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Thermal Performance Evaluation of TIM Combined with Residential Windows in Different Climatic Regions in Iran

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Abstract

Windows play a significant role in the increase and loss of heat from the building envelope and determine the quantity, quality, and distribution of daylight. A strategy that involves incorporating transparent insulating materials into a double-glazed window offers the potential to provide combined improvements in thermal and daylighting performance. The thermal properties of transparent insulation materials in windows depend on various factors, such as the type of insulation material, thickness, geometry and insulation structure, location, and orientation of the window, among others. The aim of this research is to optimize three criteria: "thickness," "location of transparent insulation relative to window layers," and "direction of the wall with transparent insulation of the building window." The goal is to minimize thermal loads and reduce energy consumption in residential buildings. To achieve this, a real model was selected, and Design Builder software was used to measure the "heating load," "cooling load," and the sum of these two loads as the "total thermal load" for all three criteria in three cities of Iran with different climates: Tehran (moderate climate), Ahvaz (warm climate), and Tabriz (cold climate). The results of the research showed that for the city of Tehran, 3-inch insulation in the middle of the double-glazed window and the south front is optimal. For the city of Tabriz, 5-inch insulation on the inner surface of the window and the western front is optimal. And for the city of Ahvaz, 3-inch insulation on the outer surface of the window and the eastern front is optimal. It is worth noting that the annual heating load and total annual heating load for all three criteria have the highest values in Tabriz city. Therefore, it is recommended to use HSNPS insulation in transparent windows to reduce energy consumption in Tabriz (cold climate).

Keywords: *Transparent insulation materials (TIM), thermal performance, energy saving, daylight, residential building*

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INTRODUCTION

Energy consumption in the construction sector accounts for about 40% of the total energy consumption in most countries (Bravo Dias et al., 2020; Chae et al., 2014). Therefore, optimizing energy consumption in this sector is especially important. In addition, optimizing energy consumption reduces fossil fuels and greenhouse gas emissions (Maftouni and Motaghedi, 2020; Chen et al., 2019). Comprehensive attention to residential use design, such as daylight and building openings, leads to space creation with maximum thermal comfort, which also leads to the desirability of the space.

Feeling satisfied with the quality of an environment has a positive effect on the relationship between residents. Based on studies conducted in the field of providing thermal comfort using daylight in space, the physical factors of the environment can be a suitable tool to create a balanced space. Therefore, designers can provide the ground for improving the quality of spaces by predicting and designing various activities, involving special physical considerations, and controlling the light entering the space to provide thermal comfort (Bakhtyari and Fayaz, 2019). Factors affecting the daylight in a building are the size and location of the window and the glass material (Pilechiha et al., 2020).

Today, glass is one of the components of a building, and in addition to beauty, its correct performance against climate change, humidity, temperature, and mechanical and thermal shocks are also significant parameters (Aburas et al., 2019; Peng et al., 2019). So that for each of these factors as a capability, certain standards have been upgraded according to climatic conditions and the type of building, and even the installation conditions and the type of framework affect its performance (Darvish et al., 2020).

Glass has made the shape of modern and contemporary buildings more aesthetic performance. In addition, it sometimes provides daylight and is resistant to annual climate change. Desert glass, for example, transmits heat slowly and solar radiation quickly (Huang et al., 2021; Acosta et al., 2016). Two important guidelines followed by glassmakers in Europe are (Shaik et al., 2022):

- Production of layered glass with high efficiency: creating a triple layer or solar radiation control glass to save energy.

- Better communication with the consumer: To ensure these products have the best advantage, an energy label is installed on window glass, which changes according to weather conditions (The energy label provides an indication of the energy efficiency (and other key features of products) to help you make an informed choice when making a purchase, and for future reference).

Window glass plays a dual role in the building. A thermal insulation function that provides reduced energy consumption for heating, air conditioning, and natural light. It also ensures adequate sound insulation levels. These requirements can be met using special materials with high thermal insulation and light transmission properties (Tong et al., 2021).

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Using transparent insulation in a transparent building wall can create thermal comfort for people.

Applying traditional insulation equipment (e.g elevated polystryrene (EPS), extruded polystyrene (XPS) and mineral fibre products) to the building envelope is a commonplace and mature exercise to develop thermal resistance (Harish and Kumar, 2016). Novel insulation technology, which include Vacuum Insulation Panels (Huang and Niu, 2015) and aerogel (Jia et al., 2018) can offer the specified thermal resistance, the use of layers which can be much thinner than traditional insulation substances and, as a result, lessen the thickness of the building shape. among the various additives that shape constructing envelopes, window systems, which can be liable for as tons as 60% of the overall strength consumption of a constructing (Jelle et al., 2012), are highly essential elements. that is because home windows structures make a contribution to both heat gain and heat loss thru the constructing envelope and additionally decide daylight hours distribution and daytime availability (Sun et al., 2017a). A method that entails the mixing of transparent insulation materials within a double-glazing unit offers the capability to deliver combined enhancements in thermal, sun and daytime performance (Sun et al., 2018a).

Transparent insulation materials (TIM) were originally designed for pleasant collectors to increase the amount of insulation in the collectors while not drastically reducing the solar energy transmission (Čekon and Čurpek, 2019). These materials can have two key properties simultaneously; A) Insulation against heat loss, b) Conduction of solar energy (Amein et al., 2021).

Today, these materials are used passively in the construction industry. These materials are used in the walls of houses to insulate and absorb solar energy simultaneously. The house walls act as a heat reservoir that absorbs solar radiation, converts it into heat, and slowly returns it to the indoor environment. In recent years, with the development of transparent insulating materials, they have been used in windows, walls, skylights, roofs, and high-performance collectors. These materials function similarly to opaque insulators. However, these materials can transmit daylight and sun energy, reducing the need for artificial lighting and heating (Zhou et al., 2019). These materials can transfer heat through conduction and radiation (Ammar et al., 2021).

Thermal and optical properties of transparent insulation materials depend on the type of materials used, their structure, thickness, quality, and integrity (Paneri et al., 2019). These materials usually have a hexagonal, capillary, or cellular structure. Materials such as aerogels, granules, or integrated silica can improve insulation. Depending on the structure and type of materials used, their arrangement can be classified as follows (Figure 1).

The arrows in these diagrams represent the sun's rays and the direction of these rays as they pass through the transparent insulation layer. The parallel mode of absorption, which is the best (Sun et al., 2017), reflects the most rays into the interior of the building While minimizing the amount of radiation reflected in the outside environment.

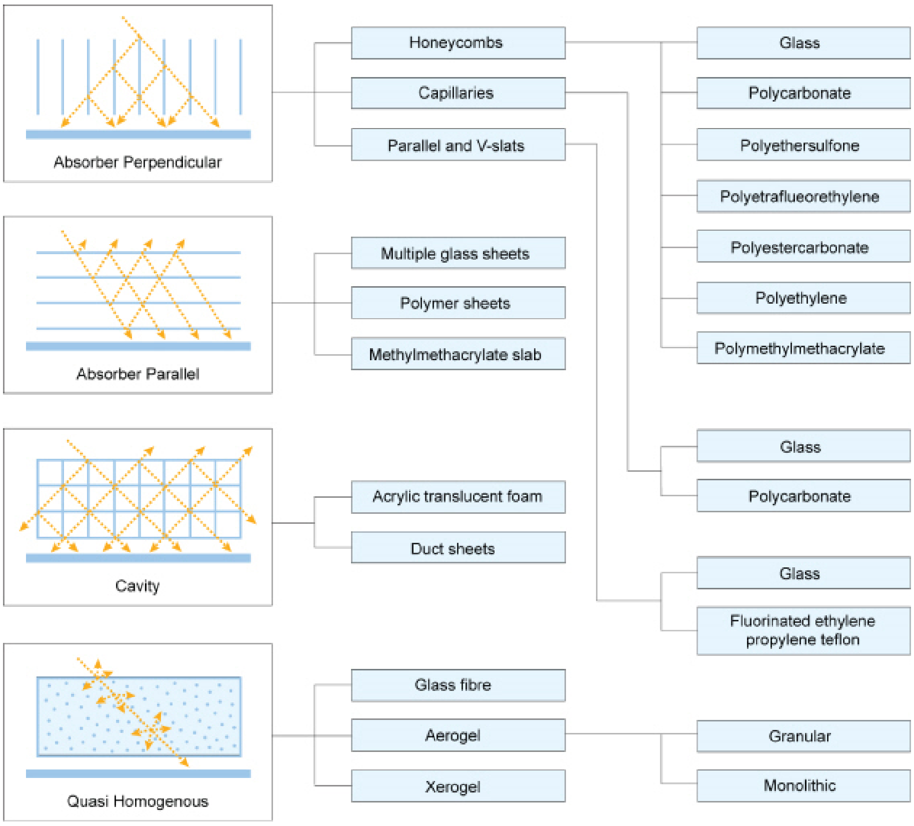

Figure 1. TIM geometry types with material and heat losses associated (Paneri et al., 2019).

The most used parallel absorber mode consists of glass or plastic plates parallel to the absorber (Sun et al., 2016). One of the disadvantages of this method is the reduction of solar reception and the reduction of solar radiation through several plates. The cell walls will be perpendicular to the adsorbent surface in the vertical adsorbent mode. This increases its reflection by the walls, resulting in more radiation reaching the absorber surface. The cavity structure is also a combination of the previous two methods. In this case, we will see a decrease in the transmitted radiation coefficient and heat transfer. The final state also includes transparent aerogel insulation materials and glass fiber. Clear silica airgel and matte carbon airgel are usually used (Buratti et al., 2017). The transparent insulation used in this research is hollow silica nanoparticles (HSNPs).

Their thermal insulation characterizes transparent insulation materials (TIM) due to the use of trapped or vacuum air layers between transparent walls to limit heat transfer (Sun et al., 2018b). Trapped air has excellent thermal insulation properties due to its low heat conductivity. Transparent insulation can be considered a material with a hexagonal structure added between the distance of two walls (Paneri et al., 2019). Although these materials are transparent to the sun, they are also good thermal insulators. Heat transfer rate and solar radiation transmission coefficient are two parameters used to classify these

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materials (Wong and Eames, 2015). These materials can transmit short-wavelength radiation and, at the same time, prevent the passage of long-wavelength radiation. Therefore, short-wavelength solar radiation can pass through these materials, and these materials block the passage of long-wave heat radiation. The solar energy that collides with these materials is reflected and then reaches the absorber surface due to reflection inside the material (light refraction phenomenon). Also, these materials have a higher heat resistance than standard glass due to their lower conductivity (Sun et al., 2018c).

The heat transfer in the hexagonal structure of these materials is usually by radiation and conduction, and no convection occurs (Wong and Eames, 2015).

Fibrous materials and gaseous foam plastics provide some insulation due to low thermal conductivity but are not transparent (Cai et al., 2016).

A nano-spaced polymer film consisting of hollow silica nanoparticles (HSNPs) dispersed in polyurethane (PU) provides a good thermal insulation matrix and is transparent. HSNPs with siliceous shells and nano-sized hollow interiors are composed of a core-shell structure prepared by the sol-gel reaction of silicon alkoxide (TEOS) (Abdul Mujeebu et al., 2016). One of the advantages of using HSNPs is that the quasi-vacuum state in the nanospace is formed when the size of space is close to the average length of the free path of air molecules in space (Fuji et al., 2015). Therefore, heat tends to be transferred along the siliceous crust of HSNPs rather than through other materials in the film. Scattered HSNPs clothing in the film is the key to transparency and good thermal insulation.

Wong et al. (2012) simulated the performance of TIM glazing that incorporated a 22 mm polymethyl methacrylate (PMMA) capillary slab on a south-facing façade. The annual results they predicted for the climate of London showed that when compared to standard double glazing, daytime internal temperature swings were reduced, and up to a 6.1% heating energy saving in the winter could be achieved. In a study by Sun et al. (2016), transparent plastic sheets formed between glass panels to create transparent and parallel insulation (PS-TIM) have been proposed as a strategy for heat transfer between double-glazed window panels. The results show that the aspect ratio of 0.35 can reduce CONVECTION. The PS-TIM structure can also reduce thermal conductivity by 35 to 46% compared to similar double-glazed glass without PS-TIM.

Hao et al. (2018) designed and assessed a new TIM product made of SPACER fabric composite. This product offers more flexibility and less weight than traditional TIMs. The results show that the stable shrinkage temperature of SPACER fabric composite can be up to 98°C at ambient temperature and up to 32°C at 1100 W/m2. Therefore, SPACER fabric composite is extremely useful in transparent insulation materials. The paper by Paneri et al. (2019) provides an overview of TI systems and materials (TIM) by identifying TI systems based on geometry, materials used, and overall heat losses in these geometric designs. The results of this study show that in existing TIM technologies, TI systems containing aerogels have the lowest heat transfer (U-value) and better solar transfer (g-value) at a lower thickness than other TI systems.

Research by Perkska et al. (2020) Energy efficiency of a transparent insulated solar wall (SW-TI) with honeycomb insulation made from modified cellulose acetate for different climatic conditions in Poland, different coatings orientations, and Different insulation thicknesses were analyzed. The monthly thermal balance obtained using the proposed model presents results after calculating the heat gain for opaque building coatings with transparent insulation in PN-EN ISO 13790: 2008. Research by Wang et al. (2020) introduces the basic principles of thermal and optical properties of silica aerogels and highlights their adjustability through artificial control and processing.

"In addition, the use of silica aerogels in transparent thermal insulation windows is discussed." ("(PDF) Thermal Conductivity Performance of Silica Aerogel after ...") Sun et al. (2018) present the first step in developing a new intelligent window system that enhances energy efficiency and a bright indoor environment by integrating a transparent insulation material structure (TIM) with a thermo-tropic material Achieves. The annual simulation results predict that by carefully selecting the properties of the thermos-tropic material, the TT PS-TIM window system installation can save up to 27.1% Compared to a typical double-glazed window under the modeled climate of Rome.

Research of the thermal and optical performance of TIMs contained in the cavity of double-glazed constructed home windows is fairly short. Lien et al. (1997) researched overall performance of glazing with incorporated capillary TIM in terms of daylight hours distribution and visible connectivity as well as energy consumption of its software on a row residence. Simulation effects confirmed that changing a part of a traditional wall with a TIM wall led to annual strength savings of between sixteen% and 20%. Moreover, they counseled that visual connectivity is related to the thickness of the structure as well as the gap and attitude between the observer and the glazing system. Growing distance from the window results in an increased variety of vision, and increasing the thickness of cloth has consequences of a lower variety of imaginative and prescient. larger diameter capillaries also result in a bigger obvious vicinity. Wong et al. (2012) conducted a laptop simulation of TIM-glazing using a 22 mm PMMA capillary slab on the south dealing with façade. The results for a complete calendar 12 months confirmed that during evaluation with popular double glazing, daylight inner temperature swings have been reduced and, while mixed with thermal mass, sun protection and herbal air flow techniques, TIM-glazing has the ability to reduce heating energy load in winter and overheating in the summer season. In the research of Zhang et al. (2021), to reveal the discrepancy between the test theory and the experimental heat transfer process when measuring translucent thermal insulation materials using the HW method, the heat transfer process with transient conduction and

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radiation is simulated numerically. Numerical analysis shows that TC thermal insulation materials with low extinguishing capability measured using the HW method at high temperatures were overestimated.

Insertion of TIM material may also block and scatter daytime transmitted through the window (Garnier et al., 2015). This prevents robust direct daylighting and undesired glare, ensuing in a greater at ease and uniform distribution of sunlight hours into the occupied area and therefore diminishes the requirement for shading devices (Sun et al., 2017a). The predictions from the research via Sun et al. (2017b) suggest that the inclusion of Playstation -TIM systems stepped forward the luminous surroundings through decreasing the hours of over illumination and in so doing ended in a more uniformed illumination of the working plane for distinct climates (i.e. Stockholm, London, Beijing, Hong Kong and Singapore). But, the reduced solar and visible transmittance also extended the predicted strength required for area heating and synthetic lights, whilst the solar radiation and/or out of doors illuminance become lower. Novel switchable glazing is some other capability system supposed for software in buildings, providing the capability to improve both energy and daylighting performance (Zhang et al., 2019; Aburas et al., 2019. This is completed especially thru its ability to alter sun and daylight transmittance in response to the various outside surroundings (Flor et al., 2018).

The thermal properties of TIM in windows depend on various factors such as the type of insulating material, thickness, geometry and structure of the insulation, location and orientation of the window, etc. (Paneri et al., 2019). Most of the previous research on TIM has focused on its application in solar collectors. In the field of its application in building windows, two criteria, "type of insulation material" and "insulation geometry and structure" have been investigated, and other criteria affecting the performance of TIM in building windows have not been evaluated. The innovation of the present research is the simultaneous analysis of three criteria: 1) comparison of the cooling load, heating and the total load of using transparent insulation based on the location inside, in the middle and outside of the window, 2) comparison of the cooling load, heating and the total load of using transparent insulation for four directions different in residential building, 3) comparison of cooling load, heating load and total load comparison for different thicknesses of transparent insulation, in three different climates (Tehran, Ahvaz and Tabriz cities in Iran).

Therefore, the aim of the current research is to investigate the thermal comfort conditions with regard to the placement of the transparent insulating layer in the windows of the building and to analyze the changes in temperature and energy consumption for all three criteria in a case study by answering the following questions:

1. What is the best placement of TIM in the window for each climate in order to minimize thermal loads?

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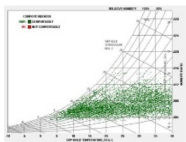
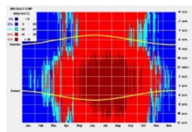
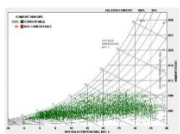
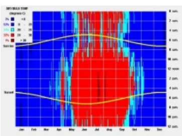
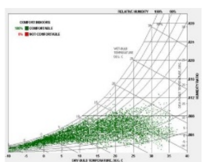
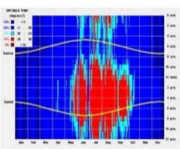
2. What is the best TIM thickness for each climate in order to minimize thermal loads?

3. What is the best orientation of window with TIM for each climate in order to minimize thermal loads?

RESEARCH METHOD

Solar radiation is also considered to achieve thermal comfort by analyzing climate data. Design Building simulator software has been used to simulate and analyze all information and data. Researchers have widely welcomed this software due to its graphical environment, air conditioning design, CFD, and other capabilities, and its validation has been examined by ANSI / ASHRAE 140-2014 standard (Bakhtyari and Fayaz, 2019). On the other hand, the analysis of thermal conditions in the building of the case is considered the same for all three climates. Therefore, the relative errors are equal in all stages and do not have a significant effect on the total energy demand. 4 spaces in 4 different directions based on the use of transparent insulation in the sample glass of low-density residential buildings in three cities of Tehran (temperate climate), Tabriz (cold climate), and Ahvaz (warm and humid climate) are analyzed. This study focuses on the optimization of three criteria: "thickness", "location of transparent insulation relative to the window layers" and "direction of the wall with transparent insulation of the building window" to minimize thermal loads and reduce energy consumption in residential buildings.

Table 1. Geographical and climatic characteristics of the cities considered for analysis.

City Name	Latitude	Longitude	Above sea level	Construction group	Range of comfortable conditions in the city	The annual temperature of the city
Ahvaz	31.28	48.72	1200	Buildings with high energy consumption and its predominant thermal requirement are cooling		
Tehran	35.41	51.19	1120	Buildings with medium energy consumption		
Tabriz	38.05	46.17	1361	Buildings with high energy consumption and predominant thermal requirement are heating		

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This analysis is based on the measurement of "heating load", "cooling load" and the sum of these two loads as "total thermal load" of indoor air temperature and annual energy consumption. Three criteria of heating, cooling, and air temperature are considered to achieve thermal comfort. Finally, the results of the studies are compared, and an optimal example is presented in line with the purpose of the research, as shown in (Table 1).

(Figure 2) shows the plan of the 3rd floor (due to the lack of heat loss from the floor and ceiling) of a residential complex located in Tehran. The height of the floor, regardless of the thickness of the ceiling, is 2.90 meters, and the thickness of the ceiling is 0.35 meters. The window's height, OKB, and width are 1.5, 1.2, and 1.5 meters, respectively (Figure 2).

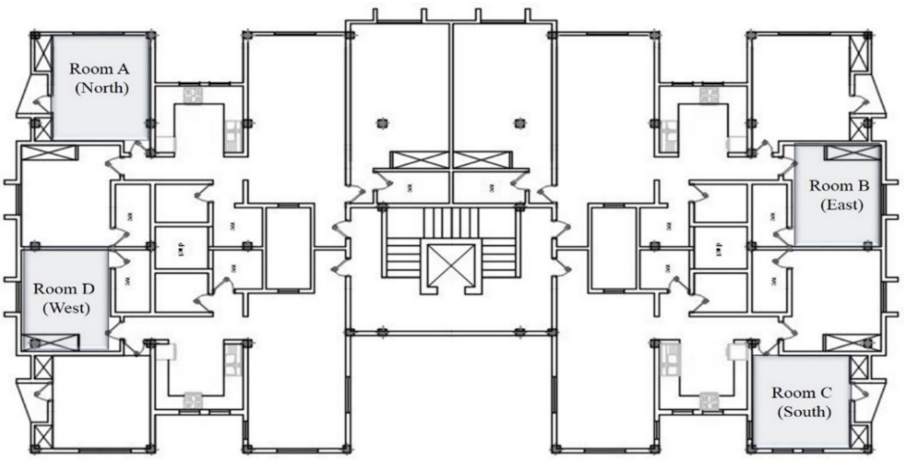

Figure 2. Residential complex plan

The characteristics of the studied spaces in this research are presented in (Table 2).

Table 2. Specifications of the spaces under study in the plan

Space	Floor area (m2)	Exterior wall area (m2)	Wall opening area (m2)
Room A (North)	25	12.5	4.5
Room B (East)	19	16.2	11.6
Room C (South)	20	11	4.5
Room D (West)	19	16.5	11.6

The thermal characteristics of the materials forming the walls are shown in (Table 3).

HSNPs transparent insulation has a conductivity of 0.019 W / m.K, a specific heat capacity of 1900 J / kg.K, and a density of 1540 Kg / m3. This study investigated different thicknesses of 1, 3, 5, and 7 inches for this insulation. The windows have a thermal break aluminum frame (heat transfer coefficient k=1.8) with double glazing (the thickness of each glass is 4 mm, and the distance between the two glasses is 8 mm), and the

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type of glass is unbreakable, the characteristics of which are defined according to the software standard. (Figure 3)

Table 3. Thermal characterizations of components

Components	Layer name	Conductivity W/m.K	Specific heat capacity J/kg.K	Density Kg/m3	Thickness Cm
External wall	Brick facade	1.1	840	1920	3
	Cement mortar	1.15	920	2000	2.5
	Brick	1.0	840	1100	3
	Plaster and soil	1.15	840	1000	2.5
	Plaster	0.7	1000	1300	0.4
	Oil color	0.1	1500	1000	0.1
Ceilings and floors	Cement tile	1.4	1000	3000	3
	Cement mortar	1.15	920	2000	2
	Concrete	0.34	840	1300	5
	Roof block	0.76	840	1920	30
	Plaster and soil	1.15	840	1000	2.5
	Plaster	0.7	1000	1300	0.4
	Oil color	0.1	1500	1000	0.1
HSNPs transparent insulation		0.019	1900	1540	0.5

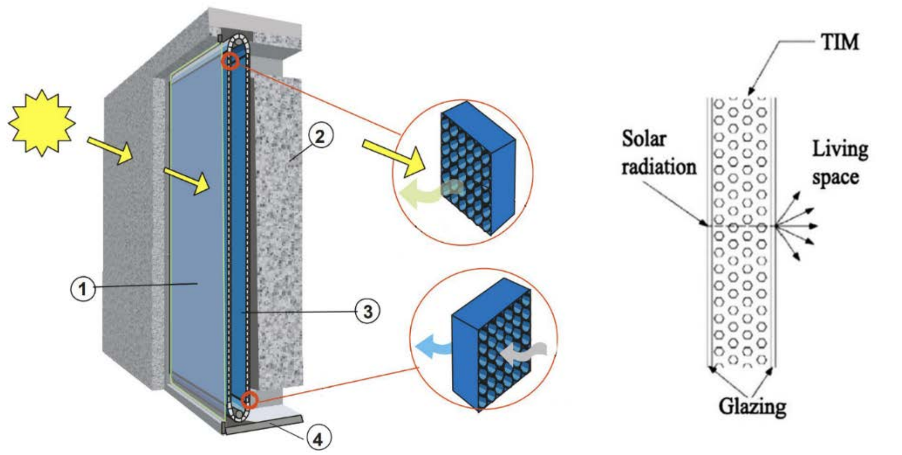

Figure 3. Configurations of TIM in window systems: (1) glazing, (2) wall, (3) TIM, (4) aluminum frame (Szyszka, 2022)

The lighting of the above building with a brightness of 500 Lux and a luminance coefficient of 0.72. The heat energy of active electrical equipment operation in a residential environment is assumed to be 52 watts per square meter. The natural airflow penetration into the building through the entrance door, windows, and other vents changes the air temperature and humidity ratio. Therefore, the rate of temperature change is assumed to be 0.7 times the air exchange rate per hour.

RESULTS

One way to reduce energy consumption in buildings is to use thermal insulation on windows. Because windows significantly contribute to the increase and loss of heat from the building enclosure and determine the

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quantity, quality, and distribution of daylight emitting into space. One potential answer to enhance window performance is to use a transparent Insulation fabric (TIM) in building windows (Sun et al., 2018b). TIM seeks to provide resistance to warmness drift without hindering the transmittance of sunlight relative to a non-transparent insulation fabric. A decrease in thermal transmittance (i.e. U-fee) of a TIM decreases undesired warmth losses from the internal space to the external environment, and for that reason reduces the construction's heating load (Paneri et al., 2019).

To evaluate the effect of using HSNPS transparent insulation, the annual thermal loads were compared in two modes of "use of insulation" and "non-use of insulation". To investigate this, the thickness, location of the insulation, and direction of the transparent wall of the building are assumed to be constant. Therefore, the comparison of thermal loads in the case of using insulation with a thickness of 3-inch and in the inner part of the glass to the north with the case of not using insulation is shown in (Table 4).

Table 4. Comparison of thermal loads in two modes "use of insulation" and "no use of insulation"

Thermal load	No insulation			Use insulation		
	Tehran	Tabriz	Ahvaz	Tehran	Tabriz	Ahvaz
Cooling	88614	59994	339579	24894	8532	97200
Heating	457542	680968	680967	156006	220482	62478
Total	546156	740961	740961	180900	229014	159678

To determine the optimal thickness of HSNPS transparent insulation, the location of the insulation and the direction of the transparent wall of the building are assumed to be fixed. The thickness of the thermal insulation in four thicknesses of 1, 3, 5 and 7 inches and in the inner part of the north-facing glass has been checked, which is as described in Table 5 (the reasons for choosing these numbers as different thicknesses for analysis, the presence of HSNPS transparent insulation with These thicknesses are in the market) (Table 5).

Table 5. Comparison of thermal loads in different thicknesses

Thickness insulation	Thermal load	Tehran	Tabriz	Ahvaz
1	Cooling	25779	14434	195960
	Heating	276507	349687	85833
	Total	302286	364122	281793
3	Cooling	19899	6356	70686
	Heating	113691	161568	45679
	Total	133591	167924	116365
5	Cooling	11405	3743	45085
	Heating	74369	102227	28631
	Total	85774	105970	73715
7	Cooling	8553	2970	32848
	Heating	52807	75557	20968
	Total	61360	78527	53816

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According to the results of the above tables, the percentage of reduction of thermal loads due to the placement of different thicknesses of transparent HSNPS insulation can be obtained as follows:
Percentage of improvement = ((amount of heat load in the state of using insulation) / (amount of heat load in the state of without insulation) – 1) * 100

The formula shows the percentage of thermal load reduction for northern glass in (Table 6).

Table 6. Percentage reduction of thermal loads using different thicknesses transparent insulation

Thickness insulation	Thermal load	Tehran	Tabriz	Ahvaz
1	Cooling	68.77	73.66	41.02
	Heating	38.37	47.18	50.96
	Total	43.31	49.32	44.47
3	Cooling	75.21	86.72	76.8
	Heating	72.9	73.98	72.5
	Total	73.26	75.01	75.31
5	Cooling	84.51	90.95	84.12
	Heating	81.23	82.43	81.64
	Total	81.76	83.12	83.26
7	Cooling	87.63	92.19	87.61
	Heating	85.8	84.29	85.75
	Total	86.1	86.72	86.96

To determine the best placement of HSNPS transparent insulation, the thickness and direction of the transparent wall of the building are assumed to be fixed. Therefore, the comparison of thermal loads in the case of using 3-inch insulation and in three positions inside, in the middle, and outside of the north-facing glass is described in (Table 7).

Table 7. Comparison of thermal loads in different placement positions

Thermal load	placement position	Tehran	Tabriz	Ahvaz
Cooling	Interior	18236	6356	70686
	Middle	19899	6356	70211
	Exterior	135491	6534	70924
Heating	Interior	113691	161568	45679
	Middle	112088	161450	45916
	Exterior	112266	160261	45382
Total	Interior	133591	167924	116365
	Middle	130324	167805	116127
	Exterior	23225	166795	116305

Also, the percentage of reduction in heat loads in different situations for each city is as described in (Table 8).

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Table 8. Percentage reduction of thermal loads using different placement positions transparent insulation

Thermal load	placement position	Tehran	Tabriz	Ahvaz
Cooling	Interior	77.04	86.12	76.8
	Middle	75.21	86.72	77.74
	Exterior	72.93	86.23	76.94
Heating	Interior	72.9	74.87	72.5
	Middle	73.24	74	72.37
	Exterior	73.2	73.98	72.65
Total	Interior	73.26	75.01	75.31
	Middle	73.85	75.03	76.35
	Exterior	71.58	75.96	74.32

Another component of insulation optimization is determining the location of insulation in 4 geographical directions in a way that results in the greatest reduction in thermal loads. In this case, the insulation thickness (3-inche) in the inner part of the glass is considered fixed and the results of this section are described in (Table 9).

Table 9. Comparison of thermal loads for insulation in different directions

Direction	Thermal load	Tehran	Tabriz	Ahvaz
East	Cooling	38448	16416	106866
	Heating	134838	200124	50652
	Total	173286	216540	157518
North	Cooling	24894	8532	97200
	Heating	156006	220482	62478
	Total	180900	229014	159678
South	Cooling	44280	14202	92556
	Heating	105462	176850	57132
	Total	149742	191052	149688
West	Cooling	36072	16092	115992
	Heating	137754	187812	50490
	Total	173826	203904	166482

Also, the percentage of reduction of thermal loads in different directions for each city is described in (Table 10).

Table 10. Comparison of percentage reduction of thermal loads for insulation in different directions

Thermal load	Direction	Tehran	Tabriz	Ahvaz
Cooling	East	65.15	68.10	69.42
	North	69.74	83.20	69.23
	South	65.50	70.75	73.86
	West	68.75	71.87	67.17
Heating	East	67.09	66.50	66.12
	North	63.92	65.59	63.49
	South	68.04	66.65	49.12
	West	65.11	68.53	66.63
Total	East	66.68	66.63	68.44
	North	64.86	67.02	67.23
	South	67.33	67.00	68.17
	West	65.93	68.83	67.01

DISCUSSION

According to the outputs of the previous section, the following results can be extracted.

• **Location of TIM:** Based on the analysis and results of the previous section, the answer to the first question of the research (what is the best location of TIM in the window for each climate in order to minimize thermal loads?) is as follows:

For the city of Tehran, placing transparent HSNPS insulation on the inner surface of the glass has the maximum reduction in annual cooling load. Placing insulation in the middle of double glazing has the maximum reduction in heating load and total annual heat load. Placing insulation on the outer surface of the glass has the minimum reduction in total annual heat load. For the city of Tabriz, placing transparent HSNPS insulation on the glass's inner surface has the greatest annual heating load reduction. Placing insulation in the middle of double glazing has the maximum reduction in annual cooling load. Placing insulation on the outer surface of the glass has the least reduction in total annual heat load. For the city of Ahvaz, placing transparent HSNPS insulation on the inner surface of the glass has the maximum reduction in annual heating load. Placing insulation in the middle of double glazing has the maximum reduction in cooling load and total annual heat load. Placing insulation on the outer surface of the glass has the minimum reduction in the total annual heat load (Figure 4).

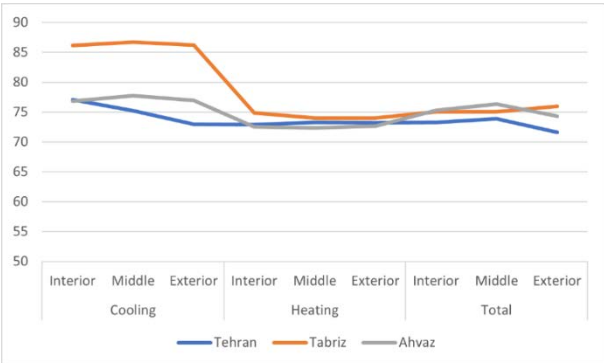

Figure 4. Comparison of the placement of TIM in three cities

In the general comparison based on Figure 4, the highest percentage of changes belongs to the reduction of the cooling load by placing the HSNPS transparent insulation in the middle of the double-glazed glass in Tabriz city. Also, the lowest percentage of changes belongs to the reduction of the total thermal load by placing transparent HSNPS insulation on the outer surface of the glass in Tehran.

• **TIM thickness:** Based on the analysis and results of the previous section, the answer to the second research question (what is the best TIM thickness for each climate in order to minimize thermal loads?) is as follows:

According to the results, adding 2 inches to the insulation thickness (converting 1 inch to 3 inches) in different cities reduces the thermal load

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by about 40 to 50 percent. This percentage will increase as the insulation thickness increases to 5 inches. Nevertheless, from this point onward, the reduction of thermal loads does not have significant changes as the thickness increases (Figure 5).

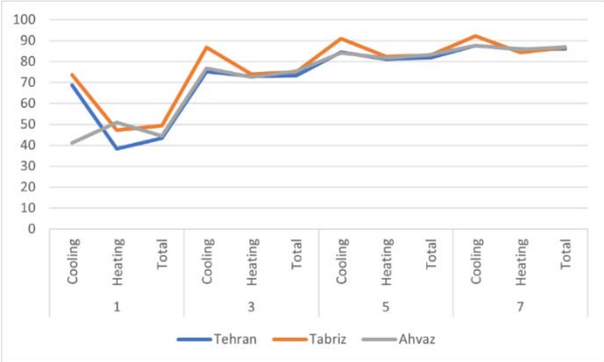

Figure 5. Comparison of the TIM thickness in three cities

Therefore, the thickness of the insulation should be selected as the optimal thickness, which in addition to the acceptable reduction of thermal loads, is also economically viable. The optimal insulation thickness is selected so that the difference between the percentage of improvement of that thickness and the percentage of improvement of the maximum thickness (7 inches) is not more than 10%. According to this issue, Tehran's optimal thermal insulation thickness is 3 inches. For Tabriz, the optimal thickness of thermal insulation is 5 inches; for the city of Ahvaz, the optimal thickness of thermal insulation is 3 inches.

• **The direction of the window has TIM:** Based on the analysis and results of the previous section, the answer to the third question of the research (what is the best direction of the window with TIM for each climate in order to minimize thermal loads?) is as follows:

The best place for HSNPS transparent insulation in the glass (windows) of rooms with different fronts, which has the greatest reduction in cooling load in Tehran, were the north, west, south, and east windows, respectively. This was also the same in the city of Tabriz. In Ahvaz, the windows were south, east, west, and north, respectively. The best location for insulation, which has the greatest reduction in heating load in Tehran, were the south, east, west, and north windows, respectively. In Tabriz, the windows were west, south, east, and north, respectively. Ahvaz had western, eastern, northern, and southern windows, respectively. The best location for insulation, which has the maximum reduction in total annual load of Tehran, were the south, east, west, and north windows, respectively. In Tabriz, they were western, northern, southern, and eastern windows, respectively. In Ahvaz are the east, south, north, and west windows (Figure 6).

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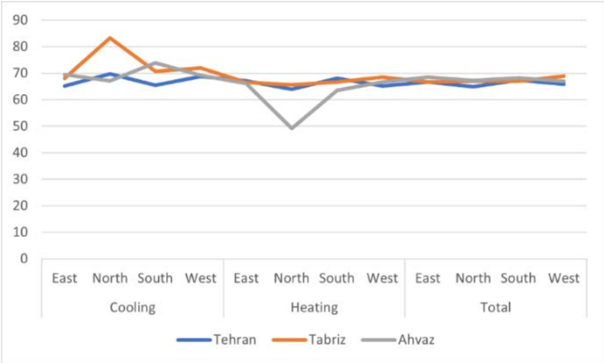

Figure 6. Comparison of the direction of the window has TIM in three cities

In the general comparison based on Figure 6, the highest percentage of changes belongs to the reduction of the cooling load by placing the HSNPS transparent insulation on the northern front of Tabriz city. Also, the lowest percentage of changes belongs to the reduction of the heating load by placing the HSNPS transparent insulation on the south face of Ahvaz city.

CONCLUSION

The use of transparent insulation is to create resistance to heat flow without blocking solar radiation from non-transparent insulation material. Less heat transfer of a TIM reduces undesirable heat losses from indoor to outdoor environments and thus reduces the heating load of the building. The thickness and placement of this insulation should be optimized.

The research results show that the change percentage of improvement in the cooling load is more than the heating and total annual loads in Tehran. In Tabriz, the change percentage in cooling and heating loads is more than the total annual load. In Ahvaz, the change percentage of improvement is high all three times. The annual cooling load in Ahvaz and the annual heating load in Tabriz have a maximum amount. Also, the total annual load is maximum in Tabriz and minimum in Ahvaz. Therefore, the use of HSNPS insulation in transparent walls was necessary to reduce energy consumption in the city of Tabriz. Also, the results show that for the city of Tehran, 3-inche of insulation in the middle of the double-glazed window and the south front, for the city of Tabriz, 5-inche of insulation on the inner surface of the window and the western front, for the city of Ahvaz, 3-inche of insulation on the outer surface of the window and the eastern front as are optimal modes.

It is necessary to mention that the obtained results are limited to the analysis of case samples in three selected cities and based on the input parameters of the software. According to the results, it is suggested that initially, the optimal insulation thickness should be calculated economically in the design of building windows; in the next step, the location of insulation and the fronts that include the most energy waste should be determined according to the climatic conditions and the materials used. Also, in cases where the building is used intermittently

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(such as office buildings), it is necessary to perform separate calculations and decide on the insulation utilization of windows. Because, in some cases, in buildings with intermittent use, the ratio of people's attendance is different at different hours of the day, and the use of insulation may increase the annual energy consumption.

One of the main reasons for heat loss in buildings is opening the windows to restore thermal comfort and receive fresh air when the heating and cooling systems are on. It is necessary to identify the actual behavioral pattern of users through field studies and consider it as an input in the software. Also, some parameters, such as the wind speed around the building and the amount of radiation received, have a direct relationship with the features around the building. The coefficients related to the wind and its reflection should be controlled according to the location of the building in relation to the surrounding context.

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Resume

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