A review of building envelope constructions designed for demanding operating and climatic conditions

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Abstract. Under the term demanding climatic conditions in connection with the topic, we can primarily imagine the excessive overheating of buildings in summer and on the other hand the exposure of the building to low temperatures in winter. Considering the extreme climatic conditions, the design of the building requires an individual approach. First of all, it is necessary to pay increased attention to the envelope structures such as roof and perimeter walls. The building can also be affected by other extreme conditions such as solar radiation and associated excessive lighting, i.e. glare in the work environment. This topic is increasingly coming to the fore due to climate change. Summer seasons are getting warmer and this problem is getting even worse. Even in locations where this issue has never been dealt with before. The article summarizes the conducted research related to the issue of overheating and excessive lighting of buildings. It also informs about how researchers in Slovakia and different locations around the world deal with this problem.

Introduction

As we all know, we have been facing climate change in recent decades. This topic is becoming more and more important nowadays. Anthropological activity worsens living conditions all over the world [1]. However, the effects of these changes can mitigate by measures in various sectors, and construction is one of them. It is the built-up urban environment that contributes to climate change. As a result of the long-term change in the outdoor climate, buildings may overheat, and the associated disruption of indoor comfort may occur. Therefore, it is necessary to reconsider the concept of the building from the initial design [2]. It is essential to design buildings that take on the dynamics of the climate throughout their life cycle. One of the main aspects of building design is the choice of materials and the structure of the building envelope. We should pay a special attention to the physical properties of these materials. It is also necessary to consider the characteristic climate-forming factors besides it's locality. However, we must not forget the critical part of the building, namely its glazed components. Precisely the unwanted solar gains through transparent surfaces cause unpleasant overheating in summer [3].

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1 Factors influencing the summer overheating of buildings

The most significant factor influencing the overheating of buildings is precisely climate change. It causes increasingly frequent continuous series of warm days, which significantly affect the thermal comfort in the interior of buildings. There may be so-called thermal stress, which occurs in an environment with an excess, or vice versa, with a lack of heat [4]. It can harm the health of building occupants and pose health risks, especially for the most vulnerable groups of people. Climate change does not develop linearly in all locations. Cities overheat faster than remote rural areas [5]. Therefore, another essential factor is the location and density of buildings.

The intensity of air exchange and increasingly higher requirements for the airtightness of buildings have an impact on summer overheating. An airtight building eliminates the heat loss produced by the heating system, but on the other hand, it does not remove the accumulated heat. For this reason, heat gains increase [6]. The outcomes of the study conducted by Laouadi et al. showed that highly insulated and airtight buildings are more prone to overheating than older ones that are less insulated and airtight [7].

Other factors are the thermotechnical properties of envelope structures and materials, their thermal accumulation, and thermal inertia. The temperature change on the inner surface depends on the heat-accumulating properties of the materials. Thermal attenuation indicates how many times the temperature amplitude of the inner surface is smaller than that of the outer air [8]. Němeček, in his doctoral thesis, dealt with the influence of the internal thermal accumulation of structures and their summer thermal stability. Emphasis on comparing wooden and masonry buildings. From the simulation study by Němeček and Kalousek, we could conclude that the accumulation mass has a lower impact than ventilation. The accumulation capacity of structures in the interior has a somewhat smaller influence, as much as the small thickness of the internal structure effectively participates in the accumulation of heat within the daily cycle [9].

Last but not least is the influence of the shape of the building envelope. We can partially solve the problem of overheating and energy efficiency already at the initial design phase when we decide on the overall form of the building. The most significant influence is the ratio between the building's surface area and volume (i.e. building's shape factor). In a study by Košir et al., the authors present the connection between the shape of the building, the orientation, and the area of the windows concerning the building's energy needs. They concluded that for the considered Central European climate, an elongated building shape is more suitable than a compact one [10]. A study from Great Britain by Lavafpour et al. investigates the geometric implications of facade design to mitigate overheating in energy-efficient houses. The authors designed a self-shading facade with the shape of an optimal sloping wall, which protects the building from excessive sunlight in the summer. It could potentially serve as an effective shielding device [11].

1.1 Factors influencing thermal stability in summer

Internal thermal stability is significant for the assessment of thermal comfort in summer and winter. It describes the temperature characteristics of the interior space of the building concerning the external conditions. Summer thermal stability of the room is an increasingly topical problem. Calculation assessment applies for the so-called Critical room – space with the expected highest heat load [12]. For the object or room not to overheat, it is necessary to ensure the correct thermal stability design. We can consider a room to be thermally stable, if it's temperature remains within the permitted values for a specified time interval [13]. Factors affecting thermal stability in the summer are structural, architectural, and dispositional solutions of the building. Also, the orientation of the building to the cardinal

points, especially the orientation of the main facade, significantly affects the heat losses and gains of the building. It influences the overall temperature regime of the internal environment [14]. Other factors that affect thermal stability are [15]:
- modification of external surfaces of the building envelope
- segmentation of the outer surface
- the ratio of opaque and glazed parts of the building envelope
- shading of glazed parts
- heat gains through transparent parts of the building envelope
- heat gains through opaque parts of the building envelope
- ventilation of the building
- the measure of the object's accumulative capacity
- internal heat gains from people and appliances

2 Solar gains through transparent surfaces

The potential source of overheating is unwanted heat gains through transparent structures. From the beginning of construction, openings were omitted in the perimeter constructions so daylight could penetrate the interior [16]. The windows are the most vulnerable part of the building. Compared to non-transparent perimeter constructions, they are up to five times weaker from a thermotechnical point of view. Excessive solar gain from windows is one of the most common causes of building overheating [17]. Němeček found in his work that solar gains through the translucent fillings of the openings have the greatest influence on the highest temperature achieved in the interior [9]. The optimal orientation of the glass facade is to the south, southeast, or southwest. Other directions require smaller glazing areas or none at all. It's about the ideology of Socrates' solar house, which perfectly illustrates the principles of passive use of solar radiation. Solar gains through the all-glazed southern facade are desirable in winter but, on the other hand, cause excessive overheating in summer. It causes increased energy costs for cooling systems, which we currently want to avoid (Figure 1.) [18].

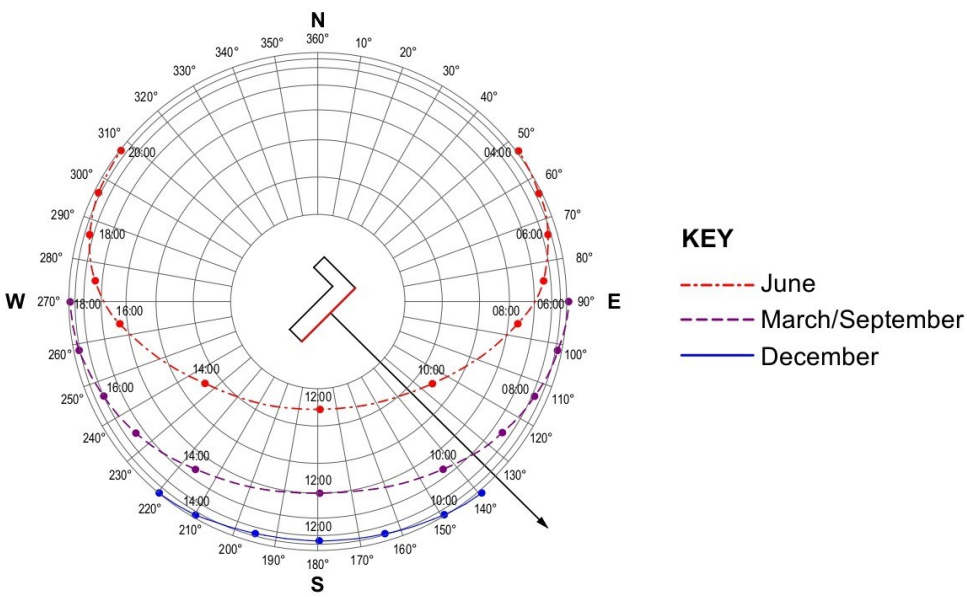

Fig. 1. Diagram of the sun's path during the year (according to [19]).

In recent years, the application of all-glass systems as building envelopes has expanded. The curtain wall has become an icon of developing cities. These structural elements are often the subject of analysis, and many researchers see the enormous energy-saving potential [20]. Apart from the disadvantage of summer overheating, these fully glazed systems also have a positive side. They ensure sufficient natural lighting in the working or living space. Natural daylight and workplace lighting are essential to optimal working conditions and employee health [17].

3 Elimination of solar gains through transparent surfaces

Transparent parts of the perimeter structure of the building are highly exposed, and their thermal insulation and other properties affect the quality of the building's interior space. The need for new technologies and approaches to improve their quality parameters is constantly increasing [21]. Solar gains through transparent surfaces can be eliminated by a generally known solution, namely shading devices. Another significant elimination factor of thermal gains is the correct selection of the type of window and window glazing. The choice of adequate elements is one of the most effective strategies for minimizing solar gains [17].

3.1 Shading elements

We already encounter the shading element in the ideology of Socrates' sunny house, which also points to the problem of summer overheating of buildings (Figure 2.). To prevent summer sunlight from entering the interior, Socrates proposed extending the roof on the south facade of the house. Roof slopes to the north. The slope angle depends on the latitude of the location and the knowledge of the geometry of the sun's rays [18].

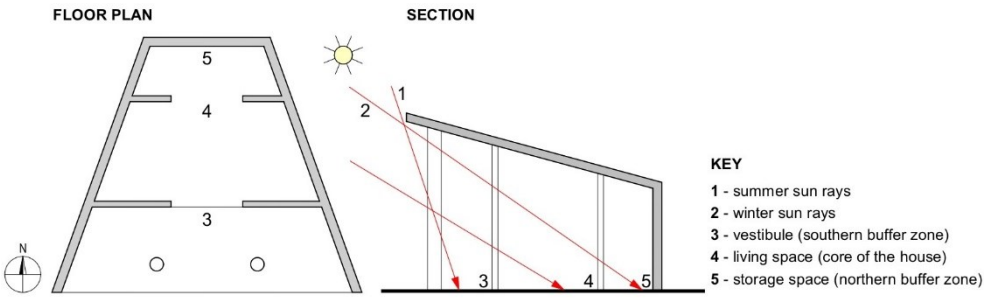

Fig. 2. The principle of Socrates' solar house (according to [18]).

Shading systems are currently an integral part of architecture on buildings with significant glass surfaces. It also regulates direct light and prevents glare and unwanted reflection of sunlight in the interior. High brightness in the visual field can disturb the visual comfort of building users [22]. Nowadays, we know a large number of shading elements. We can divide them into different points of view. According to their location, we can subdivide them into indoor (blinds, curtains, window films, etc.) and outdoor (shutters, outdoor blinds, sun shades, awnings, pergolas, etc.). Shading elements can be stationary, movable, and combined, depending on the control type, manual and automatic. Other divisions are, for example, material used, colour, surface treatment or light transmission. We generally know that external shading achieves higher efficiency than internal ones [23]. In the study by Kraus et al., the authors evaluated the influence of shading elements on the thermal comfort of commercial space in the summer season in the Central European climate

(Czech Republic). Their work aimed to study the effect of solar gains and their impact on thermal comfort. They assessed a total of 9 variants of internal and external shading. With the help of calculations and simulations, they achieved the most favourable results when applying an external semi-transparent colour film to the entire glazing area. The indoor air temperature decreased by 5.17 °C. In second place, the automatically controlled external blinds were closed, reducing the internal air temperature by 3.56°C. The outside screen blackout blinds with automatic control, in dark colour also stood up. Internal blinds with manual control fared the worst, with a temperature drop of only 1.48°C [24].

Shading elements do not always have to be part of the building. Also, the surrounding objects and landscape elements of the building locality environment affect shading. A study by Hwang et al. found that vegetation in an urban landscape can dramatically reduce a building's energy costs. Trees cast shade on buildings, reducing the internal temperature during warm seasons [25]. In another study by Chagolla et al., the authors dealt with measurements and simulations of the effect of trees shade on the internal temperature and thermal load of a test house in the climate zone of Mexico. Measurements and simulations present one warm and one cold week. The results show that the annual energy saving was increased due to the shade of trees by up to 76.6%. Therefore, shading by trees can significantly reduce indoor air temperature in warm climates and achieve thermal comfort [26].

3.2 Glazing of transparent constructions

The researcher Usta and Zengin focused on energy simulations of four different types of glazing in the climatic zone of Istanbul. Glazing depends on the thickness of the glass and the air gap. The type of glazing mainly affects the building in terms of internal thermal comfort. The study proves that building's energy demand can decrease by 25% by using a suitable glazing material [17]. In Slovakia, the critical period of overheating of buildings is the interval from April to September. During this period, solar radiation increases and causes significant heat gains in the interior of buildings. In his study, researcher Masaryk dealt with designing a system that would allow absorption or reflection of the heat-bearing part of the spectrum of solar radiation while allowing sufficient visible light into the interior of the building. The principle consists of creating a liquid layer on a transparent surface with a suitable additive. The best results reached black acrylic paint, which achieved the performance of white colour but with 1/3 of its volume [27]. Researchers Buratti et al. compared double glazing with aerogel insulation with single and double glazing in three different climates. The simulations apply to school buildings, where the glazing area was 30% of the building surface. The results show that using aerogel glazing reduces solar gain by 73% compared to single glazing and by 56% compared to double glazing [28]. Researcher Zhou also deals with aerogel glazing, and in his study, he devotes himself to a holistic review of the application of aerogel in building glazing (Figure 3.). Passive solutions, as a type of new glazing with more advanced materials, represent a more flexible way for practical applications. The study provides an in-depth analysis of the aerogel material, its production, and construction applications. The results show the potential of this material as a promising candidate for the energy efficiency of buildings [29].

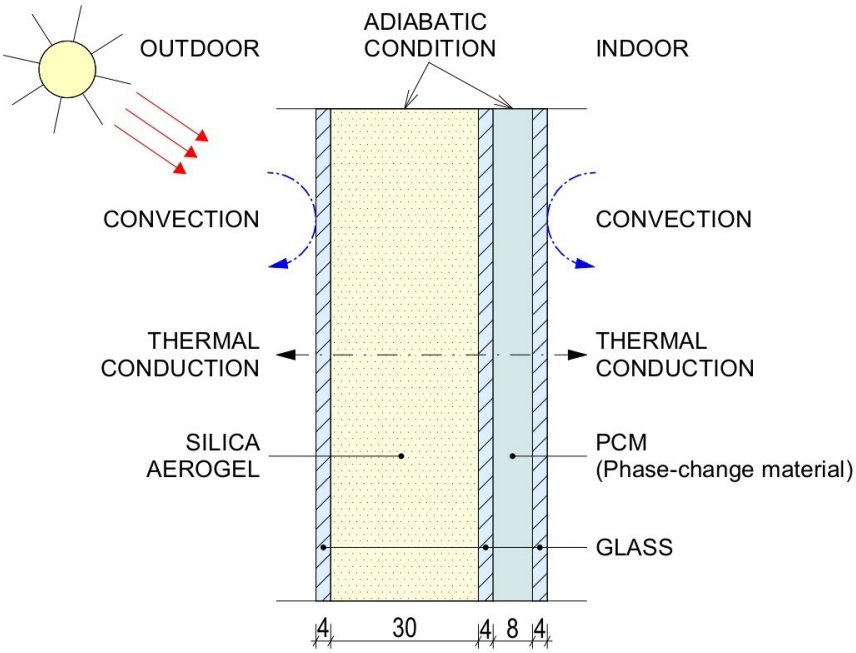

Fig. 3. Structural configuration of a PCM and aerogel-integrated window glazing system (according to [29]).

Conclusion

Due to the climate changes in recent years, we can assume an increasingly frequent occurrence of exceedingly warm days everywhere in the world. For this reason, we should pay more attention to the theme of the summer overheating of buildings [30]. However, we should not only focus on how to mitigate climate change but also on how to face its consequences. It is necessary to focus on finding a long-term efficient solution for protecting buildings from overheating. Nevertheless, we can eliminate some of the problems and help improve thermal stability by improving insulation, better quality windows and last but not least, shading elements and a shading system. Correctly designed and right-implemented sun protection creates maximum visual and thermal comfort in the interior. It leads to improved productivity, performance and above all, the health of building users [24].

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