

The effect of enhancing super insulation Aerogel for future building façades in North of Iraq

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Abstract—Aerogel is a sort of engineered porous substance. It has unique chemical and physical properties with different types of opaque and translucent. It is considered one of the most encouraging materials in various applications such as spacecraft and buildings. In building, translucent aerogel uses for window construction. It plays a vital role in enhancing building thermally and acoustically. Despite its high cost, aerogel is a brittle material. It is hard to produce large-sized free crack windows and prevents the window from being operable. It is not optically transparent, which isolates occupants from the outside view. These limitations restrict architects from using aerogel as windows on façades freely. Improved aerogel windows can get better efficient glasses, larger sizes, and transparency that experiences the natural quality of the light and outside view. It may give the building more functional façades that can fulfill people's needs in the future. So, the study will evaluate the efficiency of façade in the future. The study aims to predict the capability of improved aerogel in creating a façade that achieves human needs while increasing the efficiency of the building from different perspectives. It examines improved aerogel windows and their role in enhancing current residential buildings in northern Iraq. Ecotect and Dialux software are used as research tools. The paper concluded that the capability of improved aerogel will give the building a new façade that is more environmentally friendly and provides human comfort while still transparent compared to the current facade.

Keywords—Aerogel, building façade, Improved aerogel, occupant comfort, window design.

I. INTRODUCTION

Nodaway's major issue occupying the human mind is building energy savings. The main reason people are busy with energy-saving is that the earth's surface

temperature increased by nearly 0.6-0.9 C° between 1906 and 2005 [1]. Different activities produce an increase in greenhouse gas emissions through non-renewable energies [2]. The problem for the architect to consider is building energy consumption. The building sector represents one of the main sectors in consuming energy. It consumes about 40% of the final energy consumption [3]. Mostly it is consumed by the windows [4]. Windows are responsible for %45 of the total energy consumption of the building envelope [5]. Transparent parts of the building have a significant role in consuming energy, and it is responsible for almost 60% of total building energy consumption [6]. So, there are weaknesses of the window design thermally. It has high thermal transmittance compared with the other elements of the building envelope. Nanotechnologies relatively controlled the weaknesses by manufacturing translucent and transparent aerogel window types. Aerogel is a material where firstly produced in the 1930s [7]. It is defined as the most effective building thermal insulation. It is a very porous material with a very low density. [8]. More than 90% of the aerogel consists of air. It is the lightest solid substance that is ever known [9].

The study's main aim is to show future building façade based on the aerogel's capability on the window's performance. Windows, as an indispensable part of the building, have essential functions. It provides the spaces outside view, natural ventilation, and natural light to obtain occupant's comfort. For this purpose, this research investigates improved aerogel's impact on the façade function of a typical residential building in North Iraq. Two simulation software used as a research tool (Ecotect simulation software and Dialux). In this research, Ecotect simulation software uses to assess energy, optical and acoustic performance. Dialux is utilized to examine the lighting condition of the space on the human visual

Manuscript received 3 September, 2021; revised 21 November, 2021; accepted 5 January, 2022; published 19 January, 2022.

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This article has been subject to single-blind peer review by a minimum of two reviewers. Digital Object Identifier <https://doi.org/10.55066/proc-iccc.2021.12>

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comfort. The research compared the performance of three window types (typical, current aerogel, and improved aerogel).

II. PROPERTIES OF SUPPER INSULATION AEROGEL

The pores of aerogel are so tiny. Pure aerogel has an average pore diameter between 10 and 100nm. In general, Silica aerogels have pore sizes between 5 and 70nm, which will take from 85 to 99.8% of the total aerogel volume. Thus, it has particular material properties with very low mechanical strength. Aerogels are used for building applications that have an overall density of 70-150 kg/m³ [7, 10]. Although, dust produces while installing aerogel. However, this dust is reported as nontoxic dust that does not affect human health. So, aerogel is a nontoxic material [11]. Generally, these materials are non-flammable and fire-resistant [7, 10]. It has good water resistance and high hydrophobic characteristic [12]. With these physical properties, the super insulation aerogel has a very low thermal conductivity. Most of the tiny pores of aerogel have a dead-end, which is the main restriction of the heat transmission path [11].

Generally, the U-value of the material is around 0.01 to 0.02 W/m.K. Its unique thermal properties made it favorable to use in energy-efficient buildings [11]. The uniqueness of the material is related to its porosity, so it has a very low density [13] and is efficient thermally [14]. It has a unique property that prevents heat loss and allows solar transmittance [15]. It also has good acoustic performance. It has a very high capability to sound absorption [16].

The aerogel window is translucent. It means that it cannot provide an outside view for the users in which it blocks the occupant from outside. Despite that, it still allows sunlight to enter the building [14]. The transmission of the light will be on the base of diffuse light. The incident light on the aerogel is reflecting and scattering [7]. The light transmittance through the material is different

TABLE I

CHARACTERISTIC OF AEROGEL IN BUILDING AND ITS ADVANTAGES AND DISADVANTAGES [7, 11, 12, 15]

Characteristic	Properties	Pros	cons
<i>safety</i>	Non-flammable -----	✓	
	Fire resistance -----	✓	
	having dust during installation---		✓
	brittle material -----		✓
	low mechanical strength-----		✓
<i>Comfort</i> <i>Thermally</i>	Good water resistance -----	✓	
	Low thermal conductivity -----	✓	
	Allow solar transmittance -----	✓	
	unopenable window -----		✓
	preventing natural ventilation ----		✓
<i>acoustically</i>	sound-absorbing material -----		
<i>Visually</i>	Translucent material -----		✓
<i>lighting</i>	The light can be transmitted -----	✓	

depending on the thickness and the size of the particles. Because of the mentioned properties, its application has been limited in buildings. Table 1 shows the properties of aerogel in buildings. The Aerogel window should be integrated with transparent glass to provide building users with an outside view [11].

E. Limitations of aerogel

For using aerogel as a window, the designer should consider three limitations. Firstly, the cost of the aerogel is very high [10], Secondly its brittleness. Aerogel is a fragile material, weak to the tensile strength (low mechanical strength) [7]. It prevents the aerogel window from being operable and is recommended as a fixed window to prevent cracks [11]. Finally, aerogel is a translucent material.

A. Types of aerogel for building

There are different types of aerogel in buildings like blocked aerogel, loose granular aerogel, fib-panel aerogel, mat and rolls, blanket, aerogel plasters, and concrete aerogel. They are used for opaque parts of the buildings [9]. Nevertheless, aerogel plastic panes or double-glazed windows filled by aerogel are used for the transparent portions of buildings [6].

III. BUILDING FAÇADE

The building is defined in different ways based on its structure, envelope, mechanical, and interior properties. The envelope satisfies human needs and “responds to natural forces and artificial values” [17]. Historically, the building envelope was a shell for protecting inside space from outside while providing lighting to the inside based on the locally available material [18]. Developments of material give opportunity for the new design of building facades [19]. Technologies drive this development. Through the last few decades, façade technologies have concentrated on decreasing energy demand in the building by using advanced building materials and integrating elements and systems to make the building cope with the climate and use free energy for obtaining comfort for the occupant [20]. In general, façades can be defined as a barrier that separates usable interior space from the outside world [21].

B. Characteristics in building façade

Many characteristics combined with the building façade, which are design, construction, operation [21]. Façade should have some properties such as the structure of the façade, that related to the calculation of loads on the façade and stated that the building façade should resist any deformations or failure that may cause by different forces and should be flexible. Also, the façade should be efficient socially, regarding the capability of the façade to interconnect with the building occupant and pedestrian. Types of material are a significant issue as well. It should be resilient, durable, sustainable, give privacy against

internal and external noise, and physically efficient. Then the designers can design an energy-efficient facade with low greenhouse gas emissions, provide the possible protection from UV, and let the essential light enter the building [22]. So, a facade should give the occupant comfort, privacy, and security besides its aesthetic pleasure and well-being [23]. Nowadays, the main challenge in developing building facades is to fulfill the need of the residents while decreasing energy use in buildings [24].

C. Historical changes in building facade

Because of the constant development of building facade, the definition of the facade is changing as well. Facade can be defined from different perspectives. It is considered the external face of the building. Structurally, it is categorized into a load-bearing and non-bearing facade. Based on the material used, it is a shell of the building consisting of transparent and non-transparent parts that can create different facades like glass facade, masonry facade, concrete facade, etc. Recently, it is an integrated system that the facade became a complex structure. It uses the outdoor environment for the indoor environment [25]. As a result, the facade developed from the simple solid wall into a more complex integrated facade. The transparent part of

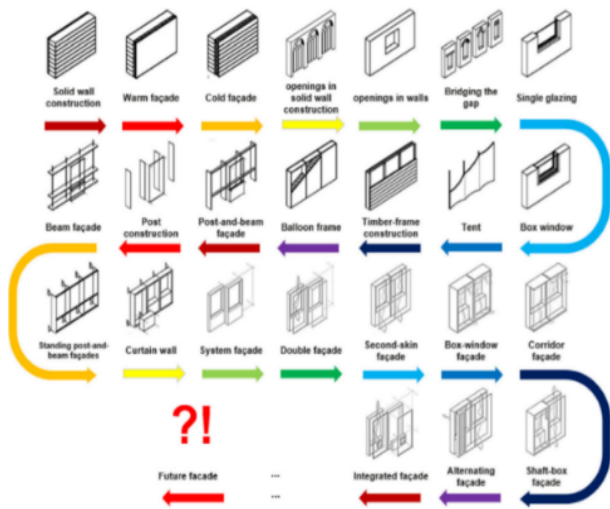


Fig. 1. Historical development of building facade (from simple wall to facade) [18].

the facade becomes much wider. It plays a vital part in contemporary architecture. It has become more prosperous in modern buildings. Figure 1. clarifies that the facade is in continuous development and changes [18]. With the facade development, most of the time, the installation cost is much higher than before. Meanwhile, it needs professionals and experts to obtain and manage a more efficient developed facade. Some developed facades, like integrated building photovoltaic facade, are becoming less efficient with time.

D. The transparent part of the building facade

Glazing is the term that describes the transparent material used in the window. Changing the glazing system

by placing aerogel between layers of the glass significantly enhances energy performance. Replacing old glazing with a higher efficient one is a common way to reduce the heat loss of residential windows [26]. The window has four main functions that incorporate with the building facade [27]. Firstly, it is the thermal function. Proper window design reduces extra heat loss in winter and heat gain during summertime [27, 28]. Secondly, visual comfort; relates to the lighting level and distribution of the light inside the space. Assessing visual comfort inside the building depends on the level of glare and lighting distribution. The acceptable illuminance value is between 100- 2000 Lux. [29]. Thirdly, outside view; is the way for connecting inside to outside. The way the window is composed should maximize the external view from the inside [27]. Finally, acoustic function, porosity, and flexibility of the material are the main characteristics to evaluate material acoustically [30]. Recently Sound reduction through the window has become important [28]. It is essential to keep the privacy of the space and provide occupant comfort. Here the vital function of aerogels is to give humans a comfortable place from a different perspective.

IV. IMPROVED AEROGEL

There are many scientific studies and experiments to decrease the limitations of aerogels. This paper illustrates some important improvements for window application to predict the next steps for implementing aerogel in the future facade.

Aerogel could be produced in two different forms for the window, which are granular and monolithic aerogel. The former one can be seen in the building window. The production of the latter one is to improve the optical properties of granular aerogel. Till now, it is not used in the building. There are prototypes of it for studies [31]. The aim of developing monolithic aerogel instead of granular aerogel is to make the material more efficient in terms of light transmission. It proved that light transmission increased twice according to the granular aerogel window. However, monolithic aerogel gives a glare outside view, and the maximum area of monolithic aerogel panel that can be produced free of a crack is (60 cm* 60 cm) because of its brittleness [11].

Experiments of the aerogel, especially silica aerogel, had been done to eliminate this limitation. Furthermore, found that there are ways to improve the mechanical properties of aerogel. The experiment of producing samples of silica-aerogel proved that with special ways, the aerogel can be bent and called (x-aerogel). It is a flexible and strong version of aerogel. However, it should be mentioned that the material will be lost nearly 50% of its thermal properties and losses its clarity to more opaque material [32]. It is a significant improvement. It can be used in large-scale applications [33].

Structural development of silica aerogel from granular to monolithic aerogel was a great step toward converting

aerogel from translucent to transparent aerogel. A company has developed the translucent aerogel into a transparent one. In which the light can go through it meanwhile protecting its properties according to the thermal conductivity. As well as, it gives aerogel good optical performance. The study Makes a remarkable material even better and states that using aerogels for solar devices and windows can be more transparent than glass. It is proven that it can be applied in windows efficiently. It can give more insulating material compared to today's triple panel window at half-price [34].

Another experimental examination of aerogel has been done to overcome the limitations. The experiment was successful in making it flexible, transparent, and still give good thermal insulation. One main point is that it can be scaled to a bigger one in future work [35]. Figure 2 illustrates a transparent and flexible aerogel. After the

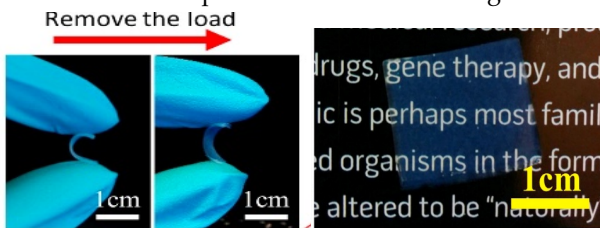


Fig. 2. Flexibility and transparency of silica aerogel [35].

experiment, a characteristic of new had been studied. The experimental research stated improved aerogel still porous material with a porosity of around 90-97%, very low density (69 mg/cm²), and very low thermal conductivity (0.018 0.003. W/m.K), and very high optical light transmittance between 390-700 mm. The ratio of optical light transmittance is about 90%, and its cost will be lower compared to conventional aerogel [35].

V. CASE STUDY

The purpose of this case study is to investigate and evaluate the improved aerogel in the building, especially single-family residential blocks (North of Iraq). The research tries to predict the causation of the improved aerogel on the future building façade.

E. Typical modern house in the north of Iraq

Researchers selected typical modern residential buildings in northern Iraq as a case study because, in the last decade, the housing sector has consumed approximately 50 percent of total energy consumption [36]. The urban fabric is vehicle-oriented, unlike historical urban areas [37]. As a result, the typical modern houses are located on broad avenues. So, the sound of the vehicle is available. The exterior windows are directed towards the streets. The area of the windows is relatively big according to the wall ratio. Typically, the entrance, kitchen, and living room are the main areas found in the front of the houses. The front ceiling shades the window at specific times during the day, called Tarma. Tarma is used for decoration and rain protection without considering the orientation and angle according to the sun and prevailing

wind [36]. The houses are mostly 200m². Most of the modern buildings are detached houses. Their orientations vary. They are poorly insulated [38]. Figure II illustrates the example of a typical residential building in the region.

The study shows the possible performance of improved aerogel. Researchers compare its performance with the available aerogel window and available window in the regions. A casual analysis is used. It shows the effect of independent variables on dependent variables [39]. The independent variables are different window types, different climates, and orientations. Dependent variables include window's functions (thermal, optical, visual, acoustic performance). The casual analysis shows improved aerogel's capability to enhance the main functions of the window as a part and the building façade as a whole. The study selected two climatic data, which are Mediterranean (moderate) climate and hot-dry climate.

Figure 4 demonstrates the base model for taking the evaluation with all the mentioned variables. Variables of the models are the same, such as infiltration rate, number

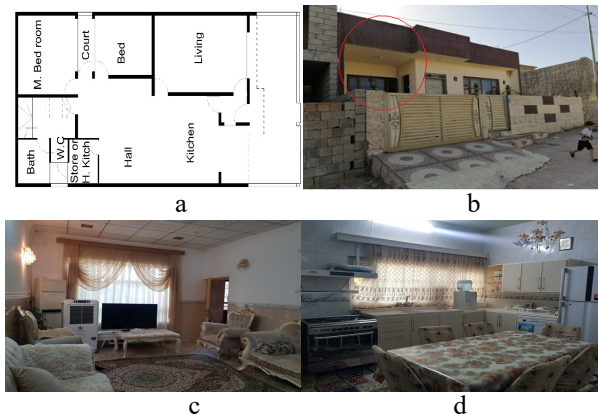


Fig. 3. Detail of typical house design in the north of Iraq. (Researchers).

(a) Plan of the typical house (10 * 20) 200 m². (b) Front elevation of the house and Tarma. (c) Living room: wall and roof covered by gypsum plaster, floor covered by carpet. (d) Kitchen: wall and roof covered by gypsum plaster, floor covered by carpet.

of occupants, time operation of the spaces. Thermal zones were put on both sides and back in the visual environment to make it a detached house.

F. Simulation setup

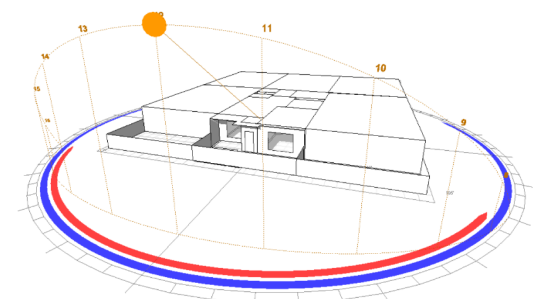


Fig. 4. Base model/ Ecotect software.

The study used Ecotect and Dialux simulation software to get numerical data. Ecotect was used to calculate building thermal, optical, and acoustic performance.

Dialux and Ecotect together were used to evaluate building visual performance. The simulation is done in the two main spaces (Living and Kitchen) for thermal performance and living space for other visual, optical and acoustic performance. The simulation was done for the entire year in the kitchen and living room to obtain thermal insulation data. Four main orientations have been taken in each model. The researchers did the simulation in both

TABLE II
INDICATORS OF WINDOW PERFORMANCE FOR OCCUPANT COMFORT USED IN THIS STUDY

Window performance	Indicators	Comfort range
Thermal	Space temperature control	Keep temperature between 18°C-26°C
Visual	Daylight factor Lighting level (Glare)	2% - 5% More than 10%
Optical	Direct solar radiation transmission	Less time needed to reduce the intensity of sound by 60Db will be more comfort
Acoustic	Reverberation time	More solar radiation transmittance is opaquer and comfort

TABLE III
BUILDING DESIGN FOR SIMULATION

Name	layers from outside to inside	Density (kg/M3)	Conductivity W/m. K
Roof	-Bitumen	1700	0.500
	-Reinforced concrete	950	0.209
	Air gap	50	5.560
	Gypsum plaster board	1100	0.650
Ext. wall of kitchen	Tile	1200	0.190
	Cement mortar	1650	0.720
	Hollow concrete block	1800	1.300
	Cement mortar	1650	0.720
Ext. wall of living	Marble	2500	2.000
	Gypsum plaster	1120	0.510
	Hollow concrete block	1800	1.300
	Cement mortar	1650	0.720
Internal wall	Mable	2500	2.000
	Gypsum plaster	1120	0.510
	Hollow concrete block	1800	1.300
	Gypsum plaster	1120	0.510
Floor	Soil (g. properties)	1300	0.837
	Concrete	2300	0.750
	Cement mortar	1650	0.720
	Tile	1200	0.190
	carpet	190 –	0.060
Commonly used window	Glass standard	2300	1.046
	Single glazed (Alum. Frame)		
Granular aerogel window	Aerogel glass (2 cm granular aerogel between two glazed panes)	80	0.012
Improved aerogel	Improved Aerogel glass (2 cm granular aerogel between two glazed panes)	80	0.013

climates, the hot-dry region of Erbil and the moderate

climate of Sulaimani. Table 2 demonstrates the indicators for evaluating different window designs. It is based on thermal, lighting, visual and acoustic performance. Table 3 shows used materials in the walls, floor, roof, and windows.

VI. ANALYSIS AND DISCUSSION

G. Thermal performance

As stated before, the selected parameter for evaluating thermal comfort is space temperature control. As shown in Figure 5, in the hot climate of Erbil, energy saving in the east is the best, while in a moderate region of Sulaimani, houses in the south are best in terms of saving energy. In Erbil's hot, dry climate, spaces with granular aerogel windows need less energy to keep the interior space comfortable for humans. Nevertheless, in moderate climate improved aerogel is the best one according to

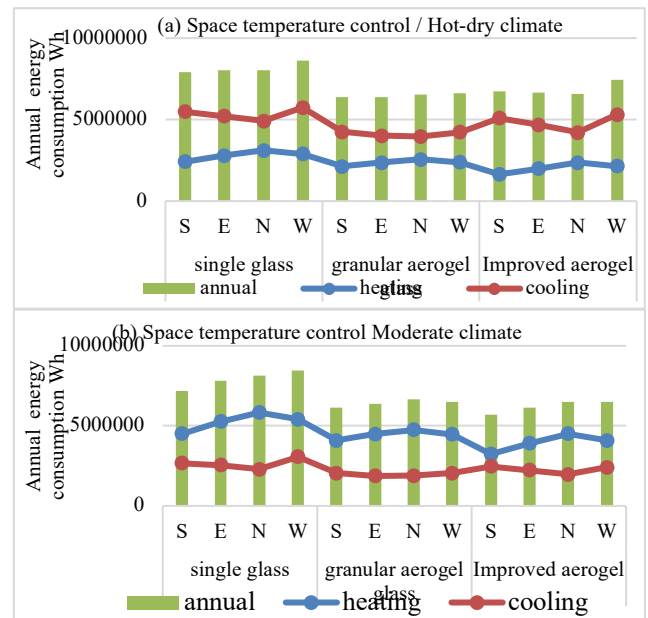


Fig. 5. The relationship between heating, cooling, and annual energy consumption. (a) Erbil city, (b) Sulaimani city.

space temperature control. Moreover, the actual case of houses in the north of Iraq needs more energy related to the other samples. The obtained data was analyzed to find the relation between the categorical variable (different material) and continuous variable (total energy consumption) in both climates.

It concluded that there is a strong relationship between energy consumption and the type of glass used. The decrease of the annual energy consumption of houses in hot climate constructing with improved aerogel was around 18% annually compared to the single glazed window. Furthermore, houses with granular aerogel windows can keep the temperature under the comfort level 25% less than a single glazed window. And nearly 6% less than an improved aerogel. Nevertheless, these proportions are different in the Sulaimani climate. The improved aerogel was the best selection for controlling space temperature. Spaces with improved aerogel

windows need less energy than single glass and granular aerogels, about 27% and 3%, respectively.

This difference occurred because granular aerogels can block solar radiation more than improved aerogels. Which is vital in a hot climate, but it is not desirable in a moderate climate.

H. Visual performance

The paper used daylight factors and daylight levels in the living room to examine human visual comfort. The study used the daylight factor to evaluate the degree of natural light in space. It is the ratio of internal illuminance to the external under an overcast sky [41]. A higher degree of daylight factor means more daylight exists in space. The comfort level is between 2% - 5%. Below 2% means the area needs artificial light to achieve visual comfort, while over 5% causes human discomfort. Figure 6 can conclude that, in all cases, the average illuminance level is within comfort level. Space with granular aerogel has a minimum daylight factor. The illuminance level of the area with improved aerogel and single gals is almost the same. The analysis concluded that the enhanced aerogel window is less efficient than a single glazed window by 1.5 %. However, improved aerogel windows are more efficient than the granular aerogel by 40%. The improved aerogel glass is less translucent than a single glazed window, still more transparent than granular aerogel. Another parameter that is important to evaluate human visual comfort is glare.

Dialux software examined glare levels in the room. The software assumed that the obtained glare value was higher than 10% means the work plane has a glare. The work plane was established 0.80 cm above the ground. Measuring the glare level was taken based on the longest day of the year. Besides, measuring the glare was set at 08:00, 12:00, 17:00, and 18:00 for South, East, North, and West. It is concluded that, in both climatic regions, no glare may occur inside the space with all examined material.

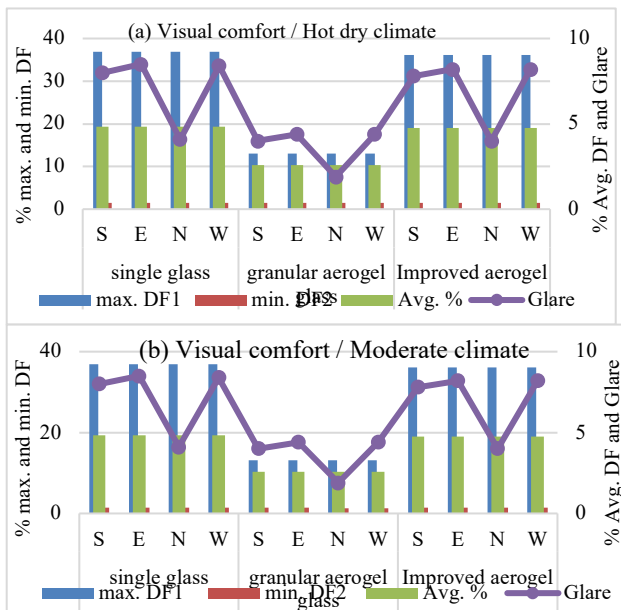


Fig. 6. Effect of the window materials on human visual comfort. (a) Erbil city, (b) Sulaimani city.

Although the possibility of having the glare of a single glazing window is higher than the other types, as shown in Figure 6.

I. Optical performance

The simulation was done to see the ratio of the material's effect on optical conditions according to each other. The amount of direct solar radiation that can enter space can determine the opacity of the material. Lower transmittance means further opaque objects. After getting the data of direct solar transmission, it is seen that the typical house model with the improved aerogel has a good performance that gives the occupant an outside view. Based on the analysis of the obtained data, it is clear that the visual effect of single glazed is higher, around 5% and 60%, than improved aerogel, granular aerogel, respectively. However, improved aerogels are more efficient than granular aerogels by 58%. Figure 7 shows the direct light transmission of the materials in both climates.

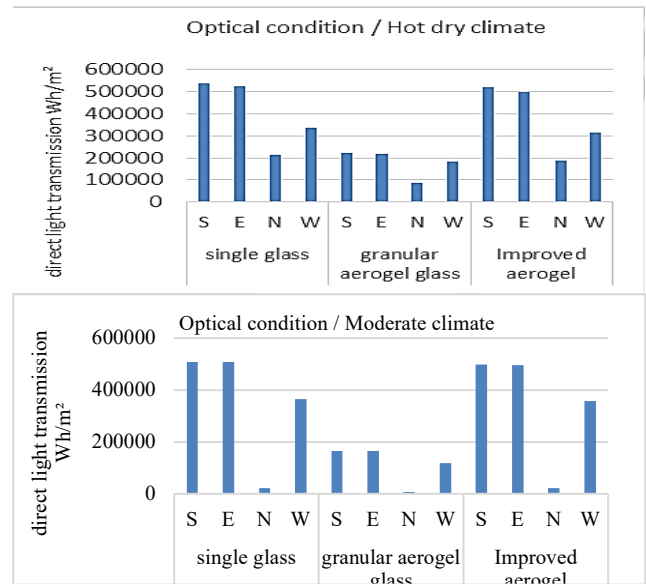


Fig. 7. Relationships between direct solar radiation and the optical condition of the selected room.

J. Acoustic performance

The study assigned a sound source at level 1.7 m above ground in the software with a 6 m distance from the tested material. It is regarding the plane of humans while standing. It took reverberation time to measure sound decay. Reverberation time measures the time needed to reduce the intensity of sound by 60 dB. The reverberation time in the single glazed window, granular aerogel window, and improved aerogel window was 195, 190, and 187 ms (millisecond), respectively. Figure 8 illustrates the vibration time of the studied windows.

The Figure shows that a single glazing window needs more time to reduce the sound level. It has less capacity to absorb sound energy, and it is less efficient than others. The improved aerogel is the most efficient one. Higher porous and more flexible material has a higher capacity to absorb the energy sound and reduce its velocity [30].

Sound absorption and decreased velocity are depending on the porosity and flexibility of the material. Improved aerogel is more porous than regular glasses and more flexible than granular aerogels.

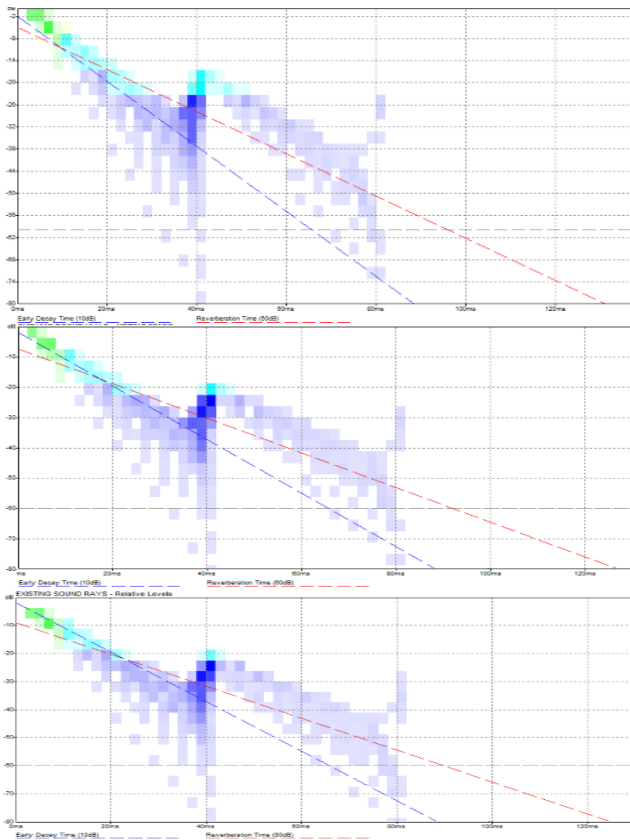


Fig. 8. The relationship of reverberation time and the cases Single glass, Granular aerogel, Improved aerogel, Respectively.

VII. CONCLUSION

The study evaluated the effects of improved aerogel and analyzed it by casual analysis strategies to find the relationship between enhanced aerogel and window functions. The research concluded that the unique characteristics of improved aerogel made the material remarkable.

It improves the function of the window. It permits natural ventilation, daylight transmission, enhances visual performance, and achieves high thermal and acoustic insulation. The current focus of the window is to make a balance between the main functions. The improved aerogel window covers these issues. Thus, the design of the façade will be free from the fenestration design problem. Different windows in terms of area and shape could be designed while still enhancing building façade performance.

Typical residential buildings in the north of Iraq did not take advantage of the benefits of modern window material to improve their performance. In a way, the typical contemporary house has a desirable level of light. The window area on the facade is wide according to the room area, and it does not restrict outside view. However, the need for sound security and thermal performance in

modern homes is critical. Nevertheless, it does not achieve with the current window material (single glass). Besides, the current residence in the north of Iraq did not take climatic consideration during house design. It could not achieve human comfort with lower energy within this material.

Meanwhile, improved aerogels can achieve human comfort with less energy consumption. Aerogel windows can be flexible and transparent with high insulation. In the future, nanotechnology of aerogels will dominate architecture building façade. It will enhance the performance of the building façade. It will improve the performance of the building façade. It gives architects the freedom to experience window design in different shapes and areas without concern about the limitations of the glass. The improved aerogel window can fulfil all the functional requirements of the window. Thus, it will enhance the building's performance as well. Improved aerogel takes advantage of both single glazed and granular windows. At the same time, it takes away the disadvantages of both materials. In other words, building thermal performance with the improved aerogel is almost similar to the granular aerogel, with low differences in different directions depending on the climate.

Nevertheless, the visual properties are almost like regular glass. Besides, improved aerogel is much more efficient than other materials acoustically. As a result, the capability of aerogels gives another dimension to the nowadays building façade. The façade can be designed differently without the limitations that the windows currently have. So, it is significant material that the architect should have information about it. They should depend on it while designing. Yet more studies on aerogels are still required and are essential to evaluate other requirements than functional requirements, such as the influences of aerogels on the aesthetic of the building façade.

REFERENCES

- [1] Nasa Earth Observatory, 2010. [online]. Available: https://earthobservatory.nasa.gov/features/GlobalWarming/page_2.php.
- [2] National Research Council, "America's climate choices: panel on advancing the science of climate change," November 15, 2020. [online]. Available: <https://www.nap.edu/initiative/americas-climate-choices-panel-on-advancing-the-science-of-climate-change>.
- [3] L. Pérez-Lombard, J. Ortiz, C. Pout, "A review on buildings energy consumption information", *Energy and buildings*, vol. 40, no. 3, pp. 394-398, 2008.
- [4] K. Alhagla, A. Mansour and R. Elbassuoni, "Optimizing windows for enhancing daylighting p-performance and energy saving," *Alexandria Engineering Journal*, vol. 58, no. 1, pp., 283-290, 2019.
- [5] A. Gustavsen, S. Grynning, D. Arasteh, Bp Jelle and H. Goudey, "Key elements of and material performance targets for highly insulating window frames", *Energy and Buildings*, vol. 43, no. 10, pp. 2583-2594, 2011.
- [6] Bp. Jelle, A. Hynd, A. Gustavsen, D. Arasteh, H. Goudey and R. Hart, " Fenestration of today and tomorrow: A state-of-the-art review and future research opportunities," *Solar Energy Materials*

- and Solar Cells, vol. 96, pp. 1-28, 2012. DOI: 10.1016/j.solmat.2011.08.010, [Online].
- [7] B. P. Jelle, R. Baetens and A. Gustavsen, "Aerogel insulation for building applications," *The Sol-Gel Handbook; D. Levy, M. Zayat, sEds*, vol. 21, pp. 1385-1412, 2015. DOI: 10.1002/9783527670819.ch45, [Online].
- [8] Z. Ülker, D. Sanli and C Erkey, "Applications of aerogels and their composites in energy-related technologies," *In Supercritical fluid technology for energy and environmental applications*, Elsevier, 2014, ch.8 pp. 157-180. [Online]. DOI: 10.1016/B978-0-444-62696-7.00008-3
- [9] U. Berardi, "The benefits of using aerogel-enhanced systems in building retrofits," *Energy Procedia*, vol. 134, pp. 626-635, 2017.
- [10] SB. Riffat and G. Qiu, "A review of state-of-the-art aerogel applications in buildings," *International Journal of Low-Carbon Technologies*, vol. 8, no. 1, 2013.
- [11] U. Berardi, "Development of glazing systems with silica aerogel," *Energy Procedia*, vol. 78, pp. 394-399, 2015. DOI:10.1016/j.egypro.2015.11.682, [Online].
- [12] M. Ganobjak, S. Brunner and J. Wernery, "Aerogel materials for heritage buildings: Materials, properties and case studies," *Journal of Cultural Heritage*, vol. 42, pp. 81-98, 2020. DOI: 10.1016/j.culher.2019.09.007, [Online].
- [13] E. Cuce, PM. Cuce, CJ. Wood and SB. Riffat, "Optimizing insulation thickness and analysing environmental impacts of aerogel-based thermal superinsulation in buildings," *Energy and Buildings*, vol. 77, pp. 28-39, 2014. DOI: 10.1016/j.enbuild.2014.03.034, [Online].
- [14] T. Gao, BP. Jelle, and A. Gustavsen, "Building integration of aerogel glazings," *Procedia Engineering*, vol. 145, pp. 723 – 728, 2016.
- [15] C. Garnier, T. Muneer and L. McCauley, "Super insulated aerogel windows: Impact on daylighting and thermal performance," *Building and Environment*, vol. 94, pp. 231-238, 2015.
- [16] C. Buratti, E. Moretti, and E. Belloni, "Nanogel windows for energy building efficiency," *In Nano and biotech based materials for energy building efficiency*, 2016, ch. 3, pp. 41-69.
- [17] C. Arnold, "Building envelope design guide- introduction," Building Systems Development Inc. The National Institute of Building Sciences, 2016. [online]. Available: <https://www.wbdg.org/guides-specifications/building-envelope-design-guide/building-envelope-design-guide-introduction>
- [18] U. Knaack, T. Klein, M. Bilow and T. Auer, *Façades: principles of construction*. Berlin: Birkhäuser, 2014.
- [19] J. Acharya, D. Joshi, and V. A. Gokhale., AEROGEL—a promising building material for sustainable buildings. *Chemical and Process Engineering Research*, vol. 9, pp.1-6, 2013.
- [20] HM. Sacht, L. Bragança and MG. Almeida, Façade modules for eco-efficient refurbishment of buildings: glazing thermal performance to Guimarães climate. *International Conference Sustainability of Constructions - Towards a better built environment*, university of Malta, 2011. [Online]. Available: <http://hdl.handle.net/1822/15102>.
- [21] MK. Namazi, P. Eshrati, D. Eshrati and SF. Nezhad, "The Study of Effective Components in Façade Engineering Towards Developing a Conceptual Framework," *Journal of Applied Environmental and Biological Sciences*, vol. 6, no. 7, pp. 61-68, 2016.
- [22] M. Eekhout, "Future for façade research at TU Delft," *The Future Envelope 1: A Multidisciplinary Approach*, IOS Press. vol. 8, pp. 135-158, 2008.
- [23] A. Sandak, J. Sandak, M. Brzezicki and A. Kutnar, Bio-based building skin. Springer Nature, 2019.
- [24] European commission, "Energy performance of buildings directive," European commission, March 20. [online]. Available: URL: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en
- [25] H. Du, P. Huang, P. Jones, "Modular facade retrofit with renewable energy technologies: The definition and current status in Europe," *Energy and Buildings*, vol. 205, 2019. DOI: 10.1016/j.enbuild.2019.109543 [Online]
- [26] J. Jenden, A. Halim, B. Afework, and J. Donev, "Energy Education – Glazing," 2020. [Online]. Available: <https://energyeducation.ca/encyclopedia/Glazing>.
- [27] M. Santamouris, *Energy and climate in the urban built environment*. London: Routledge, 2011.
- [28] Y. Tsukamoto, Y. Tomikawa., K. Sakagami, T. Okuzono, H. Maikawa, Y. Komoto, Experimental assessment of sound insulation performance of a double window with porous absorbent materials its cavity perimeter. *Applied Acoustics*, 165, 107317. 2020. DOI: <https://doi.org/10.1016/j.apacoust.2020.107317>
- [29] U. Berardi, T. Wang, "Daylight simulations in an atrium-type house," *Building and Environment*, vol. 76, pp. 92-104, 2014. DOI: 10.1016/j.buildenv.2014.02.008, [Online].
- [30] M. Hacker, D. Burghardt, L. Fletcher, A. Gordon, and W. Peruzzi, *Engineering and technology*. Delmar Cengage Learning, 2010.
- [31] F. P. Torgal, M. Mistretta, A. Kaklauskas, C. G. Granqvist and L. F. Cabeza, *Nearly zero energy building refurbishment*. London: Springer 2013. DIO: 10.1007/978-1-4471-5523-2, [Online].
- [32] M. Casini, *Smart buildings: Advanced materials and nanotechnology to improve energy-efficiency and environmental performance*. Woodhead Publishing, 2016. [Online]. Available: <https://www.sciencedirect.com/book/9780081009727/smart-buildings>
- [33] V. G. Parale, K. Y. Lee and H. H. Park, "Flexible and transparent silica aerogels: an overview," *Journal of the Korean Ceramic Society*, vol. 54, no. 3, pp. 184-199, 2017. DOI: 10.4191/kcers.2017.54.3.12, [Online].
- [34] N. W. Stauffer, "Making a remarkable material even better. Aerogels for solar devices and windows are more transparent than glass," 2020. [online]. Available: <http://news.mit.edu/2020/making-remarkable-material-even-better-aerogel-0225>.
- [35] Q. Liu, A. W. Frazier, X. Zhao, J. A. De La Cruz, A. J. Hess, R. Yang and I. I. Smalyukh, "Flexible transparent aerogels as window retrofitting films and optical elements with tunable birefringence," *Nano energy*, vol. 48, pp. 266-274, 2018. DOI: 10.1016/j.nanoen.2018.03.029, [Online].
- [36] D. H. Morad, S. K. Ismail, "A comparative study between the climate response strategies and thermal comfort of a traditional and contemporary houses in KRG: Erbil," *Kurdistan Journal of Applied Research*. Vol. 2, no. 3, pp. 320-329, 2017.
- [37] A. Al-Thahab, S. Mushatat, and M.G. Abdelmonem, "Between Tradition and Modernity: Determining Spatial Systems of Privacy In The Domestic Architecture of Contemporary Iraq," *International Journal of Architectural Research*, vol. 8, no. 3, pp. 238-250, 2016.
- [38] D. Rostam, T. Ali and D. Atrushi, "Economical and structural feasibility of concrete cellular and solid blocks in Kurdistan region," *ARO, The Scientific Journal of Koya University*, vol. 4, no.1, pp. 1-7, 2016.
- [39] C.R. Kothari, *Research methodology: Methods and techniques*. 2nd edition. New Delhi: New Age International, 2004.
- [40] A. Rashwan, O. Farag, and WS. Moustafa, "Energy performance analysis of integrating building envelopes with nanomaterials," *International Journal of Sustainable Built Environment*, vol. 2, no. 2, pp. 209-223, 2013.
- [41] S. Kubba, "Handbook of green building design and construction: LEED, BREEAM, and Green Globes," 1st edition, Butterworth-Heinemann, 2012.