Elimination Options of Solar Heat Gains Through Transparent Surfaces–Review

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Abstract. Buildings protect people from external climatic influences. The envelope structures of the building mitigate the impact of changes in the external environment. However, in recent decades we have been facing climate change, which is affected by many factors and the construction industry is one of them. As a result of long-term climate change, we can expect a more frequent series of warm days. In many cases, existing constructions cannot adapt to sudden climate changes. In summer, buildings overheat due to excessive solar radiation. It causes internal discomfort and temperature stress in the indoor environment. Summer overheating of buildings is influenced by many factors, but the potential source of excessive heat is unwanted solar gains through transparent constructions. This paper presents an overview of the elimination options of solar gains through transparent surfaces of envelope structures. Furthermore, it also deals with assessing the efficiency of the shading systems concerning thermal comfort and sufficient daylight in the workspace.

Keywords: Overheating · Solar heat gains · Shading systems · Glazing

1 Introduction

Building envelope structures form a filter between the building's internal and external environment. Their ability to react to changes in the internal and external environment must be in accordance with the requirements of the users of the internal space. The building envelope significantly affects the architectural expression of the building with its aesthetic effect. Currently, the design of buildings is subject to the influence of modern trends, and the requirements for the indoor climate are increasingly demanding. Facades with a high proportion of transparent surfaces have become an icon of modern times and developing cities. In addition to the aesthetic appearance, the so-called curtain walls primarily ensure maximum daylighting of the interior, which is necessary for efficient work and the health of the building's users. Large-scale transparent surfaces are also popular in terms of the energy efficiency of the building. Using solar gains through highly exposed parts of the perimeter structure reduces energy consumption for heating. However, in some cases, solar gains can disrupt internal thermal comfort and thereby increase space cooling costs [1].

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As we certainly know, we have been facing global warming for a long time now, and the problem of overheating buildings is now well-known to everyone. This unpleasant phenomenon is occurring more and more frequently as a result of climate change. Even in climate zones where the problem of building overheating was not previously solved. Therefore, it is necessary to pay more attention to this topic. First of all, it is important to focus on mitigating the climate crisis. However, we must also know how to face its consequences [2]. Nowadays, we already know various methods and technologies for mitigating the negative impact of sunlight. The contribution provides an overview of the management of heat gains through transparent surfaces using shading technology and glazing systems. The goal is to understand how to eliminate or reduce solar heat gains through transparent surfaces [3].

2 Solar Gains Through Transparent Surfaces

A solar gain is an effective form of passive heating. Solar radiation is mainly infrared short-wave radiation, which can pass through transparent surfaces and heat the internal structure of the building. Conversely, back-radiated or reflected long-wave radiation is not able to pass back through the glazing. It causes heat accumulation in the interior Re (Fig. 1) [3].

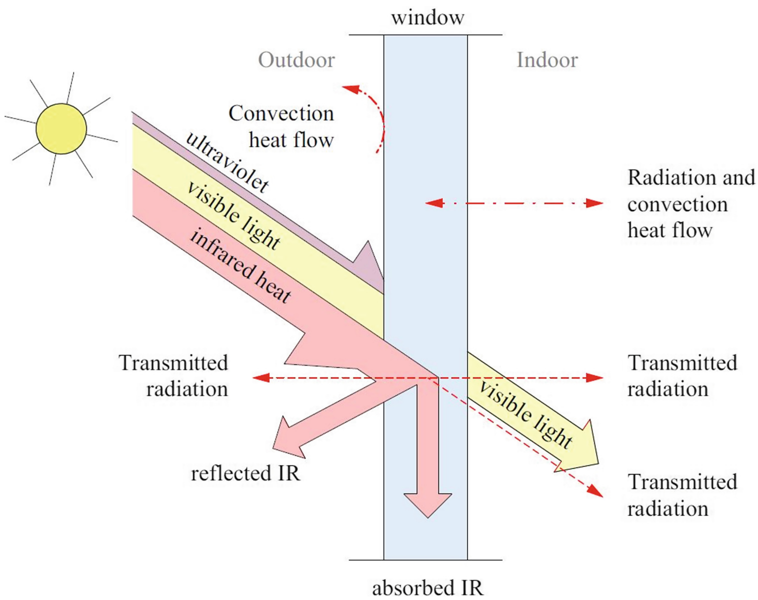

Fig. 1. Reflection, absorption, and transmission of solar radiation through glazing (according to [4]).

Infill structures are the most exposed elements of the building envelope. Most of them are mainly made of glass. They significantly contribute to the creation of an optimal indoor climate and also to the building's energy losses. The primary function is the provision of natural daylight to the interior, the visual connection of the interior and exterior, insolation, and also ventilation of the interior space. In addition, they represent an important role in other functions, so they are the key elements of the building. Unlike non-transparent structures, windows are up to 5 times weaker. They are also the most vulnerable part of the building. The quality of the lighting of the space and the intensity of the solar gains are influenced not only by the size and shape of the transparent surface but especially by its orientation to the cardinal points [5].

Another factor is the shape of the building and its location. It significantly affects the amount of received solar energy. An improperly designed building will be affected by direct sunlight, which will mean overheating of the interior space during warm summer days. Solar energy is considered the largest and most disused source of energy. There are various ways to use the free source of sunlight to save energy in buildings. Solar radiation is used as a passive solution to compensate for the heating needs in the winter. But on the other hand, in the summer season, it can cause overheating of the building due to excessive solar heat gains and thus increased energy consumption for cooling [6].

Solar gain generally refers to the increase in the temperature of an object or structure in the environment. Objects can capture and absorb solar radiation and as a result, their temperature increases. The amount of solar gain depends on the capability of the glazing material to transmit solar radiation into the interior space and on the intensity of solar radiation. The greenhouse effect, which is well-known in the concept of global warming, also works on this principle [7]. Solar heat gains through transparent surfaces are determined as the difference between the transmitted solar energy through the window and its heat loss through conduction. In transparent and translucent buildings, the so-called solar heat gain coefficient has a significant influence on the heating and cooling load. Not too many studies are available in the literature dealing with this coefficient for innovative solutions such as glazing. Measuring methods for solar heat gains, whether through shielded or unshielded transparent surfaces, are still imprecise and often simplified [8].

3 Elimination of Solar Heat Gains Through Transparent Surfaces

Nowadays, when energy is extremely important, we try to design the most energy-efficient structures. The purpose of an energy-efficient structure is to minimize heat loss and, conversely, to ensure maximum heat gain from solar energy in winter [9]. Solar heat gain forms a significant part of the total heat gain of the interior space. However, it is necessary to pay increased attention to its reduction during the cooling season. For this reason, the topic of eliminating solar gains has become a crucial area of scientific research. This issue is important for designing buildings and their energy efficiency. From this point of view, reducing solar radiation is a decisive factor [10]. Nevertheless, it is necessary to think about this problem already in the initial design of the building. We must not forget the correct orientation of the building and transparent surfaces, as well as the disposition of the interior space [11].

In the case of existing buildings, where we can no longer influence the orientation, there are solutions to alleviate this unpleasant phenomenon. There are well-established methods for solving this problem today. The most effective strategy includes modifying transparent surfaces and choosing the right type of glazing or shading systems. There are various shading devices and systems. The researchers also discovered a new type of glazing, the so-called intelligent glazing system that promises controlled regulation of sunlight. We must not forget the shading by the surrounding environment, which also has a significant impact on the internal solar gains in the building [12].

3.1 Shading Systems

Precisely shading systems can significantly limit the overheating of the interior in summer. It can reduce and eliminate unpleasant glare and ensure the visual comfort of the interior space. Another advantage is the provision of privacy for the users of the building. Currently, many types of shading technology are known, and each has advantages and disadvantages. When choosing an adequate kind of shading, it is necessary to consider its advantages and simultaneously avoid its drawbacks. Due to climatic conditions and the diverse functions of buildings, it is impossible to use a generalized manual for shading elements design. For instance, in tropical climate areas is necessary to use year-round shading, but in colder regions, shading is required only during summer. The shading device can regulate and control daylight access to the building [13]. We can categorize shading systems from different points of view. According to the position, control method, material solution, whether they are fixed, movable, or combined elements, etc. Re (Fig. 2) [14].

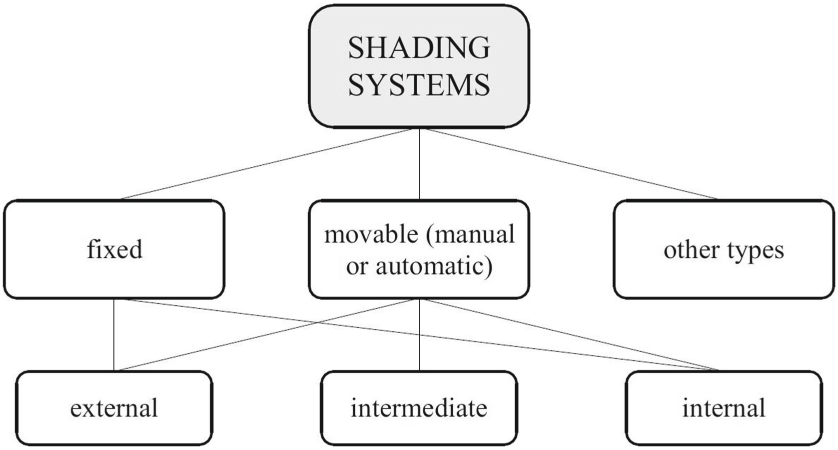

Fig. 2. Solar shading systems for buildings: a possible classification (according to [14]).

The researchers in Estonia in their study analyzed the performance of different types of shading systems on energy consumption in an office building in Tallinn. The results showed the shading system is an effective way to control energy consumption in administrative buildings. Shading efficiency varied with orientation. The evidence points in favor of dynamic systems. They have better results and thus outperform static elements [15]. In a study by Kandar et al., the authors focused on shading the buildings by their own geometry. Specifically, self-shading by the inclined wall of an office building in Malaysia. The self-shading strategy of sloping walls has proven to be significant in reducing direct solar gains. The study found that an inclined wall with an angle of 65° from the horizontal level was the most effective, while a significant decrease in energy consumption for cooling was noted [16]. The authors Joshi M. et al. focused on the integration of fixed exterior shading elements, which represent overhangs above the windows. They observed a significant decrease in solar heat gains. However, they emphasize, the results may vary depending on orientation, location, type of glazing, etc. [17].

According to the authors Babot F. et al., it is necessary to capture direct sunlight before it hits the glazing surface. Pursuant to the study, external shading devices are the most suitable and effective. Energy savings in this case can range from 10 to 40% [18]. In the following study, authors Kraus M. and Senitkova I. compared individual shading elements. In order to calculate the internal thermal comfort, they considered a total of 9 shading variants of the commercial building. The best results were achieved by shading with external semi-transparent window films. The second place was taken by an external blind with automatic control. Internal blinds with manual control had the worst shading efficiency [19]. External shading generally has the best effectiveness in mitigating solar gains before entering the building interior. However, outdoor equipment is exposed to the weather effects and is less durable and maintenance costs are higher. Interior shading, on the other hand, is less effective at protecting against solar radiation but is better in terms of control and availability. It is also not exposed to external conditions, so maintenance is easier and the service life is longer. According to the authors Naboni and Jakic, the most suitable alternative is intermediate shading. It regulates solar radiation and is sheltered against weather influences [20]. The authors Ardabili N. G. et al. also dealt with intermediate shading. Using simulations, they found the system is inefficient for warm climates. Although, in a mild climate, the system could save 15–30% of energy consumption for heating and cooling [21].

3.2 Glazing Systems

Modern buildings are often highly glazed and require a large amount of energy to maintain thermal and visual comfort. In order to reduce the energy costs of building, it is necessary to replace conventional glazing with new energy-efficient glazing systems. In the market, there are many intelligent glazing systems available that can improve the quality of a building's indoor climate [22]. Interesting types of glazing are, for instance, tinted glass, vacuum glazing, low-emissivity glazing, PCM (phase-change material), etc. One noteworthy type of glazing is thermoelectric (TE) glazing, which in addition to reducing energy, can also generate electricity. This glazing was dealt with by the authors Al-Fartoos M. M. R. et al. The study shows that TE glazing reduces waste heat. However, the authors encountered significant disadvantages of the glazing. The most prominent are the toxic materials from which the glazing make and its opacity. The authors want to address these problems in the future and eliminate these shortcomings [23]. Another modern type of glazing is the so-called water-flow glazing. Active transparent facade using this type of glazing was dealt with by researchers Millán B. P. et al. After analyzing the active flow glazing, it is possible to state the saving of cooling energy in the summer and the decline of the heating load in the winter while sufficient transparency is accomplished. It is a new type of glazing that, in addition to saving energy, also optimizes natural lighting. Adding to this also offers architects freedom of design thanks to its multifunctional nature [24].

A modern type of glazing is aerogel glazing, and several researchers are currently working on it. Authors Mohamed A. F. et al. addressed the effectiveness of an aerogel-based glazing system in the hot, dry climate of Egypt. As a result, the aerogel granulate reduced the consumption of cooling energy by 26.3% with adequate transparency. Their study claims that aerogel glazing can make windows more ecological and energy efficient [25]. In further research, Buratti C. et al. compared the effectiveness of aerogel glazing with simple glazing. As a result, the solar gain was reduced by 62–73% compared to simple glazing. Cooling energy savings were in the range of 22–33%. The results differed depending on the location [26]. Another researcher who deals with this glazing is Zhou Y. In his study, he devoted himself to a holistic overview of the aerogel material, its production, use, and optimization. As a result, the new PCM-integrated aerogel glazing systems are a considerably promising candidate for the energy efficiency of buildings Re (Fig. 3) [27].

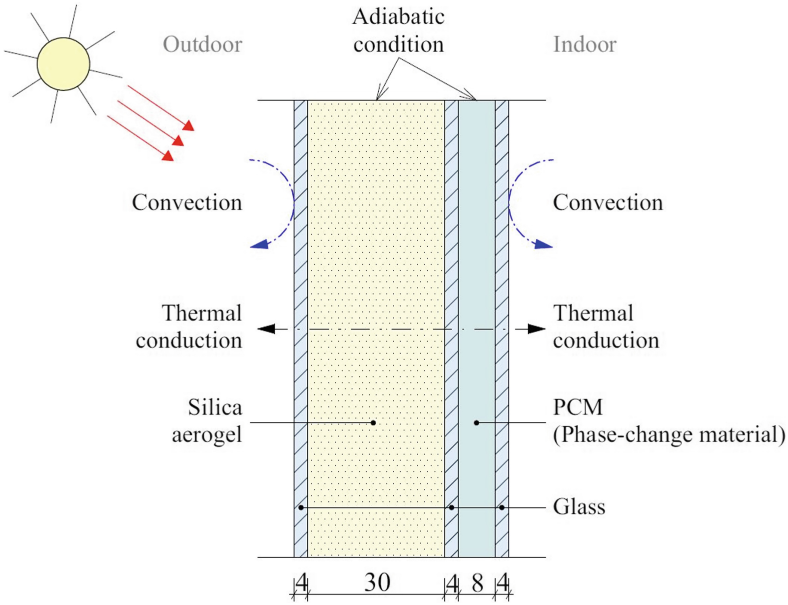

Fig. 3. A PCM and aerogel integrated window glazing system's structural configuration (according to [27]).

Coating systems. Coating solutions form a separate category for glazing systems. Currently, there are several types of coatings, such as low-emissivity foils, anti-reflection, or self-cleaning coatings. The category of colored films shows a high reflectivity of infrared radiation and helps to minimize heat exchange by radiation between the interior and the exterior. However, it will allow the transit of visible light into the interior space. According to the authors Peng Y. et al., the use of colored foil with low emissivity reduced the consumption of cooling energy by 9.87% [28].

This issue was also handled by the authors Armstrong M. M. and Burrows J. Their study was focused on a thermal mirror, i.e. a coating with low emissivity. It is a film glued to glass in a molten state, which is made as a thin transparent coating of metal oxide (tin, silver, zinc). They compared the performance of 2 glazings, namely high solar heat gain (HSG) and low solar heat gain (LSG) glazing Re (Fig. 4). The best total energy savings were reached by HSG, 13–17%, while LSG 8–10%. The energy savings depend primarily on the local climate. The authors recommend HSG glazing in locations with a dominant heating season, and conversely LSG in locations where cooling prevails. Exactly then were energy savings most significant [29].

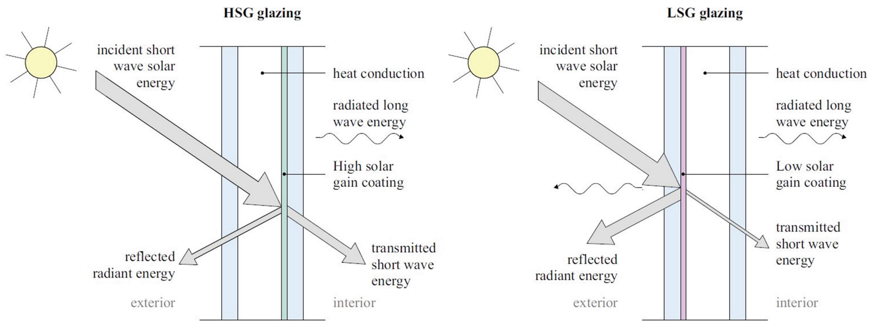

Fig. 4. High solar heat gain (HSG) and low solar heat gain (LSG) glazing (according to [29]).

3.3 Shading by the Surrounding Environment

Last but not least, solar heat gains in buildings are also influenced by shading by surrounding buildings and the environment. For instance, proper landscaping can also be one of the factors affecting thermal gains. However, especially trees and surrounding vegetation effectively shade and thus reduce solar gains. Also, plant evapotranspiration can decrease the ambient air temperature by up to 5 °C. Based on the growth habit, different types of plants can be selected to provide the desired shading [30].

Authors Chagolla M. A. et al. dealt with this issue in their research. Through measurements and simulations, they monitored the impact of shading trees on energy savings for heating and cooling in the climate of Mexico. The total annual energy saving in comparison with an unshielded building was up to 76.6% [31]. Other authors also dealt with the influence of tree shading on the energy saving of buildings. In a study by Hsieh C. et al., the authors compared four situations based on different tree characteristics. They observed the cooling effects of trees on buildings, due to their shading and transpiration. The results showed that it can reduce the total energy consumption of the building by 10.3–15.2%. The topic of reducing the cooling load of buildings is attracting increasing attention. However, there are no general methods, to apply this idea to a specific building or locality [32].

4 Conclusion

The use of solar energy is a fundamental part of energy-efficient strategies. Solar radiation penetrates the building through transparent surfaces, contributing to passive heating. On the other hand, it can cause overheating and glare of the interior space and thus increase costs during the cooling season. This problem is only getting worse with global warming. Therefore, it is necessary to face these consequences. The most important is to design proper sun protection for buildings to ensure visual and thermal comfort. Currently, we know several available options to control this negative phenomenon and thus achieve inner comfort. The correct indoor climate affects not only the energy balance but mainly the health and productivity of building users [33].

This contribution offers an overview of the issue of solar thermal gains and the usual but also the latest elimination options, which are still in the research stage. The paper reports a review of some published scientific papers regarding elimination options, which should be evaluated already in the initial phase of building design. Even with the orientation of the building and its location on the ground, we can influence the resulting energy consumption. Buildings should be designed concerning the given climatic conditions. The resulting optimal strategy for the elimination of solar heat gains, therefore, depends mainly on the location and its climate. There is no general methodology for elimination options, and each building needs an individual solution. Currently, we can use the help of software that generates the optimal geometry of the shading system according to the selected requirements. In any event, we must not forget the importance of this topic in today's world [34].

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References

1. Puškár A, Fučila J, Řehák I, Vavrovič B (2002) Obvodové plášte budov. Jaga Group, Bratislava
2. Metz B (2010) Controlling climate change. Cambridge University Press, Cambridge
3. Song Y, Duan Q, Feng Y, Zhang E, Wang J, Niu S (2020) Solar infrared radiation towards building energy efficiency: measurement, data, and modeling. Environ Rev 28:457–465
4. Aminuddin AM, Rao SP, Thing HW (2012) Thermal comfort field studies in two certified energy efficient office buildings in a tropical climate. Int J Sustain Build Technol Urban Dev 3(2):129–136
5. Puškár A, Szomolányiová K, Fučila J (2000) Okná, dvere, zasklené steny. Jaga Group, Bratislava
6. Tamm M, Cid JM, Paramio RC, Baulenas JF, Thalfeldt M, Kurnitski J (2020) Development of a reduced order model of solar heat gains prediction. Energies 13(23):6316
7. Leftheriotis G, Yianoulis P (2022) Glazing and coatings. Compr Renew Energy 3:360–401
8. Hassani AR, Domenighini P, Belloni E, Ihara T, Buratti C (2022) Evaluation of the solar heat gain coefficient of innovative aerogel glazing systems: experimental campaigns and numerical results. J Build Eng 62(4):105354

9. Kon O, Caner I (2020) The effect of shading factor for single and double glazing according to solar heat gain/window heat loss ratio in Turkey for residential buildings. In: IOP Conference series earth and environmental science
10. Taleb S, Yeretzian A, Jabr RA, Hajj H (2020) Optimization of building form to reduce incident solar radiation. J Build Eng 28
11. Kamaruddin M (2021) Investigation of the impact of building orientation on cooling loads in an office building in the tropical climate. J Sci Technol Virt Cult 1(1)
12. Etheridge DW (2010) Ventilation, air quality and airtightness in buildings. Mater Energy Efficiency Therm Comf Build 77–100
13. Hraška J (2020) Tieniaca technika budov. STU, Bratislava
14. Bellia L, Marino C, Minichiello F, Pedace A (2014) An overview on solar shading systems for buildings. In: 6th International conference on sustainability in energy and buildings, Elsevier Ltd., Energy Procedia, pp 309–3017
15. De Luca F, Voll H, Thalfeldt M (2018) Comparison of static and dynamic shading systems for office building energy consumption and cooling load assessment. Manag Environ Qual 29(5):978–998
16. Kandar MZ, Nimlyat PS, Abdullahi MG, Dodo YA (2019) Influence of inclined wall self-shading strategy on office building heat gain and energy performance in hot humid climate of Malaysia. Heliyon 5(7)
17. Joshi M, Buddhi D, Singh R (2022) Effect of overhang shade on the solar heat gain through window in composite climatic in Mid-Western India. J Sci Ind Res 81:1098–1106
18. Babota F, Manea D, Aciu C, Iernutan R, Molnar L (2013) Shading—the way for solar control and reduction of heat gain in buildings. In: C60 International conference "tradition and innovation—60 years of constructions in Transilvania"
19. Kraus M, Šenitková JI, Kučerová L (2022) The impact of solar shading elements on thermal comfort. In: Proceedings of the 26th international meeting of thermophysics 2021, AIP conference on thermophysics 2021, vol 2488, issue 1, Czech Republic
20. Naboni R, Jakica N (2022) Additive manufacturing in skin systems: trends and future perspectives. Rethink Build Skins 425–451
21. Ardabili NG, Feng Y, Wang J (2023) Design and optimization of thermally responsive autonomous dynamic glazed attachment systems for building solar heat gain control. Build Simul
22. Priya AV, Shaik S (2022) Crystal mud transparent slime as a glazing material for net-zero energy buildings: enhanced energy savings, diurnal lighting, and CO_2 mitigation. Energy Sustain Dev 71(2):151–166
23. Al-Fartoos MMR, Roy A, Mallick TK, Tahir AA (2022) A short review on thermoelectric glazing for sustainable built environment. Energies 15(24)
24. Millán BP, Aguirregabiria BL, Vacarezza GO, González JCS, Pérez JML (2015) Active transparent Façades including water-flow glazing. In: VII International congress on architectural envelopes, Spain
25. Mohamed AF, Gomaa MM, Amir AA, Ragab A (2023) Energy, thermal, and economic benefits of aerogel glazing systems for educational buildings in hot arid climates. Sustainability 15(8)
26. Buratti C, Belloni E, Merli F, Mastoori M, Sharifi SN, Pignatta G (2021) Analysis of Nano Silica Aerogel based glazing effect on the solar heat gain and cooling load in a school under different climatic conditions. Environ Sci Proc 12(1)
27. Zhou Y (2021) Artificial neural network-based smart aerogel glazing in low-energy buildings: a state-of-the-art review. Sci 24(12)
28. Peng Y et al (2022) Coloured low-emissivity films for building envelopes for year-round energy savings. Nat Sustain 5:339–347

29. Armstrong MM, Burrows J (2008) Window glazing study at CCHT shows good results. NRCC 14–15
30. Hwang WH, Wiseman PE, Thomas VA (2016) Simulation of shade tree effects on residential energy consumption in four U.S. cities. Cities Environ 9(1)
31. Chagolla MA, Alvarez G, Simá E, Tovar R, Huelsz G (2012) Effect of tree shading on the thermal load of a house in a warm climate zone in Mexico. In: Proceedings of the ASME 2012 international mechanical engineering congress and exposition, Texas, pp 761–768
32. Hsieh CM, Li JJ, Liman Z, Schwegler B (2018) Effects of tree shading and transpiration on building cooling energy use. Energy Build 159(4):382–397
33. Altan H, Ward I, Mohelníková J, Vajkay F (2008) Daylight, solar gains and overheating studies in a glazed office building. Int J Energy Environ 2(2):129–138
34. Aguilar-Santana JL, Velasco-Carrasco HJM, Riffat S (2020) Review on window-glazing technologies and future prospects. Int J Low-Carbon Technol 15(1):112–120