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The Thermal Efficacy of Double, Triple, And Quadruple Glazing Under the Extreme Heat Conditions Prevalent in Dubai's Climate (A Field-Based Investigation).

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ABSTRACT

This study thoroughly investigated the thermal characteristics of three distinct glazing types utilized in Dubai: double glazing (DG), triple glazing (TG), and quadruple glazing (QG). A thermal chamber was skillfully constructed employing these three glazing forms, which underwent exposure to the severe summer conditions representative of Dubai. The thermal metrics within the chamber were documented and subsequently compared for analytical purposes. Environmental data loggers were strategically positioned inside to monitor and assess the air temperature and relative humidity across the box's three compartments. The primary objective was to ascertain whether the thermal performance in the QG compartment was significantly enhanced relative to the TG and DG compartments, attributed to its superior U-value. It is anticipated that the inner air temperature of the QG compartment will be lower than that of the other two, indicating superior thermal performance. To establish a foundational benchmark for this research, an independent weather station—isolated from surrounding structures—was used to measure the microclimate in the vicinity of the experiment. The hot box was strategically oriented toward the south to optimize exposure to both direct and indirect solar radiation during the morning and afternoon hours. The findings reveal pronounced differences in the thermal efficiency of the three glazing types, particularly during the daytime in the summer months. QG demonstrated exceptional performance, with a lower air temperature profile recorded within its compartment in contrast to TG and DG. Overall, the data from this study suggest that the incorporation of additional layers within the glazing system effectively mitigates heat transfer to internal environments, with QG achieving the lowest internal air temperature. This research aims to illuminate the practical implications of employing QG glazing, particularly in the pursuit of enhancing building energy efficiency while drawing comparisons with its double and triple-layered counterparts.

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1.The Narrative.

Glass has undeniably prevailed in Dubai, propelling the city into a promising future with unwavering confidence (Reisz, 2021). The narrative tells double glazing system has been standard in Dubai for a long time, while triple glazing is reserved for healthcare facilities. Concurrently, quadruple glazing is emerging in locales such as offices, airports, and public institutions. The quadruple principle is employed in advanced glazing systems, such as vacuum glass, which consists of multiple layers of glass separated by vacuous gaps (Qiu et al., 2025). The question of interest concerns which approach is most beneficial for Dubai's extraordinarily hot and humid environment (Calautit et al., 2025)

This paper puts forward a simplistic hypothesis that the addition air gap enhances thermal efficiency, aligning with the long-standing notion that thicker is better. This principle represents a fundamental antithesis to the notion of vacuum glass lining utilizing passive glass, which necessitates heightened scrutiny to enhance energy management in light of the impending constraints anticipated in future electrical power supplies (ALKodmany, 2020).

2.Aims and Objectives

Glass has undoubtedly triumphed in Dubai, propelling the city into a promising future without hesitation, Reisz(2021) & Kanna (2010) .Passive glass types need better energy management due to limited future electrical supplies.(AL Kodmany, 2020)The study aims to prove the effectiveness of specific glazing types in hot, humid climates. To find optimal glazing solutions for Dubai's hot and humid climate. It examines various types of glass, focusing on multilayered glass. It tests their performance when facing south and north over three months of summer in Dubai.

The objective of the experiment was to find the best glazing option for Dubai's unique climate. Replicating an air gap in multi-layered glass is supposed to enhance U-value, SHGC, and SC. Research object is to explore tripling the air gap in quadruple glass to combat Dubai's extreme heat and humidity, as the idea that thicker is better. (Duakouvic,2020)

This methodology involves employing an experimental prototype glass box in conjunction with various glazing types to ascertain which indoor configuration is optimal based on the specific glass type and its orientation. The potential of utilizing multiple glass layers remains underexplored (Schittch, 1999) This approach adheres to the scientific method, following a systematic bottom-up framework.

The experiment is meticulously designed to incorporate three distinct compartments featuring various glass facades commonly utilized in Dubai. Simultaneously, a heat logger is strategically installed within each chamber, diligently monitoring and recording the indoor thermal gain. In accordance with the findings of Chummy et al. (2016), the results are poised to elucidate superior thermal performance outcomes.

3.The Climate

Dubai's climate, situated within the Tropic of Cancer at 25.16°N and 55.18°E, is characterized by intense heat and humidity Santamouris et al.(2020).Dubai, recognized as a coastal city within Zone Bo as per the ASHRAE (2021) updated report and Dubai Codes (2021). Dubai has an extremely hot desert climate. The climatic conditions are illustrated in Figures 1 , emphasizing that summer constitutes the longest season characterized by elevated temperatures and humidity, with daytime temperatures soaring to 50°C and humidity levels reaching up to 90%.

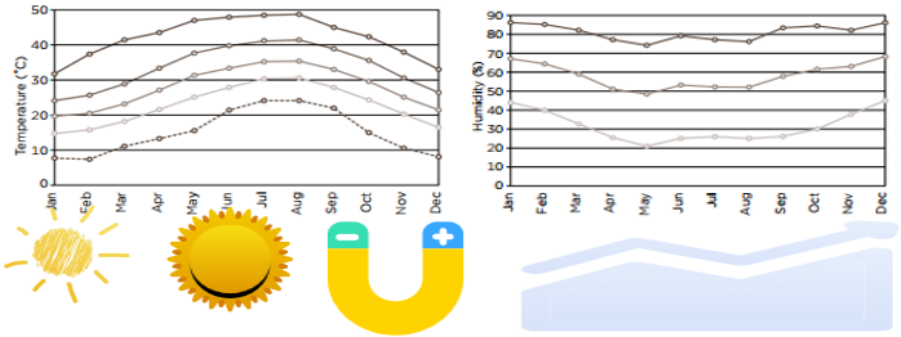


Figure 1 depicts the air temperature & humidity of Dubai as extracted from the Dubai Codes, 2021.The left curve represents air temperature & the resembling sun icons refer to the extreme heat that starts in May until the end of the season. The right graph illustrates the increasing trend in humidity. The patterns show the highest and lowest temperatures and humidity, easily readable.

4.Dubai Glass Building & Research Review

Dubai regulations aim to enhance energy efficiency in glass buildings and reduce carbon emissions. Double-glazed windows have been mandatory since the 1980s. New glass products are triple or quadruple-layered for better insulation in critical environments. Figure 3 showcases glass buildings in Dubai.



Figure 2. illustrates the glass buildings located in Dubai.

Fig. 2. A captivating leftward view of downtown, 2024, captured from a highway bridge designed for the Burj Khalifa. The middle picture in Fig. 2 B depicts the Financial District, 2023. The last in Fig. 2 C is the roof of the podium of the index building, 2010 .All pictures are by the author, 2024.

The decision-makers' opinions mentioned in the Dubai Map 2040 focused on processing the scientific accomplishments as much as possible without limitation. The ambition to create a Dubai digital twin is considered essential among architects and engineers. Shifting away from traditional trends is the new normal.

In the Burj Khalifa, the world's tallest building, the architectural design is a marvel of modern engineering. Fig. 3, various glazing types are used. Some sections have quad glazing, while others have double glazing. The glass is silver low-E with a solar heat gain coefficient (SHGC of 0.3), and a shading coefficient SC of 0.35.

Quad panes are used for office envelope windows in extreme cold or intense heat. They are compatible with the newly implemented fresh air addition systems, which are commonly integrated into high-rise HVAC systems in Dubai. The practice of retrofitting or renovating existing structures is observed, despite the city's relatively recent establishment. Advanced innovations in glass can be observed in the Emirates Towers (built in 2000) , recently in the low-rise MBRL Library building (2022), and in Al Maktoum International Airport (DWC , or OMDW), which partly opened in 2023 but is expected to be completed in 2050.



Fig. 3. Burj Khalifa. Pictures by the author.

The One Za'abeel twin towers and the Al Wasl twisted tower, both situated in Dubai, incorporate quadruple and triple glazing where deemed essential, in addition to double glazing. The architectural design showcases a sleek, volumetric rectangular form.



Fig. 4. left is One Zabeel & right Al WASL by the author, 2025

Wind-deflecting components are crafted as vertical cut glass liner pieces, as depicted in the developer's blueprints. Double-skin glazing was implemented in the upper sections of the structure to emphasize the concept that no single glazing solution is optimal. The building was engineered to withstand seismic and wind pressures, with glass and steel deliberately chosen for their durability and suitability for tall structures' skeleton. Fig. 4 left is One Zabeel & right Al WASL by the author, 2025



Fig. 5. showcases the Expo Wing of 2020, situated in the top left, alongside the Expo's transformative glass of the central dome from 2021, captured by the author in 2021.

Expo 2020 Dubai exemplifies the utilization of a passive combination of double, triple, and quad glazing as necessitated, as evidenced by government publications and actual site data. The central dome building's architectural design includes glass facades that change color, controlled by a shading system. The Emirates Wings at Expo 2020 in Fig. 5 have glass envelopes and canopies designed to adapt to the sun's movements in different seasons.

The glass products utilized in Dubai adhere to European standards (EN 410) and U.S. standards (NFRC 300/200). Choosing triple or quadruple glazing is considered a progressive option over double glazing, which fails to meet the increasing energy requirements. The triple-glazed assemblies, characterized by an air gap or laminated construction, in conjunction with PVC framing as opposed to aluminum, are currently operational, as depicted in Figures 6 A, B, C, and D. The implementation of triple glazing in residential projects has been utilized by architects for several years. In contrast, quad glazing, as in Fig. 6 C is employed in offices, educational institutions, and healthcare facilities.



Fig. 6. shows a real sample of glazing types used in Dubai.

6A, on the left, illustrates triple glazing with a PVC frame. Figure 6B depicts triple glazing with lamination; Figure 6C showcases quadruple glazing with an air gap & outside protective heat mesh. Figure 6D is double glazing with 21mm air gap and protective mesh. The pictures were taken by the author in 2024

Recent advancements in thin glass technology and lightweight frames have facilitated a reduction in the weight of triple or quad-glazed windows (as outlined in the NREL manual). The cost differential between triple and quadruple glazing, when weighed against the enhanced performance benefits, has rendered their reintroduction more viable, Kiatreungwattana et al.(2021).

Ultra-transparent glass is used in quadruple, triple, and double glazing systems to facilitate solutions for future zero-energy buildings, Bakker (2020). The implementation of quadruple glazing options can enhance energy efficiency, as it facilitates the integration of solar-collective thin-film technology, as mentioned by Bonham (2020).

The THERM 7/WINDOW 7 NFRC simulation manual (July 2024) stated that triple and quad glazing have engineering complexities, including determining insulation placement and applying alternative coatings or films. Additionally, besides the cost, managing advanced manufacturing techniques and transportation challenges is also present, Delgado (2021).

The integrated phase-change materials (PCM) situated between two panes of glass, Sadooghi et al. (2021) necessitate an inquiry into four-pane glazing systems. These configurations can yield a substantial reduction in heat gain.

The incorporation of gas infill renders them potentially as robust as solid walls. However, the challenge lies in the fact that humidity undermines the efficacy of air insulation, as it diminishes the insulating capacity when moisture is absorbed ,Arici et al., (2015) These quadruple passive windows exhibit a 50% enhancement in thermal efficiency compared to their counterparts, Kralj (2022).

Double glazing, triple glazing, or quadruple glazing exhibits lower U-values in comparison to insulation or brick. A single glass pane exhibits a U-value of 5.4 W/m² K, and the air thermal conductivity is 0.025 W/m² K, Salvador(2018).A local double-glazed window has a thermal transmittance of 2.1-2.5W/m² K. Insulating gases like argon (0.017 W/m² K), krypton (0.0094 W/m² K), or xenon (0.0056 W/m² K) could improve thermal performance, but were not used, and no frame was employed. The width of the air gap typically ranges from 12 mm to 20 mm. The recommended air gap is between 15 mm and 16 mm for maximum thermal efficiency. The optimal gap size depends on the properties of the gas insert layers. For instance, the optimal gap is 14-15 mm for argon, 9-10 mm for krypton, and approximately 6-7 mm (equivalent to 0.28 inches) for xenon. Table 1 illustrates the optimal gap size for the different insulating gases.

Table 1. shows the optimal gas and gap sizes, Duakouvic (2020).

Air	**12 mm -20mm as the best gap is 16mm**
Argon	14-15 mm as the best gap is 12 mm
Krypton	9-10mm the best gap is 8mm
Xenon	6-7mm the best gap is 5mm

The majority of local manufacturers utilize a 12 mm air gap, which was also the case with the glass enclosure in this experiment. Figure 7 shows the gap relation, Chmurny et al. (2016).Air is freely available and does not require special handling like gas refills, making it a sustainable choice for this experiment. Locally, the outer pane is low-E, with a minimum thickness of 6 mm or more than the 12 mm air gap, followed by 6 mm of clear glass. In triple-glazed units, the gap is widened to approximately 19 mm to 20 mm to accommodate the frame. In this experiment, all glass samples had similar air gaps to replicate the standard local window configuration.

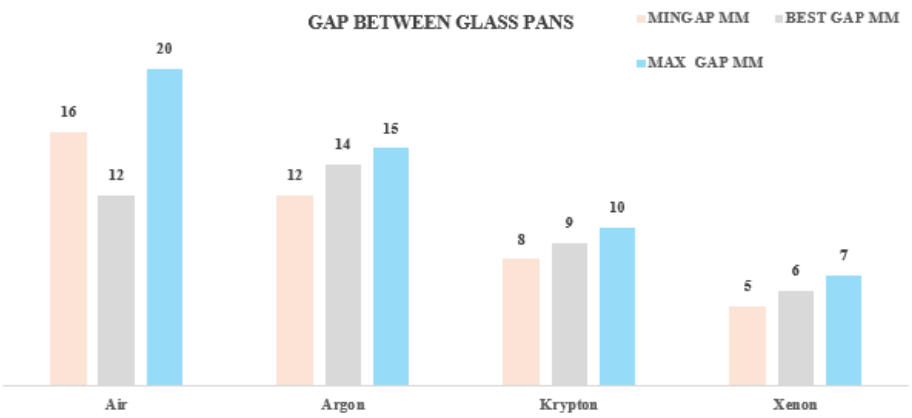


Fig. 7 illustrates the gas and gap relationship.

In this experiment, the primary layer featured a low-emissivity (low-E) glass panel, while the subsequent layers were constructed of clear, standard glass. No insulating gas was employed; only regular air was used. The air gaps were all standardized at 12 mm in accordance with the typical low-e glass window specifications, Mann et al. (2023). A frame was omitted, with a standard spacer being utilized, and all glass panels shared the same 6 mm thickness.

The panels with spacers were attached together during the factory assembly process. The frame plays a role in maximizing the energy efficiency of the glass, leading to an overall enhancement of approximately 30-40% , Patterons(2022). Many architects prefer a concealed frame style. Opting for UPVC or timber materials ensures superior installations, despite incurring additional expenses, Favoino et al,(2022)

Table 4. illustrates glass variables.

Glass type	**U-Value**	**SHGC**	**SC**	**VLT (%)**
Single glass	5.7	The hue and clarity of the glass.		
Double	~1.6 - 1.8	~0.50 - 0.55	~0.58 - 0.64	~70 - 75
Triple Glazing	~1.0 - 1.2	~0.35 - 0.40	~0.41 - 0.46	~60 - 65
Quadruple Glazing	~0.6 - 0.8	~0.25 - 0.30	~0.29 - 0.35	~50 - 55
UPVC or timber frames improve the U-value by approximately 30-50%.				

The glass variable factors are evaluated in Dubai in accordance with local regulatory codes rather than solely relying on laboratory or manufacturer certifications, as mentioned in Table 4 glass variables. Cutting-edge systems incorporating rare metal additives for frames and building thermal bridging or polymers for superior heat rejection claim to achieve remarkably low U-values as low as 0.8 W/m² K, Aksamija (2021) .

The shading coefficient varies from SC values ≤ 0.4 to minimize cooling loads; lower values are considered optimal due to the absence of any shading elements besides the glass box's own shadow. The data presented were obtained from the European standards EN410/673, utilizing WinDat WIS version 3.0.1 software, LBNL Window 7.3/7.4 software, and various calculators such as Therm and EnergyPlus. The U-value illustrated in Fig. 8 presents the concept in a more simplified manner, highlighting that the inclusion of frames undermines the quality of the U-value, rendering it inferior.

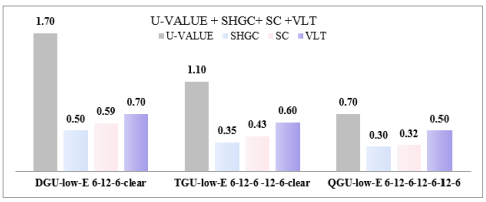


Fig. 8 illustrates the concept in a more simplified manner, highlighting that the inclusion of frames undermines the quality of the U-value, rendering it inferior.

4.Methodoloy

A pragmatic experimental methodology was adopted, adhering to a bottom-up paradigm. Relying on authentic data gathered from the site itself, in accordance with the established NFRC 201 protocol known as the hot box, the study also adheres to Chmurny-2016's evaluation of triple and quadruple glazing, wherein he bestowed commendation upon the latter. The experimental setup entails the construction of a chamber that measures 170 cm in length, with an inside height and depth of 50 cm each. This chamber is segmented into three compartments, each measuring 50 cm in inside width, ensuring uniformity in size.

A 170x60x60 cm glass box was divided into three 50x50x50 cm sections. Each section housed one double-glazed unit (DGU), one triple-glazed unit (TGU) , and one quad-glazed unit (QGU) with a facade of 30x40 cm glass panels as advised by test labs. Internal heat loggers were positioned inside each compartment facing the glass. Another heat logger, as a weather station, was placed outside. The box faced south from June to September 16, then north until September 30. 2 depicts a glass enclosure.

The walls and ceiling of the chamber are fabricated from polystyrene foam 5cm thick, a material commonly employed for roof insulation in buildings. All components are assembled using fast-acting adhesive glue. The glass units were skillfully assembled as a singular entity, free of frames, precisely tailored to the dimensions of 30 cm x 40 cm, similar to those found in laboratory analyses. The glass units were affixed to the chamber facade utilizing foam and securely sealed with plastic tape. Fig. 3 shows the three-glass combination for the glass box.

The experiment was conducted in Dubai, with the southern orientation purposefully selected. Figure 3 illustrates the specifications of the glass box. The glass box shown in Fig. 4 , which contains a heat logger, while outside, approximately 1.50 meters away from the chamber, lies the heat logger named ENV, as the weather station marked in red. The walls between the enclosure consist of 5cm thick building insulation foam. Each glass unit was sealed without any provisions for ventilation as a new high-rise building, Wood & Salib (2013).

The glass box was elevated to a height of 1.50 meters, where 174 Testo heat loggers were installed at the center to facilitate data collection. Furthermore, a separate heat logger, identifiable by its red hue, was placed outside, roughly 1.50 meters from the glass box to monitor local climatic conditions. Figure Figure 4, the glass hot box at the site was fixed to a table.

All panes are positioned using setting blocks and secured with silicone or plastic. Frames are rendered unnecessary, as clearly illustrated in Fig. 9. The outermost pane is fashioned from low-emissivity tinted reflective glass, akin to that local glass used in buildings, while the subsequent layers are composed of clear glass. The air gaps measure 12mm, and the glass is 6mm, as fabricated locally. Fig.10

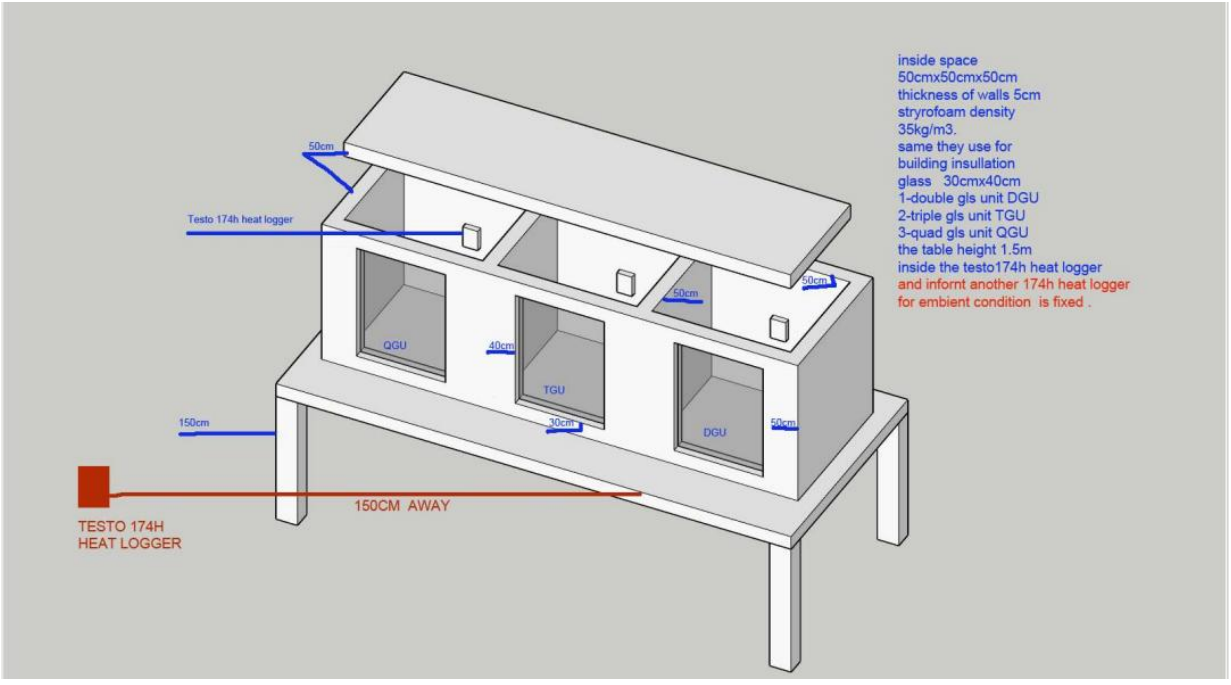


Fig. 9. depicts a glass enclosure.

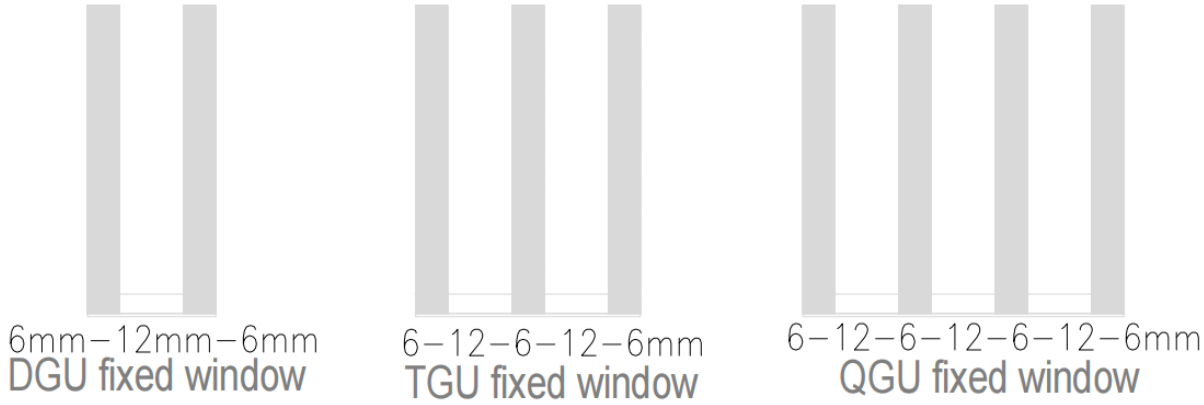


Fig. 10. shows the three-glass combination for the glass box.

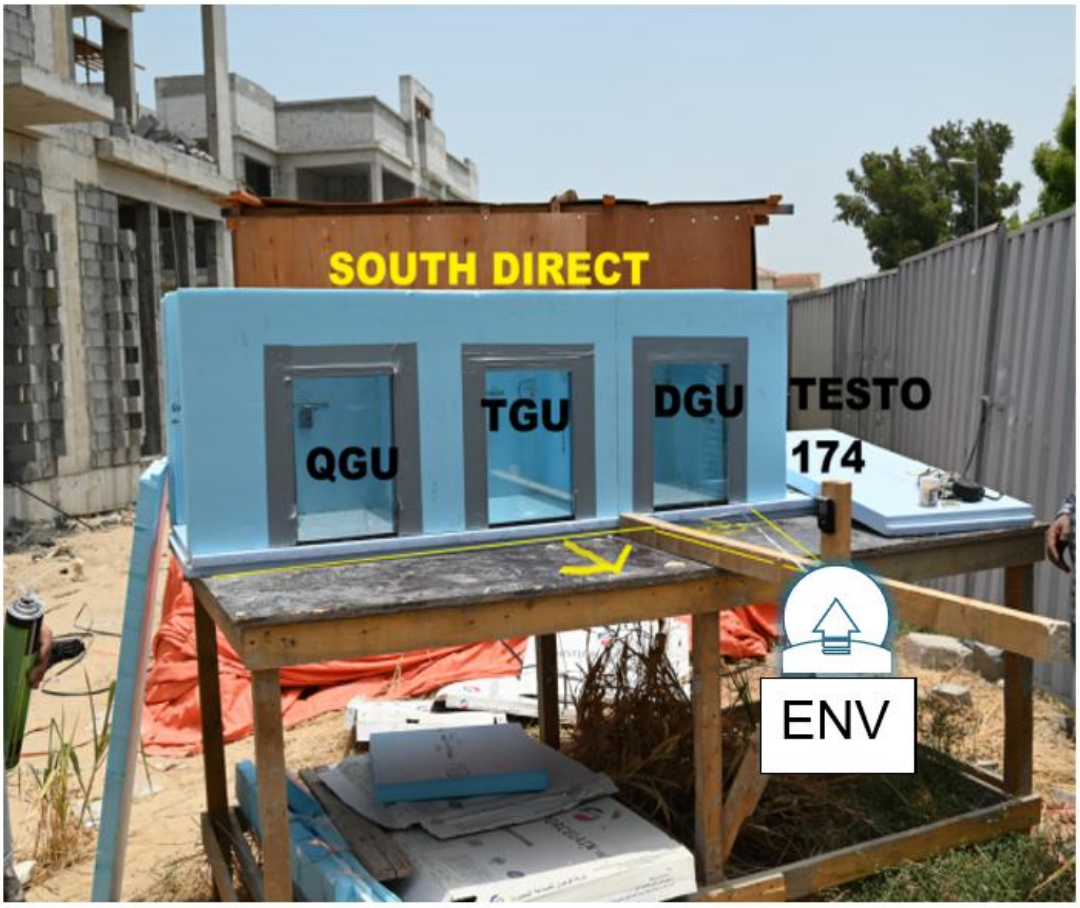


Fig. 11. the glass hot box at the site was fixed to a table.

The entire assembly was affixed to a wooden table measuring between 90-150cm, depending on the available space. Throughout the duration, there was a deliberate absence of ventilation, maintaining a fully enclosed environment. Fig. 11

The construction methodologies were aligned with the Passive House standard for energy-efficient design, initiated by Dr. Wolfgang Feist in Darmstadt, 2005, Germany, providing a guideline that is frequently assimilated into Dubai's building regulations. It is shown in Fig. 4 that the three units are fixed to the glass box heat chamber.

All materials employed in construction serve distinct purposes, such as the polystyrene utilized for roof insulation and the rapid-setting adhesive applied for

sealing pipe coring sleeves and openings. Glass is commonly used for windows. Figure 12 provides the details and dimensions as drawn in AutoCAD.

Figure 13. illustrates the procedure for collecting data and subsequently transferring it to the designated software for the heat logger.

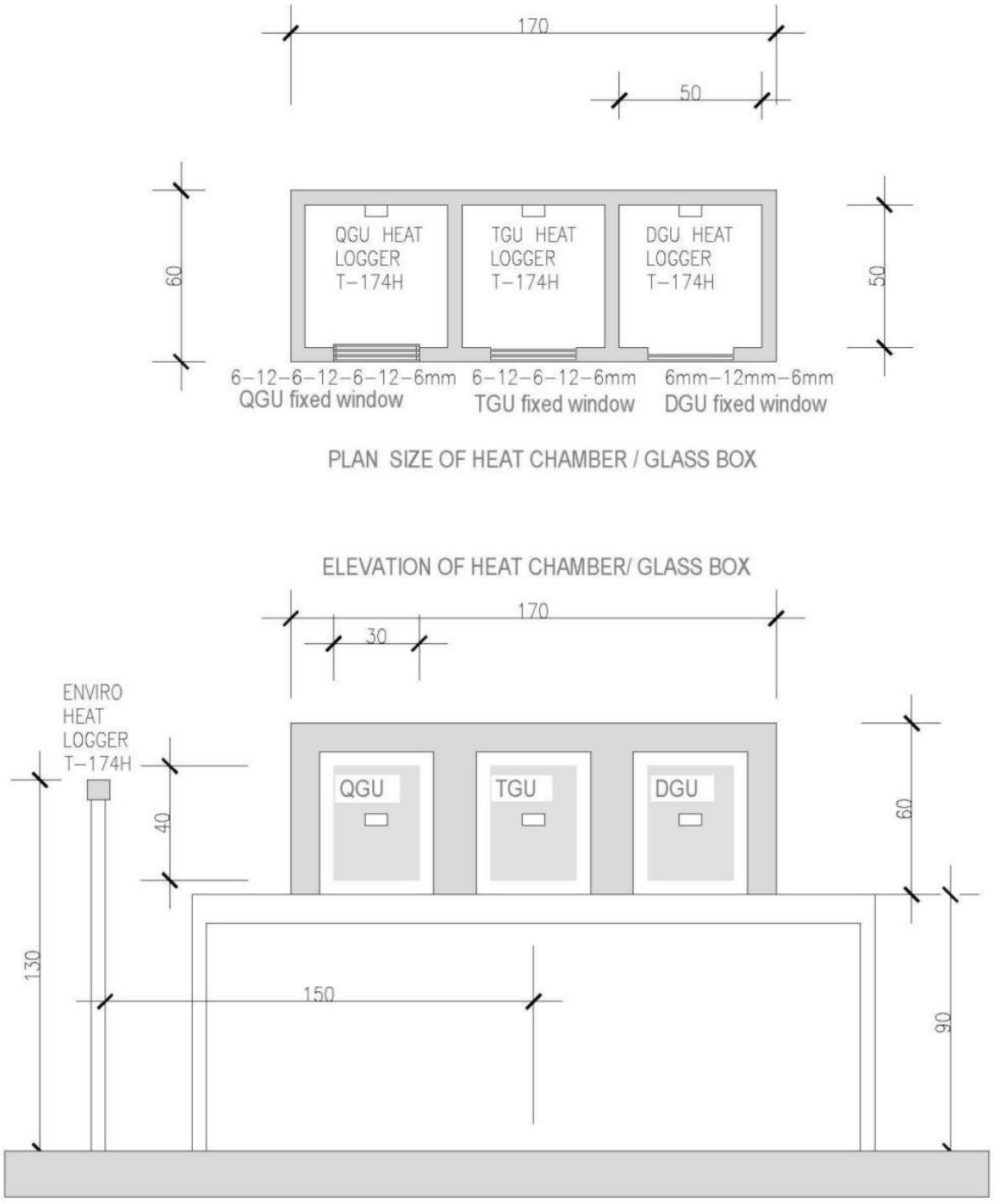


Fig. 12. The glass box shows the CAD drawing for size and height.



Fig. 13. The Testo 174 Heat Logger.

The logger, featuring an advanced interface, continuously records data on an hourly basis, with the information subsequently extracted through specialized software for digital record-keeping.

Heat loggers Fig. 13. were inserted into glass box chambers with names corresponding to the glass units facing them. Each heat logger was labeled with a glass type and allocated to a specific chamber. Table 2 shows variables following the local DM code that reflect the manufacturer's certification for glass specifications. It is the authority's quality control as one step in an attempt to manage fabrication in the UAE.

Table 2. shows glass specifications.

	Definition	**Remarks & clarification**	
1	The outer glass layer is of low-E type.	The inner glass layer is clear.	
2	The outer layer follows EN410 & US NFRC.	Second, third, & fourth panes' specifications.	
3	The Hue-coat:	Blue-green AS14T	Clear, glass, DSRI.
4	Light external reflection:	20% outer layer	36% inner pane
5	Light internal reflection:	30%	22%
6	EN410 SHGC /G value 12mm air:	0.11	0.19
7	EN410 SC:	0.13	0.22
8	U-value	1.84W/m2. K	1.65W/m2. K
9	US NFRC SHGC:	0.12	0.18
10	NFRC SC:	0.11	0.15

11	The U-value is provided.	1.84W/m2. K	1.7 W/m2. K
12	The U-value estimate is provided.	1.84W/m2. K	1.66 W/m2. K

The U-value in Table 3 worsens during the summer months as materials reach their saturation point for absorbing more heat. This principle applies to both air and glass, including the frame. The specified U-value pertains to the glass and the frame together. It is worth noting that the frame adds an extra 30-40% to the glass U-value. Memari (2013). For the purpose of identification, the heat logger facing the double-glazed unit was denoted as DGU, the triple-glazed unit as TGU, and the quad-glazed unit as QGU, while the outside heat logger was named ENV . Testing commenced in mid-June, aligning with the onset of summer in the UAE.

Table 3. presents the glass box U-value according to the codes.

(Musgraves, et al., 2019 Springer Handbook of Glass 1srt edition)

Dubai Green Code Rate	**DGU**	**TGU**	**QGU**	**Horizantal**
Summer U-value W/m2.K	2.1-3.0	1.8-2.2	1.3-1.7	1.3-1.7
No frame U-value W/m2.K	1.6-1.8	1.1-1.2	0.6-0.8	------
SC as EN410	0.5-0.6	0.4-0.46	0.29-0.35	0.25-0.2
SHGC as EN410	0.50-0.55	0.3-0.4	0.25-0.3	0.21-0.17
VLT-Visible Light Transmittance	0.7-0.8	0.6-0.75	0.5-0.65	0.5-0.65

Heat loggers were calibrated to collect data on an hourly basis from the commencement to the conclusion of the experiment conducted on September 30th. The glass units utilized in the assessment were crafted from 6 mm commercial-grade glass, commonly available in the local market.

The glass box was sealed, devoid of ventilation, establishing an environment similar to a "heat oven," paralleling contemporary buildings with fixed glass and no openings. The assessment started on June 19, 2024, and ended on September 30 in accordance with the summer heat regulations in Dubai. The glass box was sealed to the ground to prevent it from falling down. The glass box tests the indoor impact. Heat loggers were collected on September 30th.

5.The Results

Research indicates that evaluating indoor temperatures against the surrounding environment is essential, regardless of orientation. The glass box was placed facing south, which is considered poor window positioning in the summer. Dubai Minicipality standards gave a ratio ideally kept at a maximum, set at 40% for all orientations. The north orientation is allowed to be fully open at 100% . Both the eastern and western sides adhere to U.S. regulations, maintaining an opening ratio of 40-50%. However, it is evident that a reevaluation of these ratios is imperative. In practice, these two orientations, having a low sun angle, are both avoided in design.

The compartments lacked proper ventilation and were totally locked. The glass box container was never opened, even for inspection. It was securely locked in place, facing the southern orientation until mid-September. However, upon a comprehensive analysis, it was determined that the quad-glazed unit surpassed both the double-glazed and triple-glazed units over a three-month period.

It exhibited a maximum internal temperature that was 8°C lower than the double-glazed unit and 6°C lower than the triple-glazed unit during daylight hours. This was provided at the end when loggers were out by the machine program itself without any interference. Throughout the night, all units demonstrated comparable temperatures due to the elevated humidity levels, which were uniformly high across all units, although lower than the external humidity. As the distinctions among the various types became apparent, an alternative method was necessary to validate the findings. The heat index equation was used to derive a numerical value by incorporating both temperature and humidity.

$$HI = C_1+C_2*T+C_3*RH+C_4*T*RH+C6*RH_2+C_7*T_2*RH+C8*T*RH_2+C9*T_2*RH_2$$

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The heat index equation was used to forecast the combined impact of temperature and humidity, both of which govern indoor air quality, which is crucial for comfort and overall satisfaction. It is important for the health, comfort, well-being, and productivity of building occupants to achieve optimal levels of PMV or PPD indoors without conducting any surveys. The ideal temperature range is set at 20-24°C for summer and 23-27°C for winter, while maintaining humidity levels between 30-60% to prevent excess moisture or dryness.

All data points were recorded for temperature and an equal number for humidity, all calculated using Excel for four heat loggers (ENV, DGU, TGU, QGU) situated both indoors and outdoors (ENV), resulting in a grand total of data points. All original data points recorded are documented on GitHub in CSV format. Figure 14 shows where data saved location .

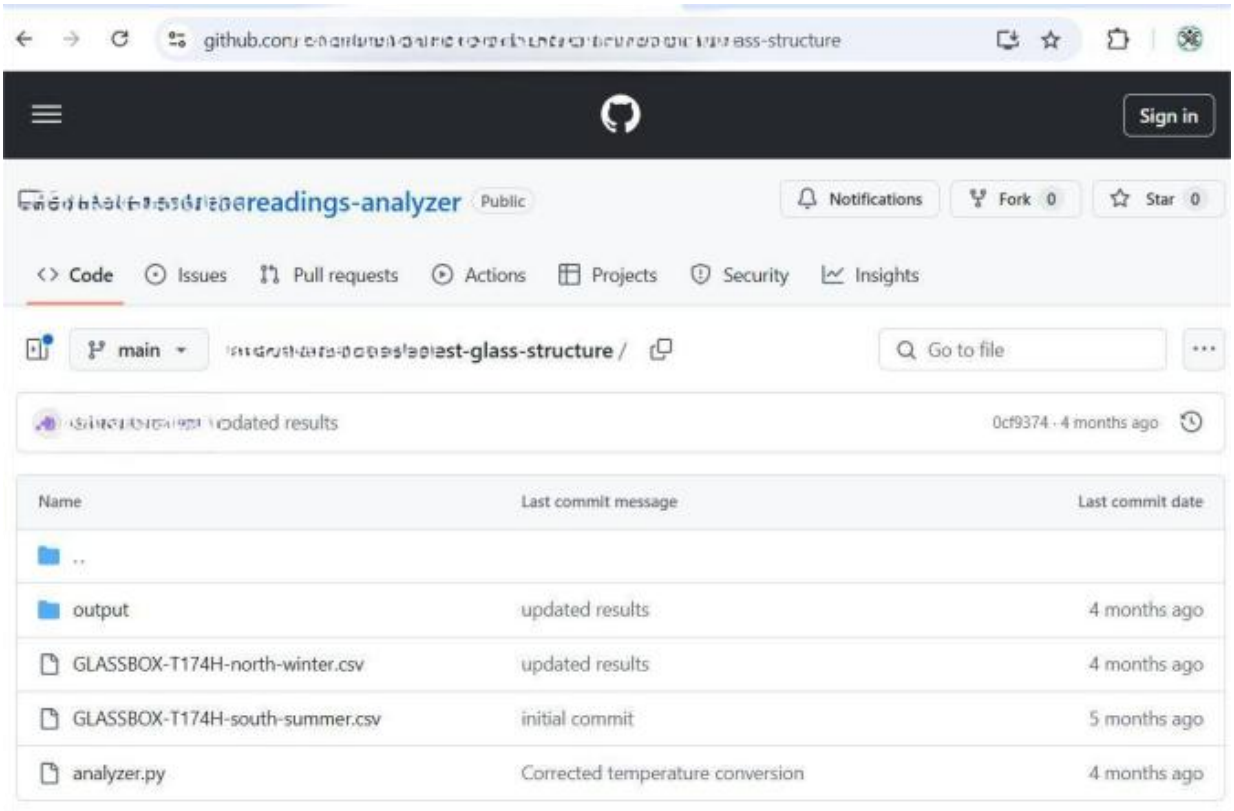


Fig. 14. shows the original data in CSV format.

The period under consideration encompasses the entirety of summer; however, for illustrative purposes, the designated timeframe is from July 17th to July 28th, during which the glass box was oriented toward the south. The discrepancies in the heat index exhibit limited relevance attributable to the dimensions of the prototype, which are limited. The accuracy of the instrumentation, coupled with the abbreviated duration of the study, compromises the range between the various glazing types. The outcomes among the three categories will increase by about 17% as implied by Wild (2014) in fig.15 as mentions that the actual real-time thermal gain is always higher than the experiment.

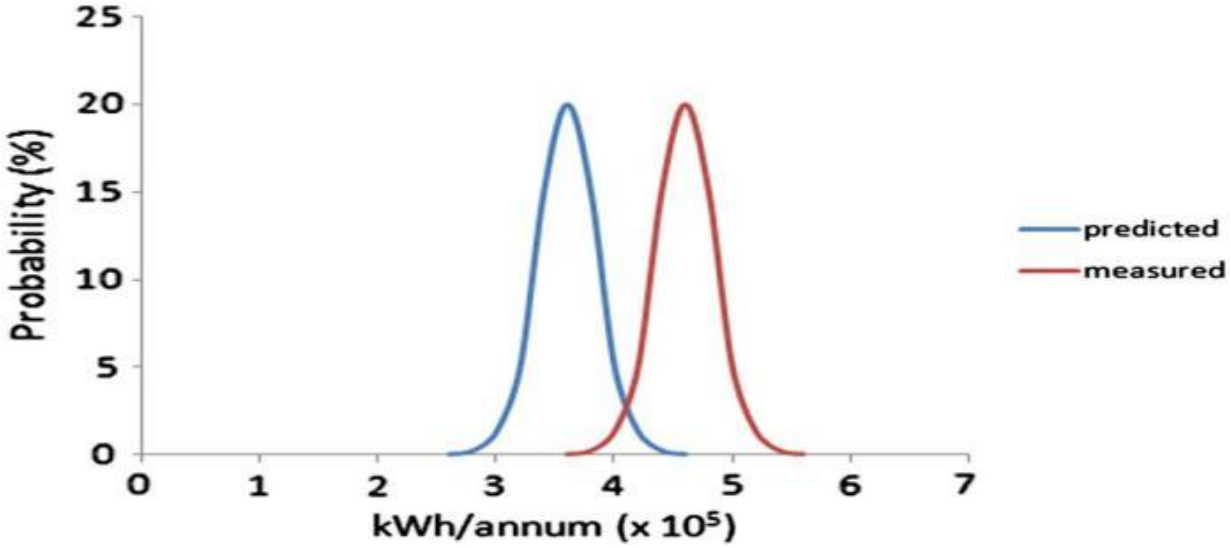


Fig. 15. shows that experimental data is less than actual calculation.

The experiment's component, function of time, and accuracy of tools indicate that a modification factor needs to be introduced as performance variations broaden with scale due to operational complexities. This phenomenon occurs when examining the energy consumption of the same location but at different times. The reality is considerably more complex than that of an individual experiment. (Swan & Ugursal, 2009)

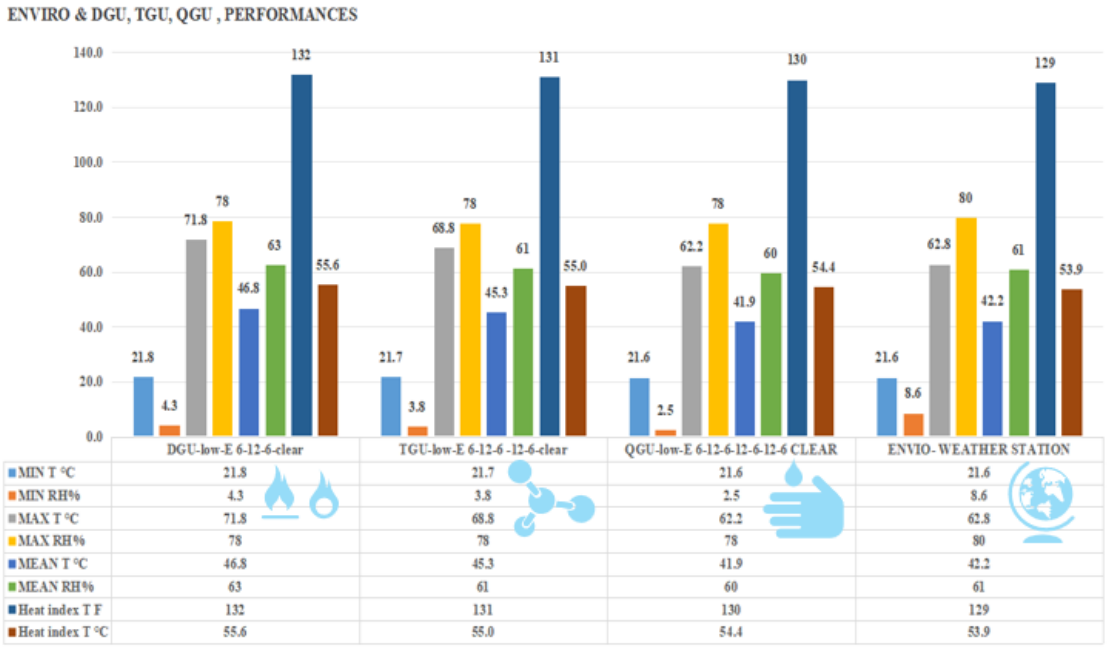


Fig. 16 presents the outcomes of the computation of temperature and humidity.

The globe is the ENV, while the hand is QGU, and the atom is TGU and the flam is DGU

Fig. 16. presents the outcomes of the computation of temperature and humidity.

The globe is the ENV , while the hand is QGU , and the atom is TGU and the flam is DGU

The experiment demonstrated that during the daytime, the peak midday temperature reached a differential of 9°C, with the quad registering a maximum of 62°C, significantly higher than the double scouring at 71°C, while the triple recorded a temperature of 68°C. Conversely, at night, the discrepancies diminished, narrowing to a mere 0.1°C, attributable to the influence of humidity.

The humidity within the compartment was unmanageable, exhibiting a similarity that rendered the

results unclear when expressed in Fahrenheit. However, converting these figures to Celsius in the final row of the figure reveals a range between 2°C and 4°C. The outcome was satisfactory, but it showed that an extended timeframe of approximately one year was needed, as suggested by researchers from Spain, Santamaria (2020). The columns in Fig. 16 illustrates that quadruple measurement is superior to the triple and double values. Furthermore, the quadruple value closely aligns with the outdoor environmental temperature recorded by the heat logger, ranging between 1°C - 2 °C, as collected at the time.

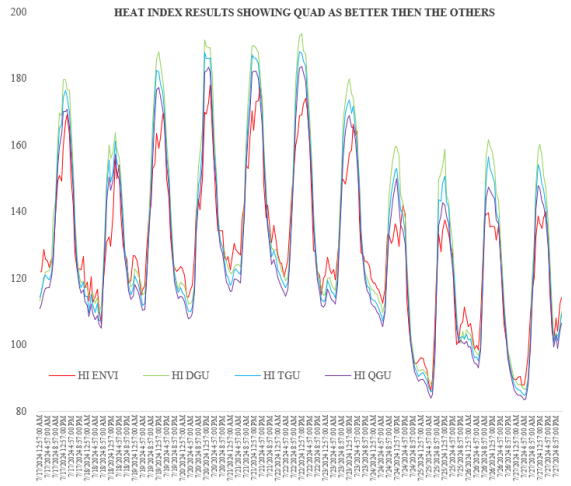


Fig. 17. Illustrate the HI mathematical outcomes of the indoor temperature 17th to the 27th July 2024 as the Y-axis presents the HI and the X-axis represents the time.

Figure 17. illustrates the translation of the results into a discernible pattern. The glass box prominently showcased the quad glazing (QGU) as superior to all alternatives, despite the absence of ventilation, any internal air circulation, or a cooling system. That explains why the quad QGU or multi-layered glazing became common practice in commercial buildings in Dubai as the accelerating climate heat wave became the new normal.

The figure 17 shows the heat index results for the outside heat logger called Env in red, followed by QGU in purple, followed by TGU in blue, and then DGU with a clear gap in green. The pattern is for a week's time starting from 17th July until the 24th July in 2024.The TGU is nearer to QGU than to DGU.

The relationship of heat, temperature, and relative humidity are contradict each other, as shown in Fig. 18, making all the units be within the same level when their peak wave during the daytime was above 160 then reversed down at night below 120 . The relationship between humidity and temperature illustrated in Fig. 18 explains that even at nighttime, the QGU performs better than the others. The shape illustrates the intricate relationship between temperature and humidity, which is similar to the butterfly effect.

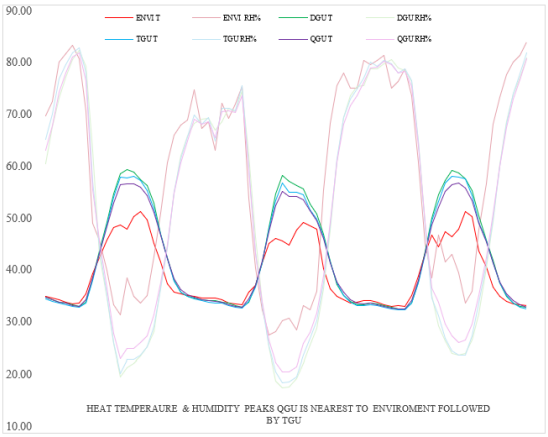


Fig. 18. Present the conflict of heat and humidity is similar to a butterfly effect.

while the y-axis presents the temperature or percentage of humidity, The x-axis represents time.

Also, when examining the one-day performances illustrated in Fig. 19 The DGU exhibits a rather disappointing spike in comparison to the QGU and TGU, despite all three demonstrating a straightforward similarity during the night. The results show clear findings from three days and nights.

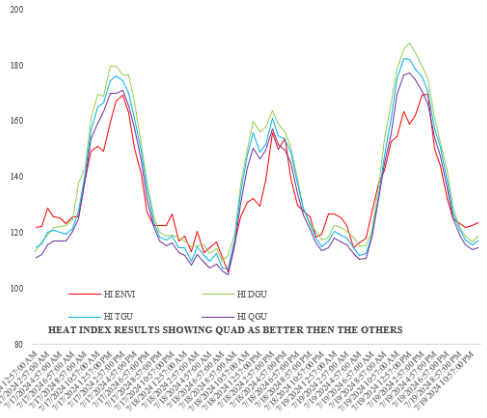


Fig. 19. The DGU exhibits the least favorable performance in comparison to the QGU and TGU, as it necessitates a span of three days and nights to attain clarity.

It is reasonable to suggest that the QGU & TGU were engaged in a competitive dynamic, reflecting one another as parallel distinctions during daylight hours. Prolonged research could yield additional evidence by considering various factors, such as different orientations. Furthermore, the incorporation of higher-quality glass or the addition of an insulation layer could provide a more comprehensive understanding.

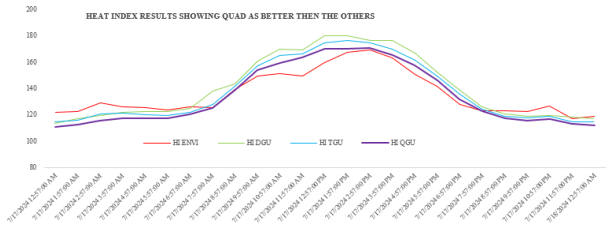


Fig. 20. shows one day the quality of different types of glass.

The superiority of quadruple glazing for indoor daytime use surpasses other glazing, offering more potential in any space shown in Fig. 20 that present one day and night only. It is an excellent outcome, as fundamental scientific principles suggest. U-value, (SHGC), (SC) are better for quadruple glazing compared to triple and double glazing. The inclusion of an additional air gap in quadruple glazing contributes significantly to its enhanced performance.

The study of the glass box's performance was constrained to a two-week period when it was oriented towards the north. It revealed that the northern exposure remained perpetually in shadow due to the sun's elevated position during the summer months. Nevertheless, all options were largely comparable, as the duration of exposure in the northern orientation yielded fewer results compared to the southern orientation.

The results obtained from the northern region were collected over a two-week period. As shown in Figure 21,the glass types exhibited comparable indoor performance values in the northern orientation. The HI results for the different glass types were situated in close proximity to one another. Notably, the quadruple glazing still demonstrated superior performance. The disparity between the performance values of the different glass types remained minimal between TGU & QGU. The time allocated for the function was less than recommended by other researchers, which provided the opportunity to pursue the study with greater depth regarding the northern trajectory in Dubai.

HI HI Time / hoursTime / hours

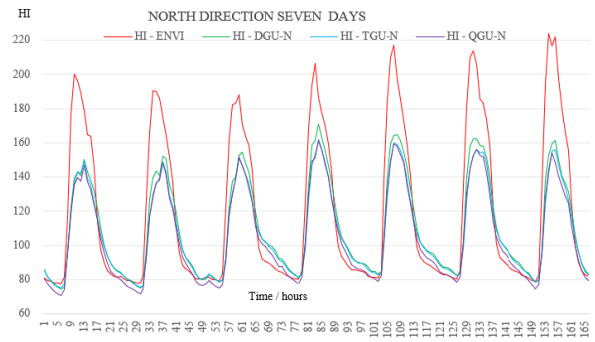


Figure 21. depicts one week's HI results showing the lowest point at quad, followed by triple, and concluding with double compared to ENV.

Through a comprehensive analysis conducted over three days, Fig. 21 delineates the HI resultsfor one week, which demonstrate remarkable consistency in the south. The lowest indoor HI recorded by the quad was followed by triple. In addition, a detailed examination of a single day reveals that the quad and triple configurations predominantly overlap in substantial segments; however, the quad configuration is primed for enhanced performance.

HI HI

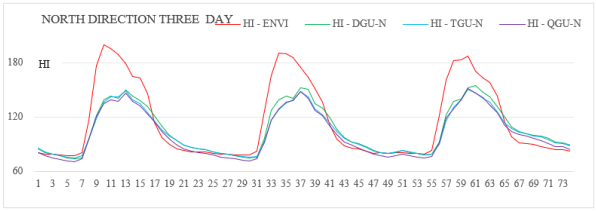


Fig. 22. illustrates the three days of HI results, revealing the lowest indoor performance achieved by the quad, yet closely paralleling that of the triple.

The north direction made the DGU HI result closer to the environment, meaning the value of the differences between inside and outside is less (TEXT-TINT) as shown in Fig. 22 . It is a manageable daylight that diminishes and joins the ENV. HI in scope as nightfall approaches. That makes it an economical selection & good for summer time at north direction. Fig. 23 shows it more clearly when considering one day.

The supplementary layer enhances efficiency in the sothern & northern regions during the summer months. The quad is getting of 8oC less for indoor than outdoor environments during daytime and nighttime. Triple is between quad, and parallel to the double is saving 5oC for indoor rather than the outdoor logger ENV during the daytime while noting the outdoor temperature at nighttime, which makes it better than double and quad.

Dubai experiences a few chilly nights during one week in December through the end of February. The advantages of the quad system should be monitored considerably during the chilly times unless adequate balancing is provided . In such cases, the quad system regains its efficacy by preventing heat loss.

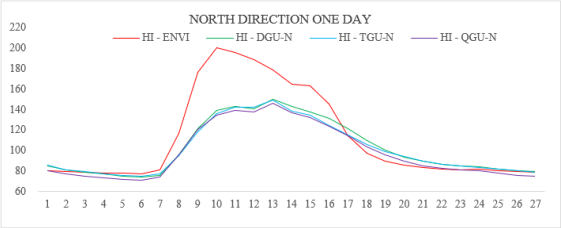


Fig. 23. illustrates the Heat Index (HI) for double glazing, which closely aligns with the environmental HI, rendering it an economically advantageous selection.

However, HVAC in Dubai is designed for better cooling. Looking closer at the gap between the ENV. HI results of the outdoor and indoor HI. The result shows that quad defines a difference in the limit of 3 oC to 8 oC rang better than others .

When the configurations are analyzed, it becomes evident that the quad QGU outperforms both the double and triple configurations in terms of both variables, as shown in Fig. 24 The HI integrates air temperature and humidity to gauge the perceived warmth experienced by the human body. However, an analysis of the actual temperature revealed that triple glazing is questionable. Quad glazing significantly improves performance during daylight hours, while the three glazing configurations overlap under nighttime conditions.

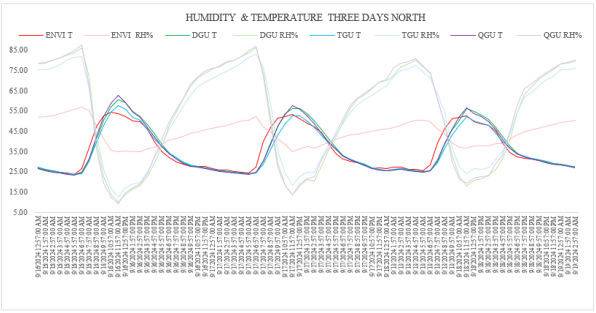


Figure 24. presents a comparative analysis of the actual data recorded by HL, both indoors and outdoors, over a span of three days, thereby illustrating the advantageous positioning of the triple.

North orientation is favored according to the local codes. Architectural consideration is the overcoming obstacle to support better design, as office activity requires; this means that orientation, as the major planning consideration, can be fixed or in hand,Aksamija (2013) .

This demonstrates that advanced systems can replace outdated methods in managing various orientations. Most city planning endeavors to optimize wind and solar access to enhance the urban environment. The vast dataset comprising thousands of readings was organized using a Python program based on the results of the heat index. The concept operates by simply comparing the heat index results of the three glass units to those of the weather station located outside. Figure Fig. 25 illustrates the results functionality in a clear and transparent manner.

The mathematical models delineate empirical data that corroborate the assertion that QGU demonstrates enhanced efficiency in terms of energy conservation, as articulated in a previously published research paper. Further exploration of the quadruple system is necessary, as the findings are dependent on temporal and locational factors.

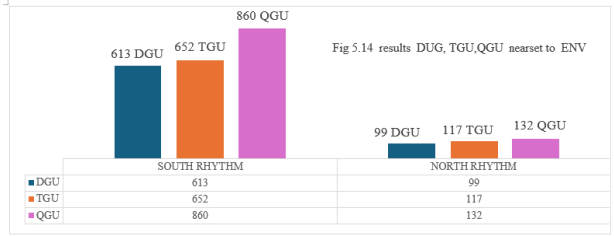


Fig. 5. 14 Results show QGU is best than other TGU & DGU

This requires analyzing parameters affecting QGU's dynamics for stability in different conditions. Also requires extra energy transmission assessments to aid in understanding efficiency and external factors. The results point to considering the advancements in material science regarding the integrity of the QGU system. The research using the glass boxes to examine the indoor impact of various glazing types has demonstrated that quad glazing offers superior performance compared to both triple and double glazing, thereby signifying an advancement over traditional double-glazing systems. The results considered the quad system to be an upgrade and better than other types. Multi-layered glazing windows are used for refurbishing old buildings, originally to reduce noise and later for improved thermal performance.

6.Conclusion

This research aimed to mimic glass curtain walls in Dubai, focusing on types of glass and their orientation. The study analyzed three glass configurations within a glass box to determine the most sustainable option for Dubai's climate. The experiments used passive glass and heat loggers. The data were organized using a heat index equation and processed with a binary Python program.

The results were acceptable for the south-facing orientation. However, the efficacy was not as identical when facing north. The data from the south orientation leaned toward quad glazing due to a three-month testing period, whereas the north data were based on a two-week timeframe. A Python-based binary program with

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straightforward logic to extract insights from vast amounts of data indicates that quad glazing may exhibit superiority. All data presented in tables in CSV format and calculations are saved in the GitHub repository.

The findings indicated that a quadruple-layer strategy performed more effectively in the southern region. In the northern area, where data were gathered over a two-week period, the quadruple-layer configuration emerged as the optimal choice, contradicting the assertions in favor of triple layers found in published reports. During the summer months, they excel at maintaining cooler indoor temperatures.

The findings indicate that employing a combination of diverse types of multi-layered glass exhibits varying degrees of energy efficiency, contingent upon the specific type, as well as the time and location. This implies that no single type of glass exhibits adequate efficiency to adapt to diverse environmental conditions. Notably, in Dubai, no project uses only one type of glass. The quality of quadruple glass is high, but it needs more proof to assure its effectiveness. Even old projects evolve as the industry progresses. More quadruple glazing testing yields new advancements to reduce HVAC load by up to 50% based on experiments in Europe and the United States.

Recent developments in advanced materials are also paving the way for improvements in energy efficiency. Research indicates that integrating nanotechnology into window manufacturing can further enhance thermal performance, potentially minimizing energy consumption in buildings. Pilot projects in urban environments are underway to evaluate the real-world impact of these innovations on energy savings and comfort levels.

Moreover, the implementation of smart glass technologies is proving to be a game changer, allowing for dynamic control of heat and light transmission. This adaptability not only enhances user comfort but also significantly reduces the reliance on mechanical heating and cooling systems. Continued collaboration between architects, engineers, and materials scientists will be crucial in shaping the future of sustainable building practices. By embracing these advancements, the industry is poised to achieve even greater reductions in carbon footprints while improving the overall building envelope performance.

In Dubai, glass VLT is modified by double glazing based on orientation in commercial or residential settings. Projects focus on aesthetics and energy efficiency due to DEWA restrictions on power consumption. Exceeding 350 kW threshold incurs costs for substation establishment. Architects must find passive ways to work around this limitation.

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