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THE LATEST DEVELOPMENT IN DOUBLE GLASS WINDOW: A REVIEW

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ABSTRACT. The main facade of buildings is the windows, through which light enters; they represent the link between the internal and external environment, where heat exchange occurs. This research reviewed several studies on double-glazed windows to determine their effect on the internal environment in terms of saving energy used in air conditioning and improving the temperature inside buildings. To achieve this goal, the researchers applied two techniques, the first one was changing the glass materials, and the other one was changing the windows design. In this review, the materials used in previous work were phase change material (PCM) such as paraffin wax, low-emissivity coating, colored glass, and air-replacement materials such as argon, which were added between the double-glazed panes. Regarding the design technique, the thickness of the air gap was changed, natural ventilation was used, and double glass windows with single and double rooms were used. The maximum improvement in temperature was 18.84°C when using double glass windows with low emissivity coating, and the best annual energy savings were achieved when using building integrated photovoltaic/thermal double-skin facades (BIPV/T-DSF), where the energy savings rate was 106%. This research review found that the amount of energy savings and improvement in temperature varies according to the direction of the building, thickness, and type of insulating material and glass type.

KEYWORDS: Double-pane window; PCM; Colored double-glass window.

1. INTRODUCTION

A significant increase or decrease in external temperatures increases internal energy expenditure to provide thermal comfort. Therefore, a solution must be found so that external light can enter the room while maintaining an internal temperature different from the external environment without the need for a large expenditure of energy to obtain thermal comfort. Double-glazed window technology was used for this purpose.

The double-glazing technique started in service in 1870 when a second piece of glass was used and fixed with clay in Switzerland, Scotland, and Germany. The invention of modern double glazing is attributed to the American refrigeration engineer Charles DeHaven [1]. The "Thermopane" system comprises two glass panels divided by an air gap, having the edges secured with rubber bands was announced in 1932 [1]. The air between the panes was desiccated to avert condensation.

The current research is reviewing the double glazing windows to estimate their impact on energy saving used in air conditioning, and the interior environment, and also to determine the improvement in the temperature inside buildings. The previous work was classified according to design, materials, and both design and materials.

1.1. DESIGN

Foroughian, S. et al. (2017), Demonstrated that the implementation of double-glazed windows may save 0.2% of power consumption, 12.4% of total residential energy use, 16.2% on gas utilization, and 50% of entire building loads. The energy simulation program, Design Builder, was employed to calculate energy-related parameters. Practical and experimental data were used to establish the model's validity [2].

Rana, A., et al. (2018). Used argon-filled, low-emissivity triple-glass and double-glass windows in two adjacent buildings. The study found that triple-glass windows performed better in winter than double-glazed windows, with a difference in temperature range of 1-3.5 °C in winter and almost imperceptible in summer.[3]

Basak et al (2023). performed a numerical analysis on a double-glazed window, which showed that when the gap between double glass window is augmented from 32 mm to 120 mm led to an enhancement in heat transfer resistance from 0.31 $m^2 K W^{-1}$ to 0.87 $m^2 K W^{-1}$ or an increase of 2.63 to 2.8 times; The overall heat flow diminishes by 3.0%, while the heat transfer resistance escalates by 3.1% correspondingly; The thermal resistance of the interstitial space between two glass units escalates from 0.192 $m^2 K W^{-1}$ to 0.2185 $m^2 K W^{-1}$ [4].

1.2. MATERIALS

Aguilar, J. O., et al. (2017), conducted a numerical simulation on double glass windows (DGW), DGW consists of evident glass indoors, air gap, and evident glass outdoors. In their work, they used a variety of types of indoor glass, the first type used evident glass (considered as reference); the second type used absorbent glass; the third type used low emissivity glass; the fourth type used a reflective glass. The result showed that the fourth type was the best in performance especially in warm atmospheres, it is also economically feasible, and heat flux is reduced by 73% when compared with the first type; types 3 and 2 showed almost the same performance, and heat flux reduces by 33.5% [5].

Aguilar-Santana, J. L., et al. (2019). reviewed the recent advances in the technology of Windows. They classified windows into two types; static and dynamic; static windows can enhance optical and thermal performance, and are considered a passive technology; the static windows (also considered conventional). Dynamic windows, also called active windows, have technology that can convert or conform to the inner interaction of substances to outer conditions. Optical and thermal performance and types of glass were explained. The results indicate that window U-values are greatly decreased by gas-filled cavities; argon, krypton, and xenon are lower by 22.2%, 33.3%, and 41.1 W/m^2K, respectively. Vacuum glazing improves insulating qualities by reducing the U-value by 42% compared to the standard double glazing filled with argon [6].

Koshlak, H., et al. (2024). Carried out numerical modeling of convection and radiation on a double-room glass unit to study the effect of low-emissivity coating applied on glass surfaces. Simulation has been made by solving fluid dynamic equations of a system and numerically solving energy for both glass and air gaps. The results showed that about 60% of heat transfer was by radiation via the normal glass; whereas, using low-emissivity coating has reduced the amount of heat flux by 20-34% relying on the number of the surface that has coating [7].

Walid, A., et al. (2021). Presented different types of single and double-glazing glass to enhance the lighting and heat performance, according to insulation and properties. They performed a numerical simulation on all mentioned types. The result of single-glazing glass showed that the low-E glazing is superior in performance, followed by tinted glass. The Aerogel glass was the superior choice among all double-glass types, succeeded by PCM glass; the double glass filled with xenon is superior compared to other types [8].

Ahmed A, et al. (2024). Showed that the least energy consumption to cooling when using double-theoretical-197 glass window, using the ratio of windows to walls (WWR) of 25%, at north orientation, while at south orientation, Gray-double glass window, minimizing the consumption of energy to cooling by 12% annual. The thickness of the glass used was 3mm indoors and outdoors, with a 13mm air gap [9].

Heydari, A., et al. (2021). Carried out a numerical study on structures in Semnan, Bandar Abbas, and Tabriz, Iran, featuring diverse window arrangements. The study sought to enhance energy efficiency by augmenting the thermal conductivity coefficient of window glass by regional climatic conditions. The research analyzed single-glazed and double-glazed windows utilizing krypton, argon gas, and air as insulating materials. The findings indicated that tempered glass diminishes cooling and heating demands while augmenting glass thickness lessens heating demands. From the result, the cooling load for single glass was 8809.26 kWh/year in Semnan, 3795.69 kWh/year in Tabriz, and 27758 kWh/year in Bandar Abbas. The enhancement in consumption of cooling load was: a) for the double-pane window of 4mm thick tempered glass with an 8mm argon-filled interstice was 7656.42 kWh/year in Semnan, 3476.9 kWh/year in Tabriz, whilst, 20015.5 kWh/year in Bandar Abbas, b) for double-glazed window featuring 4mm thick clear glass and a 12mm argon-filled cavity was in 19968 kWh/year Bandar Abbas, 3480.9 kWh/year in Tabriz, and 7763.38 kWh/year in Semnan c) for Double-glazed window featuring 4mm thick tempered glass and an 8mm air-filled gap was 20064.24 kWh/year in Bandar Abbas, 3461 kWh/year in Tabriz, and 7744.25 kWh/year in Semnan. The study advocates adopting double-pane windows, including tempered glass and air-filled inter-pane spaces for Semnan, while clear glass is recommended for Tabriz and Bandar Abbas [10]. Somasundaram, et al. (2020). Carried out numerical simulation and found that double glass can save energy 4%-10% in the tropical region when installing retrofit double glass, and original faces are colorful glass. When installing retrofit double glass windows on transparent glass after installing solar film on transparent glass was found to be more effective for protection from solar radiation by reducing the average radiant temperature by 1.3 °C. The use of retrofit hard coat low-emissivity double glazing can result in a minimized energy usage for air conditioning by up to 9% [11].

King, M. F. L., et al. (2021). examined the impact of including phase change material (PCM) inside a double glass window as insulating material with a thickness of 12mm, and the material used is paraffin as PCM. The result indicates that using PCM will reduce 9 °C during the maximum temperature of the day, the glass transmittance was more than 0.7, which allows enough light to pass into the room, indoor window temperature has been reduced by 8.5 °C, and the consumption of energy has been reduced by 3.73% [12].

Jalil, J. M., et al. (2021). added paraffin wax as an insulating material in double glass windows, they used a chamber constructed from sandwich panels with double glass windows. A 5 °C drop in ceiling temperature, an 8 °C drop in ground floor temperature, and a 6 °C drop in first floor temperature were achieved. The temperature of the internal double glass was less than the temperature of the single-pane window on the first floor and the ground floor, while the inside temperature of the double-glazed window on the ceiling was greater than that of the single-glazed window [13].

Yang, S., et al. (2020). Applied a numerical simulation for projecting the performance of building-integrated photovoltaic/thermal double-skin facades. The photovoltaic/thermal double-skin showed that naturally-ventilated air cavities combined with mechanical ventilation exhibit the lowest consumption in cooling energy, but mechanically-ventilated double-skin facades exhibit the highest consumption in heating energy. The most efficient operational mode was the naturally ventilated double-skin façade, while non-ventilated panels realized the most significant decrease in heating loads. Double-skin facades, whether naturally or artificially ventilated, can effectively capture advantageous thermal energy, particularly during winter. The annual energy conservation of 106%, 34.1%, and 86% were realized in Canberra, Darwin, and Sydney, respectively, in comparison to traditional technology [14].

Tao, Y., et al. (2021), evaluated the efficacy of standard clear glazing against low-emissivity glazing in a naturally ventilated double-skin façade (NVDSF) across multiple variables, including spectrum optical characteristics, ambient conditions, and structural configurations. The findings indicated that substituting clear glass with low-e glazing enhanced ventilation rates by 13%. Nonetheless, the performance was contingent upon the spectrum optical characteristics of low-emissivity glazing, with an increased level of absorptivity proving to be more beneficial. Environmental conditions, including solar incidence angles and intensities, influenced ventilation performance. At narrow incidence angles (<40°) and with solar intensities greater than 600 W m-2, NVDSFs performed better. The ideal cavity gap for NVDSFs was determined to be between 0.15 and 0.3 m, with ventilation rates rising to a vent height of 0.4 m. The research validates the energy conservation capabilities of utilizing low-e glazing as the interior façade [15].

Liu et al. (2022). Studying the development of a near-infrared (NIR)--activated perovskite thermochromic smart window (T-PCL window) has shown promise for energy savings across a variety of spectral ranges. The T-PCL window has low emissivity, significant near-infrared absorption, reversible color change, and intelligent solar modulation capacity. It achieved a significant 8.0°C drop in interior temperature by successfully observing a self-activated thermochromic cycle in natural sunshine without the need for environment control techniques. Potential energy savings in tropical and subtropical areas range from 9.1% to 13.8%, according to the Energy Plus simulation. Nevertheless, the T-PCL window's caesium-doped tungsten trioxide (CWO) layer excludes more than 70% of NIR light, which reduces interior heating capacity during the winter [16].

Qiu, et al. (2020). carried out a thorough analysis of a unique semi-transparent PV vacuum glazing's daylighting, total performance of energy, and thermal in several climatic regions was carried out. The primary findings were; that vacuum PV glazing is an efficient way to save heating energy in areas that experience extreme cold, scorching summers, and frigid winters. In locations with freezing winters and hot summers, it provides the utmost energy-efficient cooling. The energy savings in Kunming, Hong Kong, Wuhan, Beijing, and Harbin are 23.0-43.1%, 20.7-29.2%, 31.8-39.3%, 38.6-44.6%, and 28.7-34.0%. Nevertheless, regions with mild temperatures, such as Kunming, need more cooling energy [17].

Abdelrady et al. (2021). The effects of polystyrene foam (PS) in the wall, nano vacuum insulation panels (VIPs), and nano gel inside the window were assessed regarding yearly energy savings, yearly energy cost, the yearly energy consumption in a torrid desert climate (New Aswan City, Egypt). According to the study, compared to widely used walls, PS and nano VIPs layers among brick layers saved almost 23% of energy annually. Additionally, the nanogel layer between argon and glass and transparent glass saved 11% of the energy. Between argon and glass, the nanogel layer dramatically reduced yearly energy use by 26%. Five solutions for enhancing building insulation and energy efficiency were assessed; in social residential structures, the combination of windows and polystyrene foam insulation reduced energy usage by 47.6 percent. The minimum sample period of payback (SPP) of 17 years was the outcome of these choices [18].

González-Julián et al. (2018). Examined four types of glass as follows: case 1 (solitary transparent glass), case 2 (transparent glass - air interstice - transparent glass), case 3 (transparent glass - air interstice - reflective glass), and case 4 (transparent glass - air interstice - low-emissivity glass). The findings showed that in comparison to a single-glazed window (case 1), utilizing a double-transparent-glazed window (case 2) can minimize heat losses into the interior environment by as much as 12%. Likewise, Case 3, a double-glazed window with reflecting glass, demonstrated the most energy conservation, as much as 72.6 percent, while Case 4 demonstrated a 28.6% reduction in comparison to Case 1. Global data show that double-glazed windows with reflective glass are the best option for saving energy in warm areas, with a yearly economic benefit of the United States Dollar 30.73 over single-pane windows. Furthermore, the cost recovery period is finished in around three and a half years. However, Utilizing low-emissivity glass for double-glazed windows (case 4) in Mexico is costly.; therefore, its use is rare because the cost recovery is more than the panes' ten-year service life. Ultimately, determined that the DPW with reflecting glass (case 3) is the optimal choice for the Mexican building sector in warm regions because of its thermal efficiency and cost recuperation period [19].

Li et al. (2016). Used insulated double-pane windows, $CaCl_2 \cdot 6H_2O$-filled double-pane windows, and $Na_2SO_4 \cdot 10H_2O$-filled double-pane windows. The simulation was run in four different climates: bright summer and winter days, as well as cloudy and precipitation-laden days. The largest temperature differential between insulated and $CaCl_2 \cdot 6H_2O$-filled windows was 2.8°C, and the inner surface temperature of $CaCl_2 \cdot 6H_2O$-filled windows was inferior to that of insulated windows on overcast and wet summer days. $CaCl_2 \cdot 6H_2O$-filled windows had a lower outer surface temperature than insulated double-glazed windows, with the highest temperature differential of 6.4 degrees centigrade. The interior surface temperature of $CaCl \cdot 6H_2O$-filled windows was around 12°C cooler on bright summer days. The interior surface temperature exceeded that of insulated double-glazed windows on overcast and wet winter days, with the highest differential temperature of 0.4°C. In $Na_2SO_4 \cdot 10H_2O$-filled glass windows, during rainy and cloudy summer days, the internal temperature glass exceeded that of the inner double-insulated glass due to its elevated temperature melting, while the outer temperature surface was inferior to that of the exterior surface of the insulated double glass; on sunny summer days, the temperature difference of the interior surface was about 10.1°C, and the difference temperature of the exterior surface was around 13°C; during cloudy and rainy winter days, the temperature of the internal glass was larger than that of the insulated double glass, with the greatest difference of 1degree centigrade; on sunny winter days, the internal and external surfaces of the PCM-filled glass windows were inferior to those of the insulated windows, with the largest difference of 10-degree centigrade compared to the insulated windows. As a result, winter PCM consumption is worse than summer use [20].

Gorantla et al. (2018). studied six varieties of double-glazed windows: First, GC1 represents (green tinted glass inside, bronze tinted glass outside, 10 mm gap). Second: GC2 represents (grey-tinted glass inside, and bronze-tinted glass outside, with a 10 mm gap between the two). Third: GC3 represents (green tinted glass outdoors - 10 mm gap

- grey tinted glass indoors). Fourth: GC4 represents (green tinted glass outdoors - 10 mm gap - bronze tinted glass indoors). Fifth: GC5 represents (grey tinted glass exterior–10 mm gap–bronze tinted glass interior); sixth: GC6 represents (grey tinted glass exterior–10 mm gap–green tinted glass internal). In comparison to double clear glass windows, south-oriented GC3 combination windows are shown to be more energy efficient in the summer since they have the least amount of heat gain in buildings, at 441.23 (kW). In comparing GC3 to the double clear glass window, 19.99% less energy is used. Because GC1 combination windows have a higher heat gain in buildings—1483.74 (kW)—than double clear glass windows, they are the most energy-efficient glass during the winter. Because of this, GC1 uses 29.02% less energy during the winter than a double-pane transparent glass window. In all eight directions, the GC6 combination window saves the most money on net costs annually in comparison to the double-transparent glass window combination. Comparing the South-West, South-East, and South directions to double clear glass window combinations in the New Delhi climate zone in India, it saves 59.23, 60.54, and 61.16 US dollars annually, respectively [21].

Aguilar et al. (2015). performed a numerical study on three different kinds of double glazing—transparent glass-air interstice-transparent glass, transparent glass-air interstice-absorptive glass, and transparent glass-air interstice-reflective glass. It was possible to turn the glass window 180 degrees. The reflecting and absorbing glass are hence in contact with the outside world when double pane window (DPW) is utilized in warm climates. In contrast, in colder climates, the air within the building comes into touch with the absorbing and reflecting glass. 0.5, 1, 2, 4, and 8 cm were the air gap sizes employed in the numerical simulation. For the three research instances and climate circumstances examined, the findings indicated that the air interstice width among the glass, where the heat transfer through the interior is nearly constant, is 0.02 m. More energy is used when lower values are used because they result in a rise in heat flux in warm climates and a fall in cold climates. The largest energy savings were obtained in cold areas by Case 1, which was around 12% more than Case 2 and 30% greater than Case 3. The biggest energy savings, however, were shown in Case 3 in warm regions, where it was almost 220% and 120% greater than Cases 1 and 2, respectively. Based on global equilibrium prices, Case 3 is the most energy-efficient option. Comparisons with Case 2 and Case 1 show potential savings of up to \$10.48 and \$17.64 per kWh annually, respectively. It is advised that places with cold and warm seasons have a reversal window design, like Case 3. It is recommended because the energy conserved in warm situations (\$21.28 per kiloWatt-hour) is more than the energy added in cold conditions (\$3.64 per kWh) [22].

Xamán et al. (2016). A numerical analysis of a chamber with a double-glazed window (DGW), without and with a solar control film (SCF), was performed in Mexico City. Grounded in numerical findings of the double-glazed window system in the room (case C1) and the absence of solar control film, (case C2) with applied solar control film to the second glass in a warm climate, (case C3) with solar control film on the first glass in a cold climate, the following conclusions can be drawn: under warm climate conditions, the temperature in case C1 (33°C) consistently exceeded that in case C2 (29°C), particularly during periods when solar radiation amount was not negligible. The installation of solar control film in the window with double glazing case C2 effectively refuses approximately 1568.56 W/m2 (67.7%) over a full day from 1:00 to 24:00, compared to case C1, thereby contributing to energy savings related to indoor comfort conditions. In cold climatic circumstances, the average indoor air temperature values for case C1 were comparable to those in case C3, exhibiting a lowest and highest dissimilarity of 0.1 and 0.5 degrees centigrade, respectively. Consequently, It is possible to infer that the double-glazed window's thermal performance with solar control film (case C3) is comparable to that of the conventional double-glazed window (case C1) [23].

1.3. Design and Material

Faggal et al. (2019). An analysis of earlier research was done, and the DesignBuilder tool was used to run a simulation. The purpose of this study is to investigate how altering the kind of glass might lower energy use. Single clear glass, double clear glass, double blue glass, double bronze glass, double green glass, double grey glass, and low-emissivity double colored glass are the seven varieties of glass that were collected. The thickness of the air was 13 mm, the thickness of the glass for the other varieties was 6 mm, and the thickness of the single clear glass was 3 mm. Single clear glass was the worst type, with a cooling load ranging from 4325.44 to 3382.28; adding two sheets of clear glass decreased the load by 6.8%; using blue, green, and bronze colored glass yielded close values for the percentage reduction in cooling load, ranging from 15.48% to 18.79%; and using grey colored glass produced a reduction rate ranging from 19.53% to 15.96%. The tinted low-emissivity glass produced a reduction rate ranging from 20.13% to 24.40% [24].

Maiorov, V. A. (2020). Carried out a numerical method on single-chamber double-glazed windows and double-room double-glazed windows, both filled with argon and air, and found that the maximum difference temperatures when using a single-room double-glazed window and a double-room double-glazed window, respectively, for argon, are 14.57 °C and 16.88 °C. For air, they are 12.94 °C and 15.73 °C [25].

Maiorov, V. A. (2020). Used analytical form to minimize the losses in radiant heat transfer. Two strategies to diminish heat transfer radiative loss via double-glazed windows were identified. The initial technique uses a coating with low emissivity, and the second technique increases the number of glass layers. The analytic method also studied the effect of the location, number, and quality coating low emissivity upon the properties of the radiant heat transfer process. It was found that the maximum difference between temperatures inside and outside when using clear double glass windows was 17.87 °C, whilst it was 18.84 °C when using double glass windows with low emissivity coating [26].

Bangre, A., et al. (2023). Used a qualitative research method, and subordinate data from pertinent published scholarly publications, including research papers and journal articles, to apply the impact of using double glass windows upon the energy use of the construction. The R-value was used, representing the impedance of material to energy transmission; the greater the R-value, the larger the impedance value, i.e., the greater the window insulation value. The relation between the R-value for buildings and double glazing was explained. The U value represents the energy efficiency of the material, whereas the lower U value is preferred. i.e. less energy is gained or lost through the material. The U value for solitary glass was roughly 5.6, whereas for double glazing, it ranged from approximately 1.5 to 2.8. A lower U-value and a higher R-value indicate less fossil fuel use [27].

Zeyninejad S., et al. (2020). In their work, the double glass air flow with integrated blinds (IBAFW) has been studied numerically. The outcomes are contrasted with empirical data from the literature to corroborate the computational fluid dynamics (CFD) model. Certain areas, including the tilt angle and the entry and outer expansion, are known as structural parameters, and research has been conducted on how these affects thermal performance. The findings show that solar ventilated windows (SOLVENT) are less thermally efficient than IBAFW and that the percentage of IBAFW that are more thermally efficient than SOLVENT is approximately 330–580%; heat gain increased about 146–132% when modifying the blinds tilt angle to 60° instead of 30°. The thermal effect is decreased by 127% when increasing the air discharge, and total heat gain is increased by 106% when increasing the gap [28].

Ozel, M. (2022). Examined the influence of the glazing area on thermal efficiency in buildings located in Elazığ, Turkey, considering orientation, wall insulation, and glazing type. A numerical study was used to calculate transmission loads through walls and window glass. As the proportion region rises, the heating transmission load and cooling transmission load escalate for all wall directions. Double glass substantially Decreases for all building directions a load of heating in comparison to single glass. The research indicated that the rise in heat load is most pronounced in the north and minimal in the south, whereas the increase in cooling load is greatest in the west and east, with the minimum increase occurring in the northern region. Double glass demonstrates that an increase in insulating thickness yields a reduction of heating transmission load and cooling transmission load via all wall orientations. In a south orientation, double glass results in a 79% reduction in heating load and a 1.53% ascend in cooling load. The findings will aid in selecting glazing locations according to wall directions and glass types [29].

Li et al. (2020). Executed a numerical study on silica aerogel and phase change material (PCM) as extremely well-insulation. It was found that: the density of silica aerogel and the cycling and thermal comfort of PCM are little impacted by the specific heat of silica aerogel. Heat flow and overall energy usage both decline with increasing specific heat. The maximum and lowest heat flux values on the interior surface are determined to be 89.157 W m^{-2}, 72.271W m^{-2}, 89.134 W m^{-2}, and 72.168W m^{-2}, respectively, when the specific heat of silica aerogel is 900 J $(kg{\cdot}K)^{-1}$ and 1500J $(kg{\cdot}K)^{-1}$ [30].

Guo et al. (2020). Showed that the most energy-efficient window in all five of China's climates is the natural ventilated double photovoltaic (NVDPV) window, which provides insulation, natural air movement, and photovoltaic (PV) generating. When compared to the typical single clear (SC) window, it had the maximum savings rate (22.04%) in the Harbin environment. In the Lhasa environment, the NVDPV window with a PV glass transmittance of 5% performed the best. Out of three PV windows each year, the NVDPV window with a 10% PV glass transmittance uses the least amount of power. In the city of Lhasa, which has the greatest sunlight duration, the NVDPV window produces the highest PV power production, producing 18917 kWh of energy. In China's four typical climates, the ideal window design is the south-facing NVDPV window; in tropical marine climates, the best choice is the east-facing window [31].

Xamán et al. (2014). Performed a numerical study on the double-pane window (DPW) using solar control films (SCF). Case 1 (C1) solar control film (SCF) was installed on the inner DPW, and in case 2 (C2)(SCF) was installed on the outer DPW; the gap used between glass was 6 cm. In case C1 the energy that was directed to the interior room was reduced by 52% in comparison to C2, a warm climate, while, in a cold climate, the difference between C1 and C2 was 10%.it advises using C1 in the cold and hot climate [32].

Gorantla et al. (2017). Studied four combinations of double-glazed window materials—transparent glass, bronze transparent glass, green transparent glass, and grey transparent glass, across four distinct climate zones in India. The separation between the two double-glazing panes was 10mm. The spectrum optical characteristics of the Four types of glass materials were determined experimentally by employing a UV 3600 Shimadzu spectrometer. The results indicated that grey clear double glazing exhibited superior energy efficiency compared to the other three varieties in all orientations and absorbed the least heat. The clear transparent double-glazing material was discovered to acquire the maximum energy [33-36].

2. REVIEW OUTCOMES

After reviewing the previous research, it can be inferred the following:

- The researches in which the improvement in temperature was obtained were summarized in (Fig. 1).
- The researches in which the improvement in the percentage of energy was obtained were summarized in (Fig. 2).
- The diagram explains the double-glazed window in (Fig. 3).
- Researchers illustrate the working mechanism of the double-glazed window in (Fig. 4) by reducing both the amount of solar transmission and the amount of light transmission.

Table 1 summarizes the reviewed research and is divided into six columns. The first column is the sequence; the second column contains the title of the research; the third column contains the materials used in the research, such as colored glass and low-emissivity glass, and the use of argon instead of air to fill the gap between the glass in double-glazed windows; The fourth column contains the design that was used in the research, such as changing the size of the spacer between the window panes for double glazing and the use of triple glazing, and the use of natural ventilation; the fifth column contains the method used in the research, whether it is experimental or numerical; the sixth column contains the results extracted from the research in terms of improving the internal temperature or saving the energy used to air-conditioning the building.

The governing equation that was used in research as the following [35-36]:

Continuity equation,

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i^{\rightarrow})}{\partial X_i} = 0 \quad (1)$$

Momentum conservation equation,

$$\frac{\partial (\rho u_i^{\rightarrow})}{\partial t} + \frac{\partial (\rho u_i^{\rightarrow} u_j^{\rightarrow})}{\partial X_j} = \frac{\partial}{\partial X_j}\left[\mu \frac{\partial (u_i^{\rightarrow})}{\partial X_j}\right] - \frac{\partial p}{\partial X_i} \quad (2)$$

Energy conservation equation,

$$\frac{\partial (\rho c_p T)}{\partial t} + \frac{\partial (\rho c_p u_j^{\rightarrow} T)}{\partial X_j} = \frac{\partial}{\partial X_j}\left[\lambda \frac{\partial T}{\partial X_j} + S_T\right] \quad (3)$$

- **Symbol:**

Symbol	Definition
ρ	Fluid density (kg m^{-3})
t	Time (s)
x_i	Cartesian coordinate
C_p	Specific heat (kJ.kg^{-1}.K^{-1})
T	Temperature (K)
$u_j^{\rightarrow}$	Velocity vector (m.s^{-1})
X_j	Thickness of glass (m)
μ	Viscosity (Pa.s)
S_T	Energy source term (J)
p	Pressure (Pa)

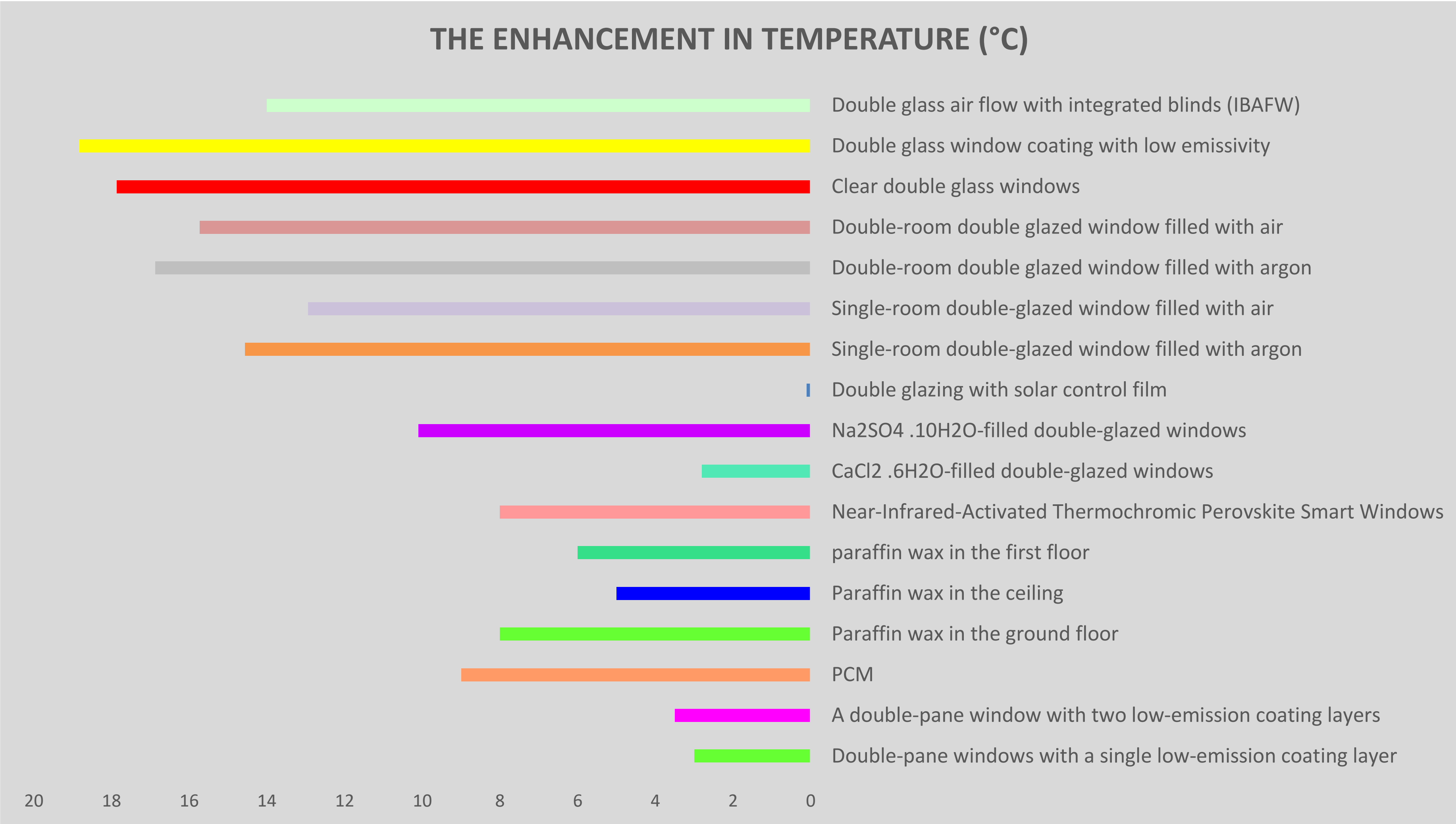

Fig. 1. The enhancement in temperature through different types of double-glass windows

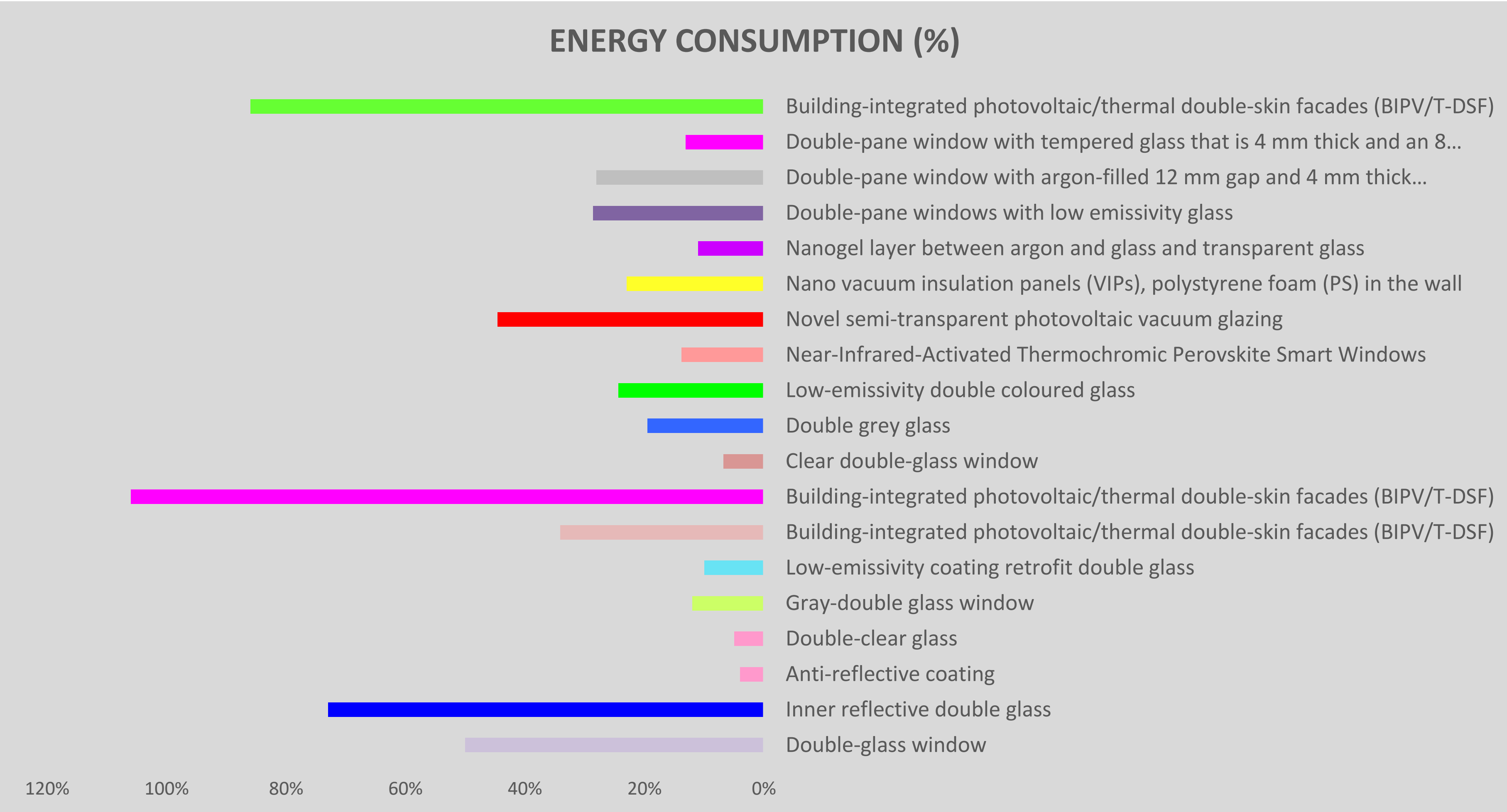

Fig. 2. Energy consumption of different types of double-glass windows

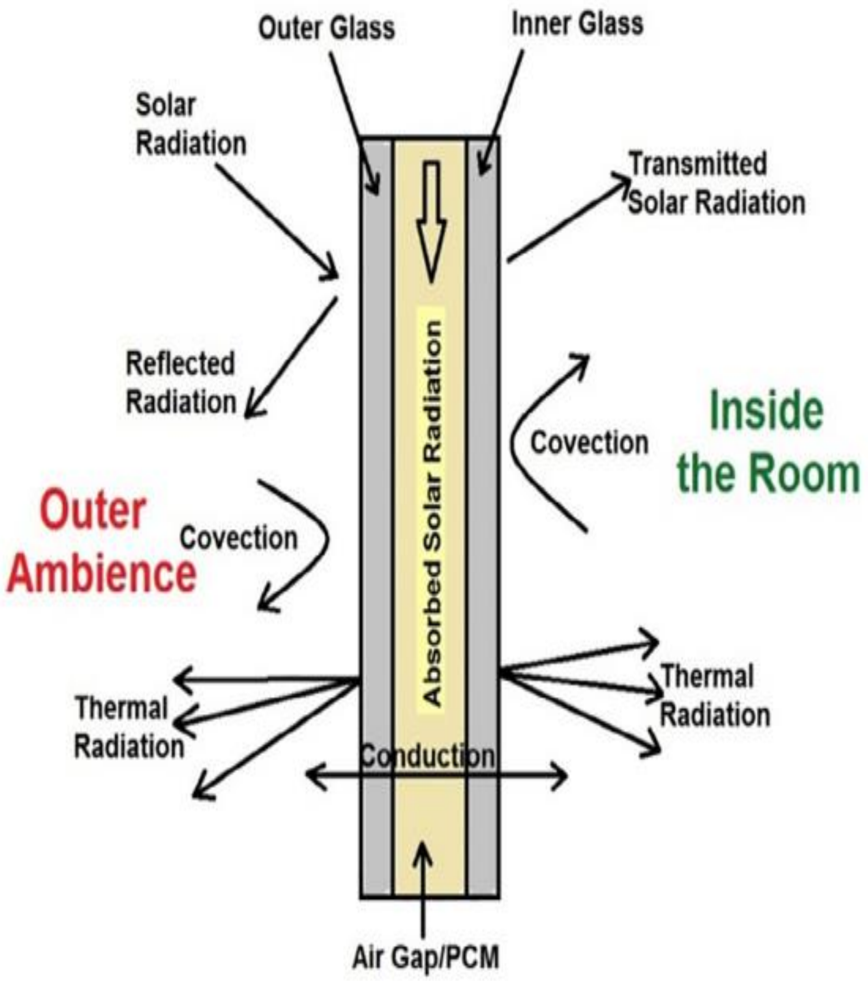

Fig. 3. *Diagram representation of the double-glazed windows [12].*

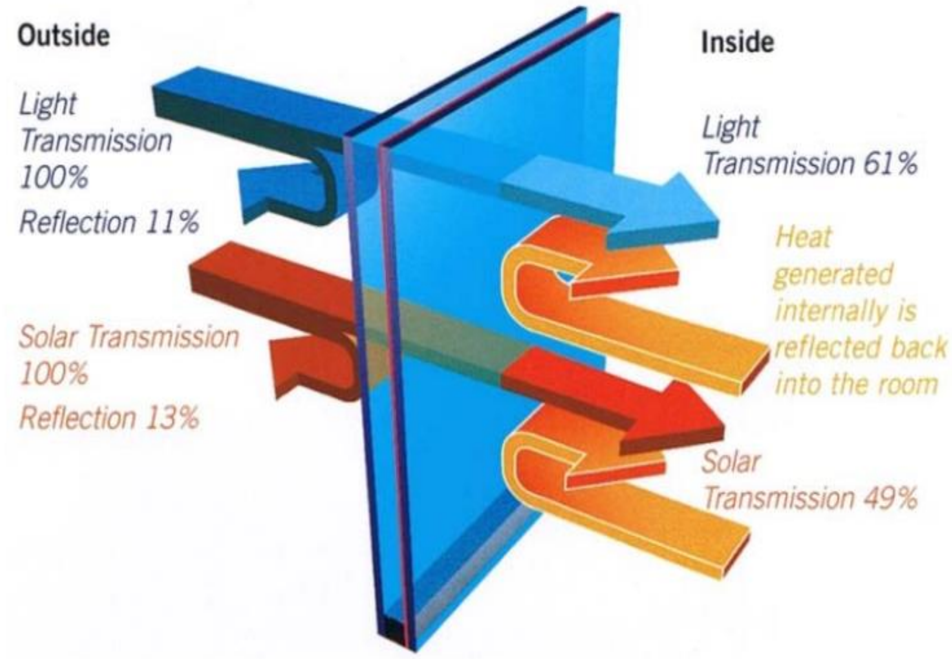

Fig. 4. Functioning of a double-glazed window [34].

Table 1. categorizes the research based on design, material, method, and results.

No.	Paper title	Material	Design	Experimental or numerical	Result (energy saving, temperature)
1	Comparative study of single-glazed and Double-glazed Windows in terms of Energy Efficiency and Economic Expenses		Single glass with a thickness of 3mm, and double glazed with a thickness of 3mm for each panel glass, and 13mm was the thickness of the air gap between the panels	Numerical & Experimental	Save energy by 50% by reducing consumption of the entire building load
2	Thermal performance of double and triple glazed windows: Experimental results from lab and in-situ measurements.		double and triple glass	Experimental and numerical	The difference in temperature between double and triple glass was about 1-3.5 ˚C in winter; in summer, The difference was imperceptible.
3	Heat Transfer Characteristics of a Combination of Two Double-chamber Windows		the gap between the double glass window is augmented from 32 mm to 120 mm	Numerical	The difference in temperature was nearly constant about 4.4-4.7 °C
4	Thermal performance of a room with a double glazing window using glazing available in the Mexican market	varying types of inner double-glass windows		Numerical	The reflective inner double glass, 73% save energy compared with clear inner double glass
5	Review on window-glazing technologies and prospects	different types of glass windows		Numerical	Demand annual for heating was reduced by 4% by the use of anti-reflective coating
6	Heat Transfer through a Double-Chamber Glass Unit with Low-Emission Coating	Double-room Glass Unit with Low-Emission Coating		Numerical	The temperature difference of a double glass window with one layer of coating and without coating was about 3 °C and was about 3.5 °C when comparing two layers of coating and without coating
7	Conventional and Advanced Glazing Technologies for	many types of glass windows		numerical	Using double-transparent glass can reduce the consumption of energy by

No.	Paper title	Material	Design	Experimental or numerical	Result (energy saving, temperature)
	Enhancing Thermal and Lighting Performance				about 5% when compared with single-clear glass
8	The impact of window orientation, glazing, and window-to-wall ratio on the heating and cooling energy of an office building: The case of hot and semi-arid climate	using double-theoretical-197 glass window at north orientation, while at south orientation, Gray-double glass window		Experimental and numerical	Gray-double glass window minimizes the consumption of energy for cooling by 12% annual
9	Effects of different window configurations on energy consumption in the building: Optimization and economic analysis	air, krypton, and argon gas as insulating materials	The gap was 8mm and 12 mm.	Numerical	Reduced cooling load by 1152.84, 314.79, and 7790.4 kWh/year, depending on the region and types were used
10	Energy saving potential of Low-E coating-based retrofit double glazing for tropical climate.	Low-E coating retrofit double glass		Numerical	can save energy by 4%-10%
11	Thermal performance of a double-glazed window integrated with a phase change material (PCM)	PCM		Experimental	using PCM will reduce 9 °C during maximum temperature
12	Experimental and numerical investigation of paraffin wax as a thermal insulator in a double-glazed window	paraffin wax		Experimental and numerical	They found that temperature has reduced by (5 °C in the ceiling, 8 °C in the ground floor, and 6 °C in the first floor)
13	Performance assessment of BIPV/T double-skin façade for various climate zones in Australia: Effects on energy consumption	building-integrated photovoltaic/thermal double-skin facades (BIPV/T-DSF)		Numerical	yearly energy savings of 106%, 34.1%, and 86% were realized in Canberra, Darwin, and Sydney, respectively.
14	Ventilation performance of a naturally ventilated double	standard clear glazing against low-emissivity glazing in a		Numerical	Increase the internal facade temperature by 21%

No.	Paper title	Material	Design	Experimental or numerical	Result (energy saving, temperature)
	skin façade with Low-E glazing	naturally ventilated double-skin façade (NVDSF)			
15	Near-Infrared-Activated Thermochromic Perovskite Smart Windows	Near-Infrared-Activated Thermochromic Perovskite Smart Windows		Experimental and numerical	It achieved a significant 8.0°C drop in interior temperature. Potential energy savings from 9.1% to 13.8%.
16	Daylighting and overall energy performance of a novel semi-transparent photovoltaic vacuum glazing in different climate zones	novel semi-transparent photovoltaic vacuum glazing		Numerical and experimental	The energy savings in Wuhan, Beijing, Harbin, Kunming, and Hong Kong are 31.8-39.3%, 38.6-44.6%, 28.7-34.0%, 23.0-43.1%, and 20.7-29.2%.
17	Use of insulation based on nanomaterials to improve energy efficiency of residential buildings in a hot desert climate	nano vacuum insulation panels (VIPs), polystyrene foam (PS) in the wall, and nano gel in the window		numerical	The energy reduction annually was 11, 23, 26, and 47.6%, depending on the material used.
18	Annual thermal evaluation of a double pane window using glazing available in the Mexican market	Single and double-glazed glass are used with one of the glass layers being transparent, reflective, or low-emissivity.		numerical	Energy saved by 12% by using double clear-pane windows, 72.6% by using double-pane windows with reflecting glass, and 28.6% by using double-pane windows with low emissivity glass
19	Thermal analysis of PCM-filled glass windows in hot summer and cold	Used insulated double-glazed windows, $CaCl_2.6H_2O$-filled double-glazed windows, and $Na_2SO_4.10H_2O$-filled double-glazed windows		numerical	The maximum difference in temperature was 2.8 °C and 10.1 °C, depending on the types used.
20	Thermal and Energy Saving Analysis by Using Tinted Double Window Glass Combinations for Heat Gain in Buildings	six varieties of color double-glazed windows		experimental and numerical	437.91 kWh was the reduction in energy cooling load in summer by double glass consisting of green glass inside and grey glass outside

No.	Paper title	Material	Design	Experimental or numerical	Result (energy saving, temperature)
21	Thermal performance of a double pane window using glazing available on the Mexican market	three different kinds of double-glazing	.	numerical	Case 3 was the utmost energy-efficient option, with potential yearly savings of up to $10.48 and $17.64 per kWh compared with Case 2 and Case 1, respectively.
22	Computational fluid dynamics for thermal evaluation of a room with a double glazing window with a solar control film	double glazing with a solar control film		numerical	When using solar film in a warm climate it reduces energy by about 67.7%, and when using it in a cold climate differences were about 0.1 -0.5 °C
23	EFFECT OF DIFFERENT WINDOWS GLAZING TYPES ON ENERGY CONSUMPTION OF A RESIDENTIAL BUILDING IN A HOT-ARID CLIMATE	Single clear glass, and six different types of double-glass	The air gap was 13mm	Numerical	The energy saved was 6.8-24.40%, depending on the type used.
24	Heat transfer through a double-glazed window by convection	double glass filled with air, and argon	single-room double-glazed window and a double-room double-glazed window	Numerical	The maximum difference temperatures when using a single-room double-glazed window and a double-room double-glazed window, respectively, for argon, are 14.57 °C and 16.88 °C. For air, they are 12.94 °C and 15.73 °C.
25	Heat transfer through a double-glazed window by radiation	double glass window coating with low emissivity	double glass window increasing the number of the glass layer	Numerical	The maximum difference between temperatures inside and outside when using clear double glass windows was 17.87 °C, whilst it was 18.84 °C when using double glass windows with low emissivity coating
26	Prospects of Double Glazed Windows in Buildings: Energy Conservation and	Low-emission coating glass	Double glass with 6-20mm thickness of air gap	Numerical	Save energy by 50% by reducing consumption of the entire building load

No.	Paper title	Material	Design	Experimental or numerical	Result (energy saving, temperature)
	Environmental Sustainability				
27	Numerical investigation on the thermal performance of double glazing airflow window with integrated blinds	IBAFW and SOLVENT	The gap size was 40-60 mm, and the blinds tilt angle was 30°- 60°	Numerical	The temperature outlet was decreased from 321 k to 307 k
28	Impact of glazing area on the thermal performance of buildings	single and double-glazed	Change the percentage of the gap	Numerical	Energy saving was 21.36% in the north, 8.39% in the west or east
29	Thermal performance evaluation of glass window combining silica aerogels and phase change materials for the cold climate of China,	phase change materials (PCM) and silica aerogel	Different sizes of silica aerogel	numerical	The most significant decrease in overall energy consumption occurs when aerogel is diminished from 20mm (404.863 kJ) to 30mm (362.402 kJ).
30	Energy performance of photovoltaic (PV) windows under typical climates of China in terms of transmittance and orientation	The natural ventilated double photovoltaic (NVDPV) window	Natural ventilated	Experimental and numerical	The NVDPV window produces the highest PV power production, producing 18917 kWh of energy.
31	Thermal analysis for a double pane window with a solar control film for use in cold and warm climates	double glass window with a solar control film	The gap between the double-pane window is 6 cm.	numerical	The study found that case 1 reduced energy directed to the interior room by 52% compared to case 2, with a 10% difference in cold climate between them.
32	Effect of Different Double Glazing Window Combinations on Heat Gain in Buildings for Passive Cooling in Various Climatic Regions of India	four combinations of double-glazed window materials—transparent glass, bronze transparent glass, green transparent glass, and grey transparent glass	10 mm gap between glasses	Numerical and experimental	The results indicated that grey clear double glazing exhibited superior energy efficiency compared to the other three varieties in all orientations and absorbed the least heat. The clear transparent double-glazing material was discovered to acquire the maximum energy.

3. CONCLUSIONS

This study represents a review of changing the design or material or both of a double-glazing window and its effect on the difference in temperature between the internal and external environment, the percentage of energy savings, or both. Based on prior research, the findings may be summarized as follows:

1. The annual demand for heating was reduced by 4% by the use of an anti-reflective coating.
2. The reflective inner double glass, 73%, saves energy compared to the clear inner double glass.
3. Gray-double glass window minimizes the consumption of energy for cooling by 12% annually.
4. Using low-emissivity coating-based retrofit double glazing can save energy by 4%-10%.
5. Use Near-Infrared-Activated Thermochromic Perovskite Smart Windows, it achieved a significant 8 °C drop in interior temperature. Potential energy saving was from 9.1% to 13.8%.
6. 437.91 kWh was the reduction in energy cooling load in summer by double glass consisting of green glass inside and grey glass outside.
7. Using double glazing with solar control film in warm climates reduced energy by about 67.7%, and when using it in cold climates, the temperature differences were about 0.1- 0.5 °C.

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