Yazd and Tabriz Cities)

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Abstract

Climate change and rising temperatures have made thermal comfort and energy management in buildings a fundamental challenge. Optimizing environmental conditions requires intelligent design and accurate simulation tools. This study aims to determine the optimal placement of atriums in office buildings located in two different Iranian climates: the hot-dry climate of Yazd and the cold-dry climate of Tabriz. Thermal comfort was evaluated using Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indicators, combined with solar radiation and climate data. Simulations were conducted using the Honeybee and Ladybug plugins for Grasshopper, enabling parametric analysis of thermal comfort. In Yazd, Summer PMV values (2.34–2.50) indicate reduced comfort, with Types 5 and 8 showing the lowest discomfort (PMV = 2.34). Winter PMV values (-3.48 to -3.63) indicate cold conditions, where Type 5 performs relatively better. During spring and autumn, PMV values for Types 5, 8, and 3 approach near-zero. Southern-oriented atrium (Type 8) maximizes solar gain in winter. In Tabriz (cold-dry), Most PMV values fall outside the comfort range (-0.5 to +0.5). Only the Atrium Type 3 achieves comfort during autumn. Type 3 receives maximum solar radiation in winter, enhancing natural heating. Strategic atrium placement based on solar exposure significantly improves seasonal thermal comfort. Type 8 (southern orientation) is optimal for Yazd, while Type 3 (northeast orientation) is optimal for Tabriz. These findings provide actionable insights for climate-responsive office building design in arid and semi-arid regions. Based on the hypothesis, Solar-based atrium placement significantly improves seasonal thermal comfort in both climates. Further research should examine other building typologies, alternative atrium geometries, and other climatic zones in Iran.

Keywords: Optimal Atrium Configuration, Thermal Comfort, Yazd, Tabriz, Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD)

1- Introduction

Atriums are popular architectural elements used in residential, commercial, office, and educational buildings. For daylight to pass through an atrium, at least one facade must be transparent (Xu et al., 2025). A glass atrium can provide natural light in places where direct daylighting is not possible (S. Xu et al., 2024). The use of daylighting through atriums not only reduces artificial lighting (Shayanian & Qhadikolaei, 2024) but also provides significant psychological and ergonomic benefits to the population (Heydari et al., 2024; Ye et al., 2025). In atriums, ignoring climatic design factors can lead to poor lighting and thermal performance (CheshmehNoor et al., 2020). Atriums receive heat based on their location, dimensions, height, and the distance between the measurement point and the transparent facade. A multi-story building with a deep atrium (atriums with a low width or length to depth ratio) may experience excessive heat on the upper floors, resulting in discomfort, while the lower floors may require artificial lighting (Gorji Mahlabani et al., 2019). In addition, architects and designers face a more difficult challenge in quantifying and accurately measuring energy consumption, which requires specific awareness and knowledge of relevant energy efficiency issues (Aldawoud, 2013).

Certain regions of China have a wide range of climates, from cold in winter to warm and humid in summer. The air-conditioning of atria in these regions consumes an enormous amount of energy. It is therefore extremely challenging to manage their respective energy consumption without compromising the indoor thermal comfort. The geometric configuration of the atrium has preliminary and significant effects on the indoor environment and energy consumption (Wang et al., 2017). However, the results show that improper atrium design may increase energy consumption or create discomfort for users (Omran et al., 2020).

It impacts not only the shape and usage experience of employees, but it can also increase overall energy consumption costs for the entire building if misused. Global carbon dioxide emissions are accounted for by the building sector, and green and sustainable building concepts have become central to architectural design (Khoroshiltseva et al., 2016), (Wang et al., 2017). An atrium provides an area for gathering and communication in public office buildings. It brings natural light and solar radiation into the building (Wang et al., 2017). Energy consumption can be high if misused. Considering the atrium's large size, external conditions may easily affect it. In hot and dry climates, this can result in reduced thermal comfort, increased temperatures, or cooling of the space. The design of large atriums in many new office buildings has been illogical in recent years, resulting in massive energy waste. A skylight is one of the most important components of an atrium. Transparent materials provide natural light and solar radiation (Fang et al., 2023). An atrium with a poor skylight heat transfer performance, a large volume, and significant amounts of light entering the atrium can result in high energy consumption, glare, and excessive heat in the summer (Dolnikova et al., 2020). This research addresses the growing need to optimize atrium design in office buildings, aiming to enhance indoor thermal comfort and energy efficiency. The study investigates the optimal placement of atria in office buildings, emphasizing the integration of atrium design with spatial requirements in Yazd and Tabriz, two cities characterized by contrasting climatic conditions: hot summers and cold winters. Yazd and Tabriz in Iran exhibit distinct climatic conditions that influence atrium design and performance. Yazd experiences a hot desert climate, while Tabriz has a cold semi-arid climate. Both cities require strategic atrium placement to optimize thermal comfort and minimize energy consumption. Improperly designed atriums can result in energy inefficiency, increased cooling and heating demands, and occupant discomfort. Efficient atrium placement and geometric configuration are critical factors affecting office worker comfort and building energy performance. Improper atrium placement in these climates can lead to excessive heat gain in the summer or heat loss in the winter, resulting in increased energy consumption. This research will examine how various atrium designs in office buildings can be adapted to improve daylight penetration and natural ventilation while maintaining thermal comfort. The study will assess the impact of design parameters, including atrium orientation, skylight dimensions, and facade materials, all of which are essential for controlling heat transfer. This study will also analyze how atrium positioning and geometry influence the energy efficiency of office buildings in Yazd and Tabriz. The research will evaluate how these design elements can reduce energy costs while ensuring a comfortable and

productive environment for occupants. By determining optimal atrium configurations for these cities, the study aims to offer practical guidelines for architects and engineers to design office buildings that meet thermal comfort standards in both hot and cold climates. The primary objective of this study is to determine the optimal atrium type for improving seasonal thermal comfort in office buildings located in two different Iranian climates: Yazd (hot-dry) and Tabriz (cold-dry).

Research questions:

- 1) Which atrium placement type provides better seasonal thermal comfort in the hot-dry climate of Yazd and the cold-dry climate of Tabriz?
- 2) How does the optimal placement of an atrium, based on solar exposure, influence seasonal thermal comfort in office buildings in Yazd and Tabriz?

1.1. Theoretical Framework and Background

In recent years, atriums have become increasingly popular in public buildings due to their attractive appearance and wide view (Lu et al., 2020; Nikghadam et al., 2025b). Furthermore, they can increase indoor natural daylighting and reduce the energy consumption of lighting to a certain extent (Acosta et al., 2018). In hot summer months, however, atriums require a tremendous amount of energy to maintain a comfortable indoor temperature (Sher et al., 2019). An atrium's optical and thermal properties are contradictory during the summer. In contrast, the indoor thermal environment is almost inversely proportional to the glass roof area (Ghasemi et al., 2015). Lighting performance is almost proportional to the glass roof area. Consequently, balancing their relationship is crucial to optimizing the atrium environment. Several studies found that atrium optical performance is primarily determined by its geometric characteristics (Nikghadam et al., 2026; van Dijk, 1995). Several factors are essential in the daylighting design of atrium buildings, including the shape (Fan et al., 2021), size (Calcagni & Paroncini, 2004), and the ratio of atriums (Samant, 2011) and glass. Atrium height and monitor roof glazing height, as well as atrium position, have been evaluated by some researchers (Huang et al., 2015). The importance of several dimensionless factors has also been established. An area ratio (AR) represents how much heat an atrium receives from the sun, defined as the ratio of the area of the glass to the area of the roof. The optimal combination of daylighting and thermal comfort based on energy consumption simulations by Design Builder is $AR = 1/4$, according to Nasrollahi (Nasrollahi et al., 2015).

Section aspect ratio (SAR) is the vertical geometric feature of atriums and is defined as the ratio of atrium height to skylight width (Wang et al., 2017). At different heights, widths, and ratios of atriums in Tehran, Rastegari (2021) sought to obtain the optimal illuminance. For providing sufficient daylight in the spaces adjacent to a vertical top-lit atrium, Ghasemi (Ghasemi et al., 2016) proposed a model of an atrium with an aspect ratio of $1/3$, a section aspect ratio of 1 , and a clerestory height to atrium height ratio of $3/8$. During winters in China's hot regions, atrium thermal environments are relatively comfortable (Yang et al., 2019), while in summer they are extremely harsh, particularly at the bottom of the building. Glass roofs have high heat transfer and transmission coefficients. Additionally, atriums are dynamically coupled by radiation and convection (Abdullah et al., 2009). The result is a high surface temperature on the glass roof and a large temperature gradient in both the vertical and horizontal spaces of the atrium (Laouadi & Atif, 1998). Furthermore, atriums reduce indoor thermal comfort and air conditioning energy consumption during the summer (Vujosevic & Krstic-Furundzic, 2018; Vujošević & Krstić-Furundžić, 2017). The majority of today's energy optimization strategies are active, such as airflow organization (Chu, Liu, et al., 2017; Hussain & Oosthuizen, 2012) and stratified air conditioning (Wang et al., 2019; Chu, Sun, et al., 2017). The use of active strategies can improve thermal comfort and energy efficiency (Moosavi et al., 2015). To solve energy consumption problems, indoor heat load must be reduced (Faraji et al., 2022). By implementing passive strategies and architectural energy conservation, atrium climatic conditions can be improved without having to compensate for potentially poor energy performance in practice (Watson, 1985). The amount of air changed per minute can be increased by 40% through stack ventilation (Cuce et al., 2019). The cooling load was reduced by 24%-32% by nighttime ventilation (Albuquerque et al., 2020). The optimization of the atrium's geometric size and design configuration has attracted more attention due to the direct reduction of heat load (Laouadi et al., 2002). According to Assadi (Assadi et al., 2011), an atrium can reduce the heating load for an institutional building by 25%. Atriums have a relationship between passive heating and

ventilation, as well as their dimensions. Using computational fluid dynamics (CFD) as well as scale model tests, Liu (Liu et al., 2009) develops a methodology for predicting buoyancy-driven ventilation in atrium buildings during the design stage. In a building atrium study by Aldawoud (Aldawoud, 2013), different shapes and geometries were examined. As a result, he identified the most energy-efficient atrium design based on an assessment of the impact of the atrium shape on the total energy consumption of the building. Wang (Wang et al., 2017) investigated how to minimize the annual energy consumption of atriums with different SARs by analyzing temperature distribution profiles and energy performance. Atrium geometric parameters have been optimized primarily by optimizing the indoor light environment or building energy consumption (Kim & Kim, 2010; Naeemae & Sü Gül, 2024), but little has been done to study the internal thermal environment during the day. A simultaneous study of the indoor climate and energy consumption was not conducted. Table 1 provides a comprehensive literature review on the optimization of atrium designs in various climates.

Table 1. Literature Review

Reference	Design parameter	Impact	Method	Case study	Results
(Li et al., 2025)	Section aspect ratio (SAR)	Zero Energy Building	Simulation analysis	T&A House (zero energy house, severe cold plateau region of China)	Transforming the atrium into a central courtyard led to an increase in both annual cooling demand (ACC) by 431.31 kWh (a 44.64% increase) and yearly heating demand (AHC) by 1480.1 kWh (a 21.91% increase).
(Xu et al., 2025)	Height-to-width ratio, skylight solar heat gain coefficient, sidewall window-to-wall ratio	building energy consumption, indoor thermal comfort, and daylighting performance.	Multi-objective fast optimization	University library atrium (Wuhan, China)	Machine learning models predicted performance 400 times faster than traditional simulations. The maximum optimization rates for building energy consumption, indoor thermal comfort, and daylighting performance were 29.46%, 10.46%, and 65.56%, respectively.
(Su et al., 2025)	Shading, air conditioning, and their combination	cooling	Computational fluid dynamics simulations	High-rise office building in Xi'an, China	Combining shading and air conditioning in summer resulted in the best cooling effect (7.87°C). Shading reduced vertical temperature gradients, and ambient temperature was the most significant factor influencing atrium temperature.
(D. Xu et al., 2024)	External climate (temperature, wind velocity), smoke	Impact of varied climates on smoke movement and ventilation efficiency	Numerical simulations, NSGA-II multi-objective optimization method	Atrium-type metro stations	Improved ventilation strategies, such as platform make-up air systems and roof mechanical extraction, significantly enhanced smoke control and evacuation safety. Optimal values of V_p , v_r , and V_c were proposed based on different climate conditions.
(Lei et al., 2024)	flow rate distribution	smoke control effectiveness and safety	numerical simulations	Building with an atrium	The makeup air flow rate was redistributed based on CO concentration, with optimal flow rate proportions (15%, 27%, 28%, and 30% for the 1st to 4th floors) significantly improving smoke control and evacuation safety.
(Pang et al., 2023)	Atrium height, platform position, atrium shape,	(CFD)	Simulation analysis	Hotels in the cold climate zone, China	The optimal platform position was at the top of the second floor. With the same atrium height, smaller STH (sunlight exposure) results in less energy consumption. With the same atrium width, a higher height results in lower energy consumption.
(Xiao et al., 2023)	south facade inclination, roof inclination	Optimized combination for balanced daylighting, energy consumption, and thermal comfort	Multiobjective optimization (MOO), metrics for UDI, EUI, TDP	Building in the HSCW zone, China	The optimal combination of design parameters (south-by-west orientation, positive south facade inclination, negative roof inclination, large SARs/SARn, SARe/SARw, small TFAR) improved energy use intensity (EUI) by 18.67%.
(Rastegari et al., 2023)	Reflectance distribution,	Optimized daylight	Simulation	Kaveh Building, Tehran	Horizontal reflectance distribution with black at the top (0.02 reflectance) and white at the

	daylight autonomy (DLA), daylight factor (DF)	illuminance and DLA			bottom (0.85 reflectance) optimized the illuminance and DLA.
(Shaeri et al., 2023)	Atrium ceiling shapes	Improved natural ventilation and thermal comfort	CFD simulation, wind tunnel experimental validation	Bushehr, Iran (BWh climate)	Specimen #12 (cube-shaped roof with blade for air pressure difference) had the highest airflow (2 m ³ /s) and the best thermal comfort (PMV = 2.6), with PMV correlated with environmental parameters like air velocity, temperature, and air pressure.

A notable gap in atrium design research is the lack of comprehensive studies that simultaneously assess thermal comfort and energy efficiency of atrium geometry, particularly in regions with extreme climates such as Yazd and Tabriz, Iran. While previous studies have examined the optical performance of atriums and their effects on natural lighting, few have investigated how geometric features influence thermal comfort throughout the day in cities with hot summers and cold winters. Further research is needed to explore the interplay between daylighting and thermal comfort in these climates, advancing sustainable and energy-efficient building design. This study aims to develop a framework for optimizing atrium configurations in office buildings to enhance thermal comfort and reduce energy consumption in the specific climate contexts of Yazd and Tabriz.

1.2. Predicted Mean Vote (PMV)

There are two main approaches for evaluating thermal comfort. First, the thermal balance approach, which is based on the results of Fanger's research under laboratory conditions, and second, the adaptive approach. The theoretical basis of the thermal balance approach is the close relationship between thermal sensations and the body's temperature regulation system (Habibi et al., 2024). In this study, the PMV and PPD indices have been used (Fanger, 1970). The Fanger model is based on the ISO 7730 standard for thermal comfort (Shaeri & Mahdavinejad, 2022). The thermal comfort of an individual can be determined using the Predicted Mean Vote (PMV) index (Khorasani et al., 2025). The PMV index uses seven scales to measure the level of thermal comfort, as shown in Table 2. The PMV index depends on six factors: metabolic rate, clothing insulation, air temperature, relative humidity, air velocity, and mean radiant temperature. This index can be formulated using Equation (1).

Table 2. PMV Index Scales with Thermal Perception

Scales	Thermal Perception
3	Hot
2	Warm
1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

$$\begin{aligned}
 PMV = 0.303 e^{-0.036M} & \\
 & + 0.028x[(M - W) - 3.05x10^{-3}[5733 - 6.99(M - W) - Pa] \\
 & - 0.42\{(M - V) - 5815 - 1.7x10^{-5}M(5867 - Pa) - 0.0014M(34 - ta) \\
 & - 3.96x10^{-8}fcl\{tcl + 272\}^4 - (tr + 273)^4\} - fcl \times hc(tcl - ta)] \quad (1)
 \end{aligned}$$

Here, M and W represent the metabolic rate and external work, respectively, both measured in units of W/m^2 . Pa is the partial pressure of water vapor, measured in Pascals, and ta and tr are the air temperature and mean radiant temperature, respectively, in degrees Celsius. The clothing surface temperature, tcl, and the convective heat transfer coefficient, hc, can be calculated using Equations (2) and (3) (Dyvia & Arif, 2021).

$$tcl = 35.7 - 0.028(M - W) - Icl[3.96 \times 10^{-8} - fclx[(tcl + 273)^4 - (tr + 274)^4] + fcl \cdot hc(tcl - t)]$$

$$hc = \left\{ 2.38(tcl - ta)^{\frac{1}{4}}, hc > 12.1\sqrt{Va} \right\} \quad (3)$$

$$hc = \{12.1\sqrt{Va}, hc < 12.1\sqrt{Va}\}$$

Va is the air velocity, measured in meters per second (m/s), And Icl is the thermal resistance of the clothing, measured in square meters per degree Celsius per watt ($m^2 \cdot ^\circ C/W$). These two equations are solved iteratively until a specified degree of convergence is reached or the maximum number of iterations is reached. Meanwhile, fcl is the ratio of the surface area of the body covered by clothing to the surface area of the bare body, which is defined by Equations (4) and (5). (4)

$$fcl = \{1.00 + 1.290Icl, Icl \leq 0.078\}$$

$$fcl = \{1.05 + 0.645 Icl, Icl \leq 0.078\} \quad (5)$$

Pa is the water vapor pressure, measured in Pascals, which is related to the thermal comfort parameter through the relative humidity of the air. Additionally, ha, which can be calculated using the equation, is related. (6)

$$Pa = 10 ha e^{((16.6536 - 4030.183)/(Ta + 235))}$$

1.3. Analysis of Thermal Comfort Parameters

The analysis of the thermal comfort parameter was carried out using linear regression statistical methods. The study of the relationship between environmental parameters was conducted to examine the intensity and direction of the relationship between the PMV index and environmental parameters by finding the coefficient of determination (R^2) and the linear regression equation using Microsoft Excel. The calculation of the coefficient of determination can be seen in Equation (6). Linear regression explains the causal relationship of the variables using the model equation, as seen in Equation (7).

$$R^2 = 1 - \frac{[\sum_{i=1}^N (Y(i) - Ot(i))^2]}{[\sum_{i=1}^N (Y(i) - Ot)^2]} \quad (7)$$

Y(i) is the value predicted by the model, Ot(i) is the calculated value, $O\bar{t}$ is the mean of the calculated values, and N is the number of data points. (8)

$$Y = a + bx$$

Y is a dependent variable that represents the PMV index value, X is an independent variable that inversely reflects the environmental parameters, a is a constant, and b is the slope coefficient of the regression line, as seen in Equation (8).

2. Materials and Methods

The modeling of this case study in this research was conducted in the Grasshopper plugin environment, which is installed on Rhino software. Simulations for lighting, thermal comfort, energy, and climate analysis were carried out in the Honeybee and Ladybug environments. Their plugins were added to the Grasshopper environment, enabling it to perform energy and daylighting analyses (Sadeghipour Roudsari & Pak, 2013). In the Grasshopper plugin environment, the Honeybee and Ladybug plugins can parametrize the building physics simulation algorithm. In other words, all variables in a simulation can be instantly adjusted, allowing for highly flexible simulations. The Honeybee and Ladybug plugins serve as a wrapper for energy and thermal comfort simulation software, connecting energy-related simulations to OpenStudio and EnergyPlus, and analyzing thermal comfort issues through these connections (Pilechiha et al., 2022). A study conducted by Ashdown et al. (2006) based on a comparative study between the simulation model and experimental analysis, it is proven that Radiance analyses perform with high accuracy. Additionally, Reinhart and colleagues show that the accuracy for simulating PMV is similar to the experimental model, indicating the reliability of the data (Zhou et al., 2023). In **Figure 1**, the research tools used in this study are specified. Thermal comfort simulations can be performed using the Legacy version of the Honeybee plugin. To calculate annual thermal comfort indices during specific periods, the use of the Honeybee Plus version is essential. The added capabilities in this version allow for conducting cross-sectional studies for thermal comfort simulations and can even calculate thermal comfort indices for short periods, such as one day.

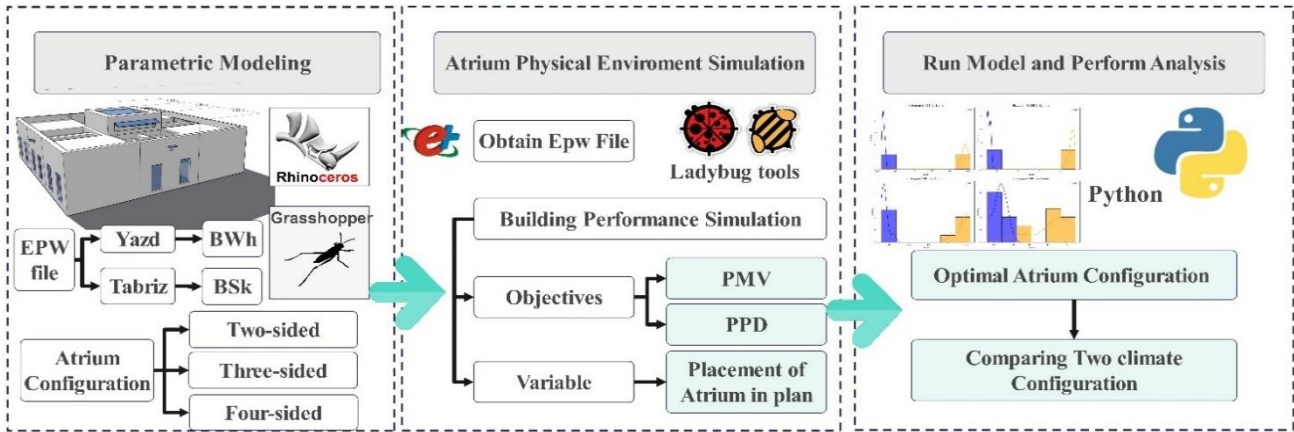


Figure 1. Research Process

Figure 1 illustrates the research process, outlining the steps involved in analyzing atrium configurations and their impact on thermal comfort in different climates. In this study, a five-story office building is considered, with the top floor being modeled and simulated. By default, the geometry of this office building is a square with dimensions of 15 meters by 15 meters, divided into nine equal sections. Each office room, by default, is 5 meters by 5 meters, and the atrium is assumed to have a fixed square geometry. What varies in this study is the placement of the atrium on different facades of the building plan. The plan is divided into a 9-grid layout, and these nine sections are rearranged to simulate various configurations. The objective of this research is to determine the optimal placement of the atrium in two different climates: the cold and dry climate of Tabriz and the hot and dry climate of Yazd. In these various placements, the atrium is indirectly connected to the office spaces through a ceiling-mounted channel. This model is explained in Table 3 by default. Additionally, three types of atrium connections to the office spaces are considered: an atrium connecting to two adjacent rooms, an atrium connecting to three adjacent rooms, and an atrium connecting to four adjacent rooms.

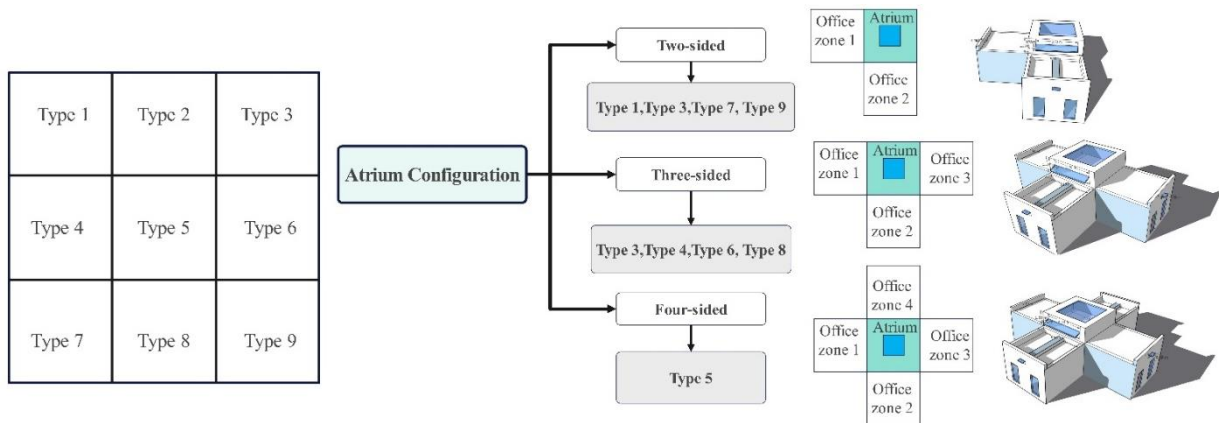


Figure 2. The Base Atrium Model

Table 3. Values during the Simulation (Javid et al., 2025c)

A five-story office building was modeled, with only the top floor simulated to reduce computational complexity while maintaining relevance for atrium performance analysis. The building geometry is a 15 m × 15 m square, divided into nine equal sections (5 m × 5 m each). Each office room is 5 m × 5 m by default, and the atrium maintains a fixed square geometry. The primary variable in this study is the placement of the atrium within the 9-grid layout of the building plan. The nine sections were rearranged to simulate various spatial configurations. The research objective is to determine the optimal atrium placement in two distinct climates, cold-dry (Tabriz) and hot-dry (Yazd) (Javid et al., 2025b). This configuration is graphically shown in Figure 2, and the base atrium model with an indirect connection via a channel. Seasonal divisions were defined according to the climatic characteristics of each city:

Yazd (hot-dry climate):

- Spring (moderately hot): March, April, May

- Autumn (moderately cold): September, October, November
- Hot season: June, July, August
- Cold season: December, January, February

Tabriz (cold-dry climate):

- Hot season: July, August
- Cold season: January, February, March
- Moderately hot season: May, June
- Moderately cold season: September

Atrium Connection Types

In all configurations, the atrium is indirectly connected to office spaces through a ceiling-mounted channel (see Table 2 for the default model). Three types of atrium connections were considered based on the number of adjacent office rooms:

- Two adjacent rooms – when the atrium is in grid sections 1, 3, 7, or 9
- Three adjacent rooms – when the atrium is in grid sections 2, 4, 6, or 8
- Four adjacent rooms – when the atrium is in the central grid section (number 5)

In the summer, atriums can become warmer if the windows are closed, which reduces the need for air conditioning. Regardless of whether HVAC systems are on or off, atrium windows allow natural ventilation to exit through the atrium by default. As a result of the ventilation channel width, natural ventilation is adequate in regulating the atrium's temperature (Javid et al., 2025a). Table 3 shows the simulation for fixed values, and Table 4 shows the materials used.

Table 4. Materials Used in the Model (Nikghadam et al., 2025a)

	Structure (m)	Thickness	Thermal Conductivity (W/m.K)	Specific Heat (J/kg.K)	Density (kg/m ³)
External Wall	Plaster	0.025	0.7	1000	1400
	Brick	0.2	0.39	840	866.67
	Uninsulated Lecca Block	0.05	0.0229	923	520
	Plaster	0.025	0.7	1000	1400
Internal Wall	Brick	0.03	0.39	840	866.67
	Plaster	0.025	0.7	1000	1400
Parameter	EPS Insulation	0.07	0.0385 Value	1200	30
Location / Climate zone	Plaster	0.025	0.7	Yazd, Iran/BWh, Tabriz, Iran/BSk	1400
Floor area	Heavy Concrete	0.15	1.06	225.00 m ² (15.00 m × 15.00 m)	2000
Channel length	Ceramic Tiles	0.01	1.3	5 m	2300
Zones height	EPS Insulation	0.1	0.0385	3.50 m	30
Room Window	Plaster	0.025	0.7	0.9 × 1.92 m ²	1400
Atrium height	EPS Insulation	0.03	0.0385	5.00 m	30
Schedule	Asphalt	0.05	0.7	Saturday to Wednesday (9:00 to 17:00)	1200
HVAC settings	Plaster	0.2	0.0385	Always off	1400
Infiltration rate per area	Heavy Concrete	0.02	1.06	0.0003 m ³ /S.m ²	2000
Number of people per unit of area	U 0.5 SHGC 0.34 Simple	0.01	520	0.10 People/m ²	923
Window					
Output intervals				Annual	

As shown in Figure 3, a channel provides an indirect connection between the atrium and office zones. This design allows air and heat energy to freely flow between the two rooms without interacting directly. Besides promoting natural ventilation, the channel also regulates temperature. There is a difference in air pressure and temperature between the atrium and the office zone. An indirect connection enhances building energy efficiency by improving thermal comfort and airflow. By reducing mechanical HVAC systems, it is possible to maintain an optimal indoor climate. The purpose of this study is to examine how channel configuration size affects thermal comfort in central atriums of office buildings in BWH and BSK climates.

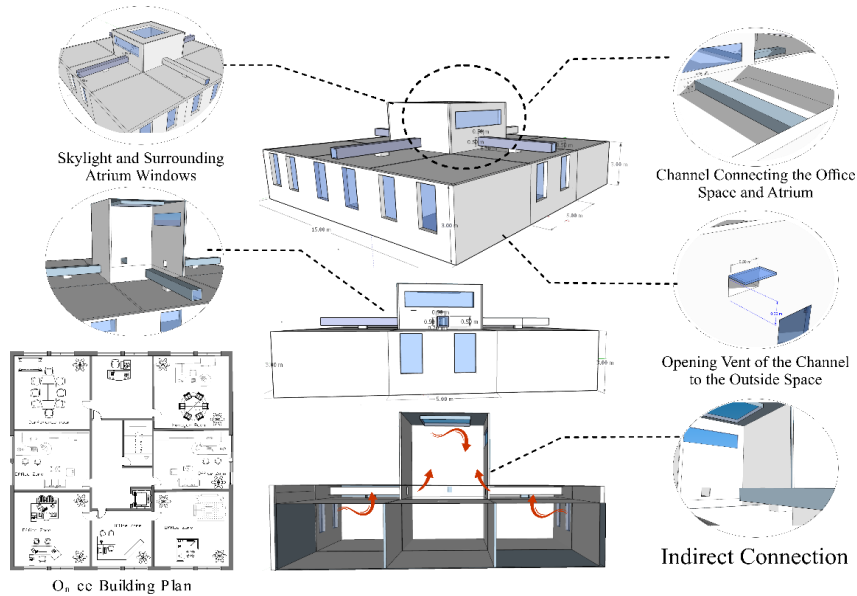


Figure 3. Indirect Connection Atrium and Office Zones by Channel

Software Validation

Validation of Honeybee and Ladybug plugins, which are widely used in daylighting simulations, was conducted in this study. A standard lighting analysis tool is operated by these plugins, integrated within the Grasshopper environment (Campano Laborda et al., 2018; Méndez et al., 2025). Numerous studies have demonstrated the reliability of these tools in different research contexts (Figure 4).

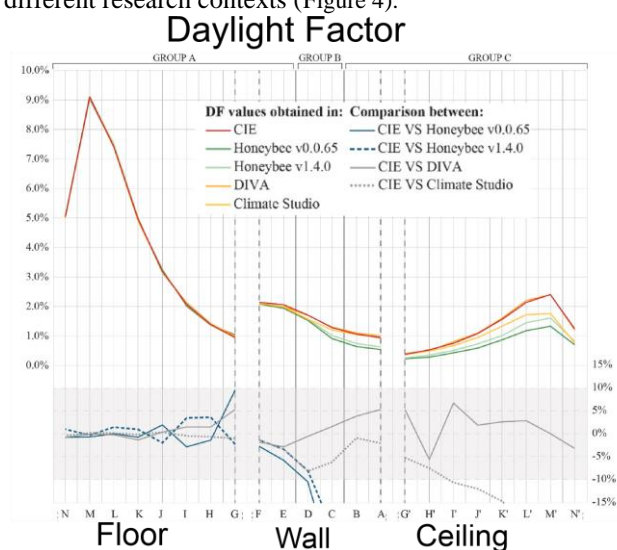


Figure 4. The Assessment of the DF using Various Tools in the CIE Test Case for a 4-meter by 3-meter Unglazed Opening (Aguilar-Carrasco et al., 2023)

By comparing Honeybee's results with a recognized benchmark, specifically the CIE 171:2006 Test Cases, this research validated the latest version of Honeybee from Ladybug Tools (1.8.0). Based on this comparison, the simulation results demonstrated high accuracy and alignment with set standards, which have significant implications for daylighting simulations (Aguilar-Carrasco et al., 2023). Additionally, the validation demonstrated the reliability of the parametric workflows used in the study, with minimal errors, indicating the effectiveness of the plugins for daylighting simulations (Institute, 2020; Mardaljevic, 1999). This study thoroughly and

°C
%
m/s
Wh/m ²
Wh/m ²
Wh/m ²

comprehensively compared the two methods. The simulation results from various programs and workflows were compared to the reference values of the CIE Test Cases. In addition to comparing the results obtained from each lighting program with the CIE Test Cases, these results were also compared with one another. In addition to

Climatic Parameter	Unit	Average	Min	Max
Dry Temperature	°C	20.89	-3.2	41.28
Relative Humidity	%	44.38	10	78.76
Wind Speed	m/s	4.07	0	8.14
Direct Normal Radiation	Wh/m ²	13271.5	0	26543
Diffuse Horizontal Radiation	Wh/m ²	299.9	209.8	390
Horizontal Radiation	Wh/m ²	18487.4	0	36974.8
Sky Cover		4.5	0	9

evaluating the accuracy of the tools through this comparison process, we also analyzed the input and use of boundary parameters through updates of each tool, including Honeybee, which has been updated to version 1.4.0 from version 0.0.65, and Solemma, which has been upgraded to Climate Studio from DIVA (Méndez et al., 2025).

Climate Analysis of Yazd: Yazd is situated in the center of Iran and experiences a variety of climatic conditions throughout the year. As a result of its location in the global dry belt, its climate is characterized by cold, dry winters and hot, dry, and long summers. As in many desert regions, temperatures in Yazd fluctuate significantly from season to season and even day to day. Yazd, for example, has an absolute minimum temperature of -3.2 °C and a maximum temperature of 41.28 °C. Based on temperature maximums, minimums, and averages, Table 5 shows Yazd's climate parameters. Figures 4 and 5 depict the climatic analyses of this region, and Figure 6 shows the UTCI chart for Yazd.

Table 5. Climatic Parameters of Yazd

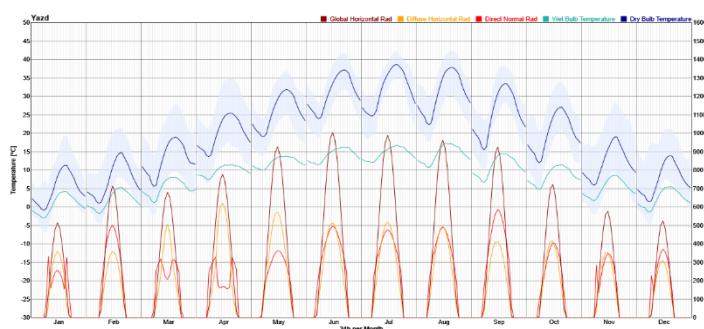


Figure 4 - Solar Radiation in Yazd

Climatic Parameter	Unit	Average	Min	Max
Relative Humidity	%	46	10	82
Wind Speed	m/s	0.5	0	10
Direct Normal Radiation	Wh/m^2	541.75	98.5	985
Diffuse Horizontal Radiation	Wh/m^2	294.25	53.5	535
Horizontal Radiation	Wh/m^2	553.85	100.7	1007
Sky Cover	%	5	0	10

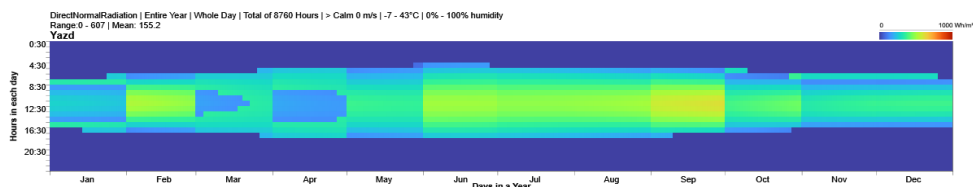


Figure 5 – Direct Normal Radiation Yazd

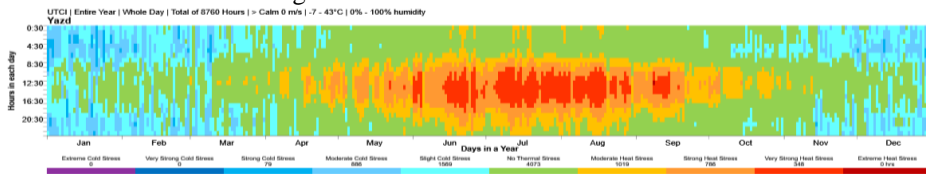


Figure 6 - UHCI Chart of Yazd

Climate analysis of Tabriz:

The climate in Tabriz is influenced by several climatic systems that are located in the northwestern region of the country. As a result of its proximity to the Zagros Mountain range, it experiences cold, snowy winters and mild, warm summers. In Tabriz, winter brings snowfall and temperature drops, especially in December and January. There are also clear seasonal temperature fluctuations in the city. During summer, the nights are usually cooler, and the heat is not as intense. Extreme temperature changes can occur suddenly, especially at night. A minimum temperature of -9°C and a maximum temperature of 40°C are recorded at Tabriz Station. Below is a table showing maximum, minimum, and average temperatures. Tabriz's charts, Figs 7 and 8, and Fig 9, contain climatic analyses for this region (Table 6).

Table 6 - Climatic Parameters of Tabriz

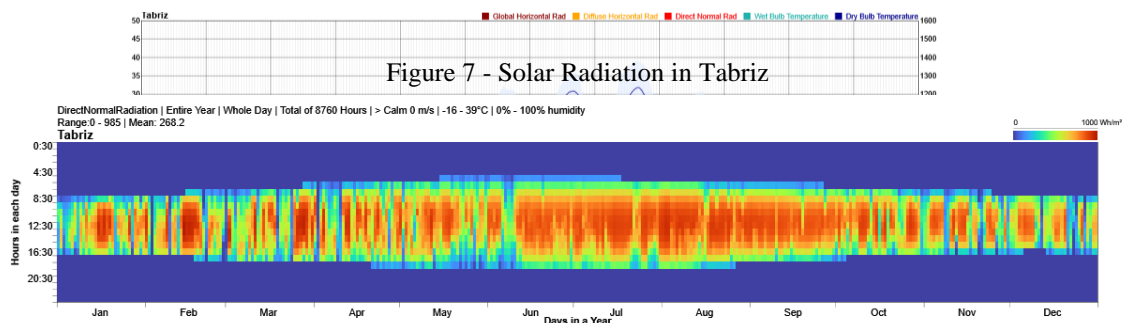


Figure 7 - Solar Radiation in Tabriz

Atrium Placement	Spring (Apr-May)	Summer (Jun-Jul-Aug)	Autumn (Sep-Oct-Nov)	Winter (Dec-Jan-Feb-March)
Type 1	-0.02	2.48	-0.75	-3.63
Type 2	-0.066	2.40	-0.73	-3.58
Type 3	0.014	2.46	-0.75	-3.62
Type 4	-0.07	2.38	-0.73	-3.59
Type 5	-0.11	2.34	-0.76	-3.62
Type 6	-0.077	2.39	-0.72	-3.59
Type 7	0.023	2.50	-0.60	-3.49
Type 8	-0.11	2.34	-0.75	-3.60
Type 9	0.033	2.49	-0.61	-3.48

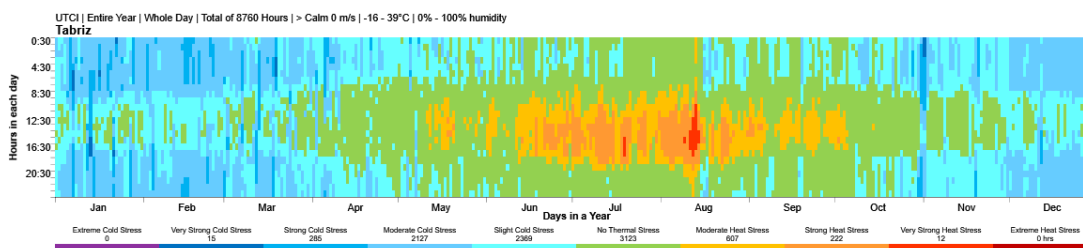


Figure 9 - UTCI Chart of Tabriz

3. Results and Discussion

Thermal Comfort Analysis Based on PMV

Yazd: This analysis evaluates Predicted Mean Vote (PMV) outputs for summer, winter, and moderate seasons (spring and autumn) in Yazd city. PMV quantifies thermal comfort, with negative values reflecting higher comfort. During summer, PMV values range from 2.34 to 2.50, where higher values correspond to reduced comfort. Type 7 exhibits the highest PMV (2.50), indicating the lowest comfort, while Types 5 and 8 show the lowest PMV (2.34), indicating improved comfort. In winter, PMV values range from -3.48 to -3.63; more negative values denote better comfort. Type 1 achieves the lowest PMV (-3.63), representing optimal comfort, whereas Type 9 records a slightly higher PMV (-3.48). For moderate seasons, PMV values span from 0.014 to -0.11, with more negative values again indicating better comfort. Type 3, with a PMV of 0.014, demonstrates the highest comfort, followed by Types 4 and 5 (PMV = -0.07). Table 7 presents the thermal comfort results for Yazd city when the HVAC system is deactivated.

Table 7. Atrium Placement based on PMV in Yazd

In Yazd city, under extreme heat conditions during the summer, Type 8, with a PMV of 2.34, performs better due to its lower PMV value. This provides superior thermal comfort. When comparing Types 5 and 8, their results are generally similar, though slight differences exist that may depend on specific environmental conditions or individual needs. For Type 5, the thermal comfort is as follows: during summer, the PMV value is 2.34, indicating relatively high thermal comfort for this season. In winter, a PMV of -3.62 provides favorable thermal comfort conditions, while in the moderate seasons (spring and autumn), a PMV of -0.07 also creates comfortable conditions. For Type 8, the PMV in summer is also 2.34, matching Type 5 and indicating comparable thermal comfort. In winter, a PMV of -3.48 is slightly less harmful than for Type 5, suggesting marginally reduced comfort. During spring and autumn, both types maintained a PMV of -0.07, demonstrating equivalent comfort levels. Both Types 5 and 8 provide similar performance during the summer, with a PMV of 2.34, indicating adequate

thermal comfort in the hot months. However, in winter, Type 5 leans slightly towards providing more optimal thermal comfort, as its PMV value of -3.62 is more negative than Type 8's PMV of -3.48. In the moderate seasons, there is no notable difference between the two types, as both exhibit a PMV of -

0.07, indicating similar levels of comfort.

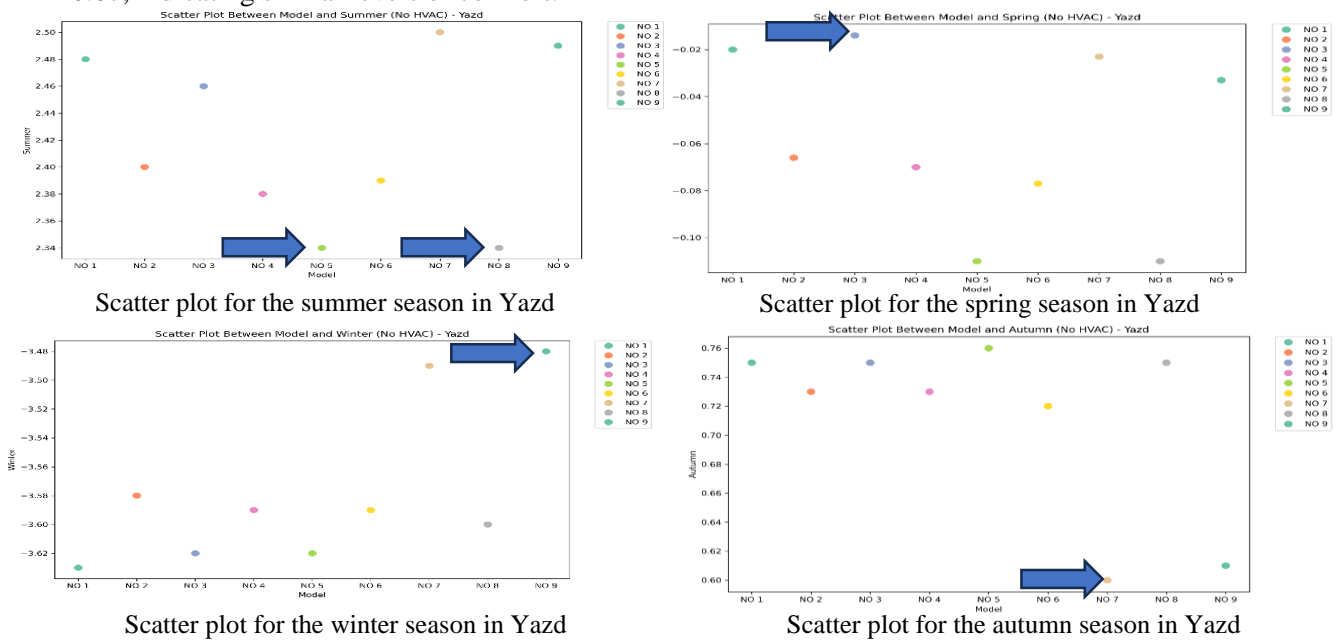


Figure 10. Scatter plot for Yazd city

Type 8 demonstrates marginally improved performance in winter, as indicated by its lower Predicted Mean Vote (PMV) value. During summer and moderate seasons, performance differences between Type 8 and Type 5 are negligible. When the objective is to minimize energy consumption or enhance thermal comfort in summer, both types are effective. For colder climates, Type 8 is preferable due to its superior winter performance. During summer, both Type 8 and Type 5, each with a PMV of 2.34, outperform Type A, which has a PMV of 4.257. As a result, Type 8 offers greater thermal comfort and operational efficiency in Yazd's hot climate. This improvement reduces reliance on cooling systems and subsequently decreases energy consumption (Figure 10).

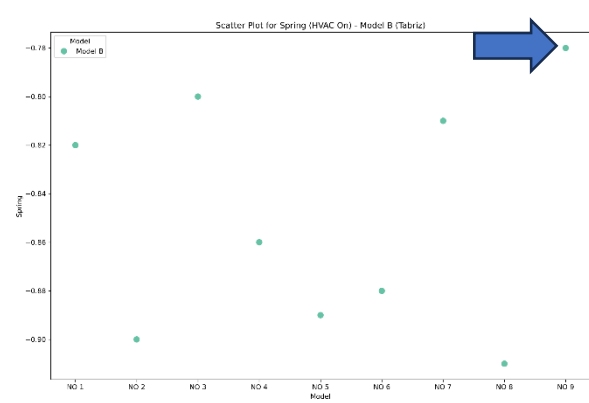
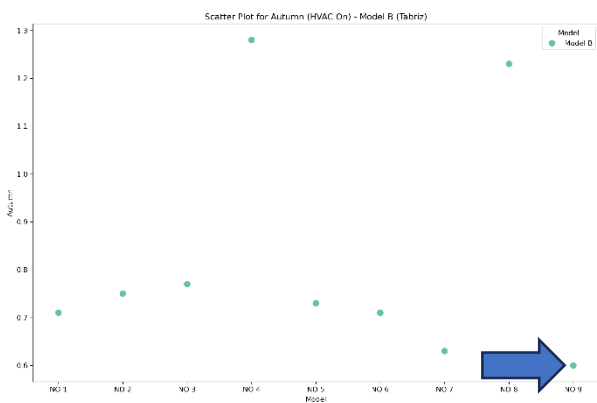
Tabriz: A Predicted Mean Vote (PMV) analysis was conducted in Tabriz city for the three seasons of summer, winter, and moderate (spring and autumn). PMV quantifies thermal comfort, with negative values reflecting greater comfort. During summer, PMV values range from 0.60 to 0.82, where higher values correspond to reduced comfort. Type 9 exhibits the highest PMV (0.82), showing the lowest comfort, while Types 2, 3, and 7 show the smallest PMV values (0.60–0.78), indicating improved comfort. In winter, PMV values range from -5.58 to -5.02; more negative values indicate better comfort. Type 3 achieves the lowest PMV (-5.58), representing optimal comfort, whereas Type 9 records a slightly higher PMV (-5.032). For the moderate seasons, PMV values span from 0.014 to -1.29, with

more negative PMV values indicating better comfort. Type 3, with a PMV of 0.014, demonstrated the highest comfort, followed by Type 2 (PMV = -1.29). Table 8 presents the thermal comfort results for Tabriz city when the HVAC system is deactivated.

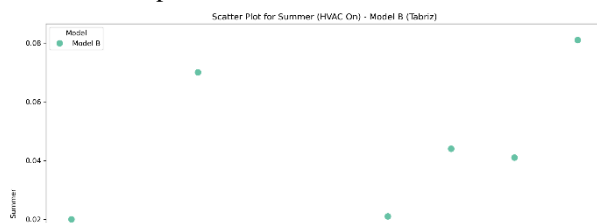
Table 8. Atrium Placement based on PMV in Tabriz

In Tabriz city, under extreme heat conditions during the summer, Type 3, with a PMV of 0.014, performs better due to its low PMV value. This provides superior thermal comfort. When comparing Types 2 and 3, their results are generally similar, though slight differences exist that may depend on specific environmental conditions or individual needs. For Type 2, the thermal comfort is as follows: during summer, the PMV value is 0.60, indicating relatively high thermal comfort for this season. In winter, a PMV of -5.14 provides favorable thermal comfort conditions, while in the moderate seasons (spring and autumn), a PMV of -0.80 creates comfortable conditions. For Type 3, the PMV in summer is 0.78, slightly higher than Type 2, indicating less thermal comfort. In winter, a PMV of -5.58 offers optimal comfort, the lowest PMV in this dataset. During spring and autumn, a PMV of 0.014 provides the highest comfort, followed by Type 2 with a PMV of -1.29 (Fig 11).

Atrium Placement	Spring (Apr-May)	Summer (Jun-July-Aug)	Autumn (Sep-Oct-Nov)	Winter (Dec-Jan-Feb-March)
Type 1	-0.70	0.72	-1.14	-5.15
Type 2	-0.80	0.60	-1.29	-5.14
Type 3	-0.68	0.78	0.014	-5.58
Type 4	-0.70	0.67	-1.21	-5.12
Type 5	-0.75	0.62	-1.26	-5.02
Type 6	-0.73	0.62	-1.24	-5.13
Type 7	-0.59	0.76	-1.12	-5.04
Type 8	-0.71	0.66	-1.22	-5.13
Type 9	-0.55	0.82	-1.08	-5.032



Scatter plot for the summer season in Tabriz



Scatter plot for the Spring season in Tabriz



Scatter plot for the Winter season in Tabriz

Scatter plot for the Autumn season in Tabriz

Figure 11. Scatter plot for Tabriz city

Based on the provided PMV data and ASHRAE 55 standards, the thermal comfort range is defined as $PMV = -0.5$ to $+0.5$. This means that if the PMV falls within this range, most people will feel comfortable, and no active heating or cooling systems are required, according to Fig 12.

For Yazd, only the spring season falls within the comfort range for most atrium placements. All placements during spring have PMV values close to zero, indicating no need for heating or cooling. However, during summer, autumn, and winter, PMV values for all placements fall outside the comfort range. This indicates a need for cooling in summer and heating in winter, as summer PMV values are highly positive (indicating excessive heat) and winter PMV values are highly negative (indicating significant cold).

In Tabriz, the situation is more severe, with PMV values outside the comfort range in almost all seasons. The only exception is autumn for Atrium Type 3, where the PMV falls within the range of -0.5 to $+0.5$, meaning no active heating or cooling is required in this case. In all other placements and seasons, PMV values are either strongly negative, indicating a need for heating, or positive, indicating a need for cooling. Overall, in Tabriz, active systems are generally necessary to maintain thermal comfort across the year. This analysis reveals that Yazd experiences naturally comfortable conditions in spring, eliminating the need for active systems, but other seasons necessitate thermal management. In contrast, Tabriz requires active heating or cooling for most seasons due to PMV values outside the comfort range.

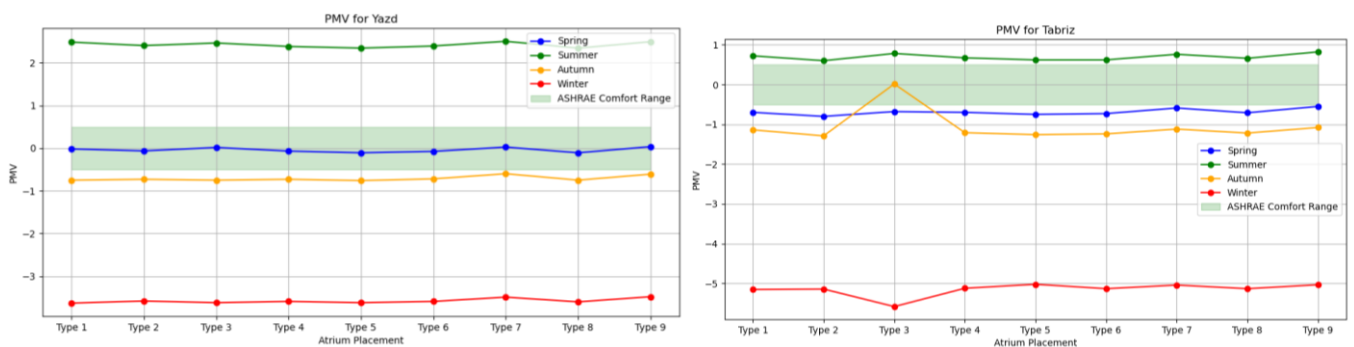


Figure 12. Placement of Atrium base on PMV

Thermal Comfort Index PPD

Thermal comfort is one of the most important factors influencing indoor environmental quality. Occupants of indoor spaces constantly seek environments that provide optimal thermal comfort. According to ASHRAE Standard 55, the ideal PMV range is between 0.5 and -0.5 . Within this range, dissatisfaction with environmental conditions decreases. In other words, the closer the PMV is to zero, the lower the percentage of dissatisfied individuals (PPD) will be (Cheung et al., 2019), Equation 9

illustrates how to calculate the index of dissatisfaction in a space based on the PMV. Tables 9 and 10 present the thermal comfort index for all orientations and the number of simultaneous openings, based on the PPD index as determined in the research. $PPD = 100 - 95 \times e^{-(0.3353 \times PMV^4 - 0.2179 PMV^2)}$

Table 9. Atrium Placement based on PPD in Yazd

Atrium Placement	Spring PPD	Summer PPD	Autumn PPD	Winter PPD
Type 1	4.99	93.00	16.85	99.98
Type 2	4.91	91.10	16.22	99.98
Type 3	4.99	92.56	16.85	99.98
Type 4	4.90	90.57	16.22	99.98
Type 5	4.75	89.46	17.17	99.98
Type 6	4.88	90.84	15.91	99.98
Type 7	4.99	93.43	12.55	99.95
Type 8	4.75	89.46	16.85	99.98
Type 9	4.98	93.22	12.80	99.95

In this analysis, the PPD (Predicted Percentage of Dissatisfied) results for various types of Atrium Placement across different seasons in Yazd are examined, as shown in Table 9.. These PPD values indicate the percentage of people who are dissatisfied with the thermal conditions, reflecting the level of comfort or discomfort in different environments. In Spring, Type 5 and Type 8 with a PPD of 4.75% cause the least discomfort, indicating the most comfortable conditions for this season. Overall, the PPD values for all Atrium Placement types are relatively low in the Spring, but Types 5 and 8 perform the best, providing the most comfort.

In the summer, when thermal conditions are more extreme, Types 5 and 8, with a PPD of 89.46%, create the least discomfort. However, PPD values in Summer are high for all types, indicating significant discomfort. Nonetheless, Type 5 and Type 8 are comparatively better than other Atrium types in providing some comfort. In Autumn, Types 5 and 8, with PPDs of 17.17% and 16.85%, respectively, generate the least discomfort, offering the best performance in this season. These values indicate relatively moderate comfort, although a significant percentage of individuals still report dissatisfaction. Type 5 and Type 8 stand out as better choices in this season compared to other types. In Winter, when the thermal conditions are harsher and colder, Type 5 and Type 8 with a PPD of 99.98% provide the best performance. During this season, all types of Atrium Placement result in significant discomfort for individuals, but Types 5 and 8 perform slightly better, causing less discomfort overall. In conclusion, Type 5 and Type 8 generally provide the best comfort in most seasons, particularly in Spring and Summer. These two types of Atrium Placement are more effective at reducing discomfort compared to others in varying thermal conditions. Therefore, to optimize comfort in Yazd, Type 5 and Type 8 are the better options.

Table 10. Atrium Placement based on PPD in Tabriz

Atrium Placement	Spring PPD	Summer PPD	Autumn PPD	Winter PPD
Type 1	10.88	5.13	40.39	99.99
Type 2	12.47	5.02	43.56	99.99
Type 3	10.36	4.67	10.00	100.00
Type 4	10.88	4.97	41.23	99.99
Type 5	9.79	5.09	44.09	99.99
Type 6	10.13	5.09	42.73	99.99
Type 7	14.05	4.72	48.22	99.99
Type 8	10.13	4.83	45.85	99.99
Type 9	15.42	5.13	40.39	99.99

This analysis examines PPD (Predicted Percentage of Dissatisfied) results for different Atrium Placements across Tabriz seasons (Table 10). PPD reflects the percentage dissatisfied with thermal conditions, indicating comfort levels in these environments. In Spring, Type 5 (PPD 9.79%) offers the most comfort, while Type 9 (PPD 15.42%) causes most discomfort. All types are moderate, but Type 5 is best. In the summer, when thermal conditions are more extreme, Type 3 with a PPD of 4.67% and

Type 8 with a PPD of 4.83% perform the best, causing the least discomfort. Type 9, with a PPD of 5.13%, also performs well but is not the top performer, exhibiting less discomfort compared to some types and more than others. Although all Atrium Placement types in summer result in significant discomfort, Type 9 still ranks among the better options for this season. In Autumn, Type 3 with a PPD of 10.00% is the best performer, causing the least discomfort. Type 9, with a PPD of 40.39%, creates the most discomfort in this season and ranks the lowest in Autumn. In Autumn, Type 3 provides the most favorable environment in terms of thermal comfort, making it the best choice among the various Atrium Placements.

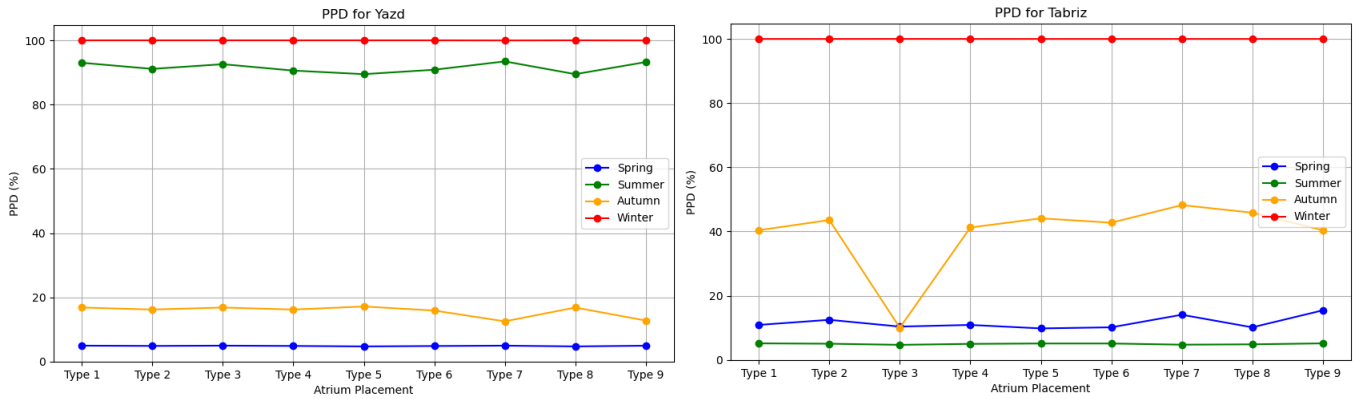


Figure 13. Placement of Atrium base on PPD

In Winter, the PPD values for all Atrium Placement types are similar, ranging around 99.99%, indicating extreme discomfort for all types during this season. Despite the high discomfort in Winter, Type 9 and the others show near-identical results. In conclusion, Type 9 is the most consistent and best-performing Atrium Placement in Tabriz. While Type 9 shows high discomfort in Winter, it provides relatively better comfort in Summer and Autumn compared to other types. Type 5 and Type 3 also perform well in specific seasons, but Type 9 stands out overall for its ability to reduce discomfort across multiple seasons. In both Yazd and Tabriz, atrium placement plays a crucial role in optimizing thermal comfort. As shown in Figure 13. Placement of the atrium based on PPD, the strategic orientation of the atrium, particularly with respect to solar exposure, can significantly enhance energy efficiency and comfort levels across different seasons.

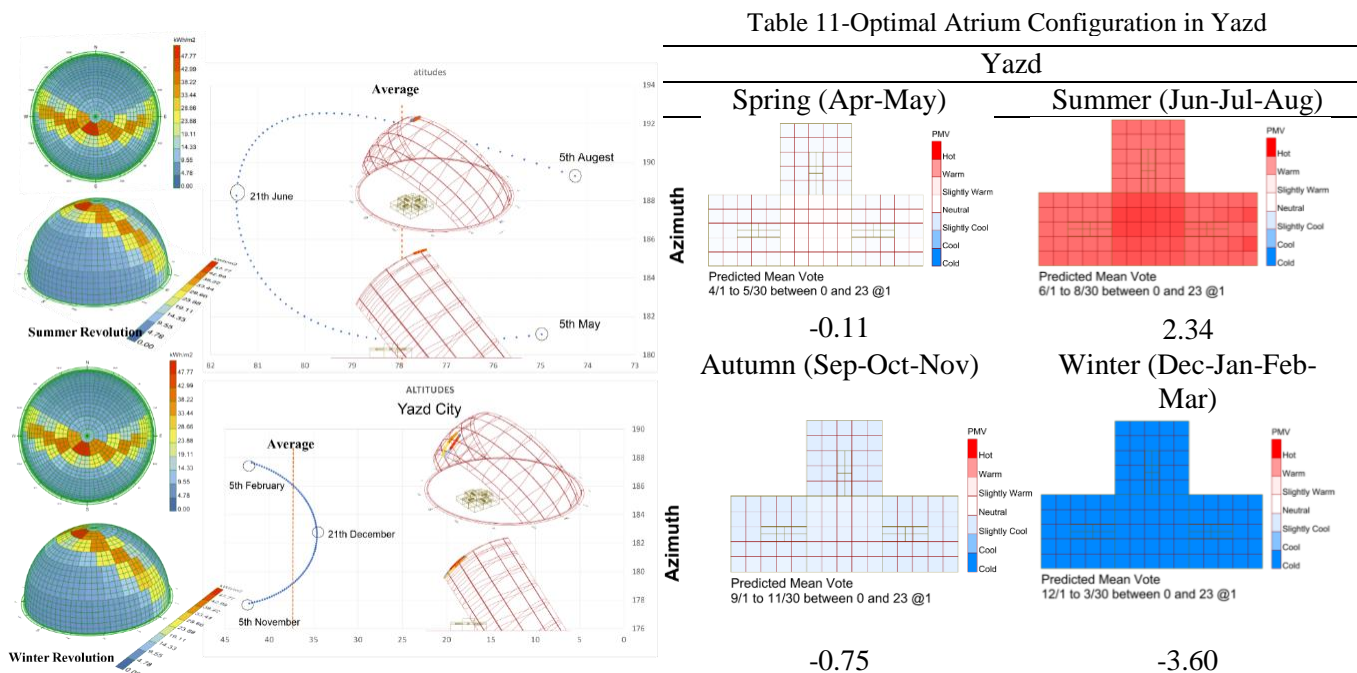


Figure 14. Climate Analysis in Yazd

Climatic and solar analysis in Yazd shows that direct solar radiation plays a crucial role in the performance of the atrium system, as it enhances the stack effect and naturally transfers heat to the building during colder seasons. Therefore, the southern façade can be exposed to sunlight throughout the day, improving overall atrium performance. Figure 14 illustrates Climate Analysis in Yazd. Considering these conditions, a central placement, specifically Atrium Type 8, which is in the path of daily solar radiation, provides the best thermal performance and maximizes building energy efficiency. In the building plan, this placement is located on the southern side. As shown in Table 11 Optimal Atrium Configuration in Yazd.

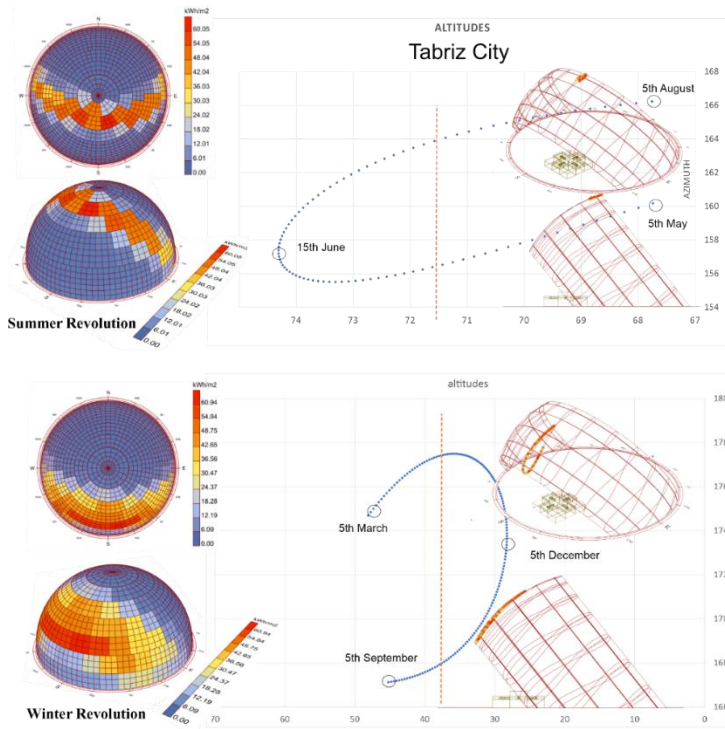


Figure 15. Climate Analysis in Yazd

In Tabriz, most PMV values fall outside the comfort range, and only Atrium Type 3 is within the -0.5 to +0.5 range during autumn, indicating that active thermal management is required for other seasons. Similar to Yazd, solar radiation is key for the passive atrium system's performance, and optimizing sunlight in winter can provide natural heating, as illustrated in Figure 15 Climate Analysis in Tabriz. Therefore, Atrium Type 3, located in the northeast of the building, ensures the best performance by receiving maximum winter solar radiation. As shown in Table 12 Optimal Atrium Configuration in Tabriz.

4. Conclusion

This study analyzed the thermal comfort performance of different atrium placements in two Iranian cities, Yazd and Tabriz, using Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices, alongside climatic and solar radiation analysis. The results reveal clear patterns regarding seasonal performance, comfort optimization, and energy efficiency.

Yazd's hot and arid climate exhibits extreme thermal conditions, especially in summer and winter. PMV analysis reveals that during the summer, most atrium types exhibit high PMV values (2.34–2.50), indicating reduced comfort. Among these, Type 5 and Type 8 demonstrate the best performance, with a PMV of 2.34, providing relatively better comfort and reducing reliance on mechanical cooling systems. In winter, negative PMV values (-3.48 to -3.63) suggest cold conditions, with Type 5 offering slightly better comfort. In moderate seasons (spring and autumn), PMV values are near zero, particularly for Types 5, 8, and 3, indicating natural thermal comfort without the need for active

Table 12-Optimal Atrium Configuration in Tabriz	
Tabriz	
Spring (Jun- May)	Summer (July-Aug)
<p>Predicted Mean Vote 5/1 to 6/30 between 0 and 23 @1</p> <p>0.014</p>	<p>Predicted Mean Vote 7/1 to 8/30 between 0 and 23 @1</p> <p>0.78</p>
Autumn (Sep)	Winter Jan-Feb-Mar- Apr-Oct-Nov-Dec
<p>Predicted Mean Vote 9/1 to 9/30 between 0 and 23 @1</p> <p>-0.68</p>	<p>Predicted Mean Vote 11/1 to 4/30 between 0 and 23 @1</p> <p>-5.58</p>

systems. PPD analysis confirms these findings: Types 5 and 8 consistently generate the least discomfort in most seasons, highlighting their suitability for Yazd's climate. Climatic analysis emphasizes the significance of solar radiation; a southern-oriented atrium (Type 8) maximizes solar gain during colder months, enhancing passive heating and energy efficiency (Figure 15). Overall, Yazd's conditions allow moderate passive comfort in spring, but heating in winter and cooling in summer remain necessary for optimal indoor comfort.

Tabriz, with a colder climate and higher seasonal variability, presents more challenging conditions for passive thermal comfort. PMV values indicate that almost all atrium placements fall outside the comfort range in summer and winter, with only Atrium Type 3 achieving comfort during autumn (-0.5 to +0.5), highlighting the need for active thermal management in other seasons. Type 3 performs best due to its favorable exposure to winter solar radiation, maximizing natural heating while providing moderate comfort in spring and autumn (Figure 16). PPD analysis supports these findings, showing that Type 3 maintains the lowest discomfort in autumn and summer, whereas most other types exhibit high dissatisfaction, particularly in winter (PPD ~99.99%). Solar radiation plays a crucial role in the passive atrium system, as maximizing sunlight in winter can reduce heating demand and enhance occupant comfort.

Yazd experiences extreme summer heat, where cooling is critical, while Tabriz requires heating in winter due to very low temperatures. Both climates benefit from solar-oriented atrium placements. Type 8 is optimal for Yazd due to its southern exposure and ability to maximize solar gain, whereas Type 3 is most suitable for Tabriz due to its winter solar access and moderate seasonal comfort.

The strategic placement of atriums can reduce reliance on mechanical HVAC systems. In Yazd, passive heating and cooling during spring and moderate seasons are feasible, whereas in Tabriz, active systems are largely necessary, except in autumn, for Type 3. Direct solar radiation is a key driver for atrium performance in both cities, enhancing the stack effect in cold seasons and contributing to passive thermal comfort. This demonstrates the importance of integrating climate-responsive design strategies when planning atrium placements. The study confirms that atrium placement, solar orientation, and climatic conditions are critical in achieving thermal comfort and reducing energy consumption. For Yazd, Types 5 and 8 provide balanced performance across seasons, particularly excelling in summer and spring. For Tabriz, Type 3 stands out as the most effective atrium design for harnessing solar heat in winter and maintaining comfort in transitional seasons. Overall, the findings emphasize the importance of climate-adapted passive design strategies in improving indoor comfort, reducing energy demand, and optimizing building performance across various climatic zones. Although this study provides practical insights, several avenues remain for future research. Researchers are encouraged to examine different building typologies to assess how atrium placement performs across various functions. The effect of alternative atrium geometries, such as rectangular, circular, or L-shaped forms, also warrants further investigation. Lastly, extending this comparative analysis to other climatic zones within Iran.

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Notes on contributors

All authors contributed equally to the preparation of this article.

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