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Evaluating the Energy Performance of Standard and Nano-Coated Glass Facades Buildings: Sulaymaniyah City as a Case Study

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Abstract:

Recently, the increased cooling energy demand has posed additional challenges to buildings, especially in the summer under prolonged exposure to the sun. Consequently, the design of the façade and the choice of glazing are vital in improving energy performance and reducing solar heat gain. The current research examines the effectiveness of nano-coated Low-E glazing VS regular double-glazing on cooling loads of southwest-facing façades of buildings in the governorate of Sulaymaniyah in Iraq. "*Autodesk Revit and Autodesk Carbon Insight Analysis*" were used to develop the modeling of three mixed-use commercial buildings, which are of different architectural forms, glazing ratios, and zoning inside the buildings. The internal loads with the same local summer climate data were used on all models to focus on the influence of the glazing type. Energy savings by using silver nano Low-E coated glass in the three case studies: Gawhary Mulk saved 40.64%, in Aqary Building, 28.84%, and 24.61% in Mix Brand. Buildings were found to have the greatest performance gains through the use of large, unshaded, southwest-facing units that had high windows-to-wall ratios. In comparison to the ASHRAE Standard 90.1, the nano-glass buildings meet or exceed the recommended cooling energy intensity (173.7 kWh/m²/year); however, in the case of standard glazing, it exceeds this in most cases. These results prove the energy-saving potential of nano-coated glazing, emphasize the decisive role of façade orientation, and justify its usage as a passive measure to cut down the energy consumption of buildings in summer.

Keywords: Standard Glass, nano-coated glass, façade orientation, energy performance, solar heat gain.

الملخص:

في الآونة الأخيرة، شكّل الطلب المتزايد على طاقة التبريد تحديات إضافية للمباني، لا سيما في فصل الصيف مع التعرض المطوّل لأشعة الشمس. وبالتالي، يُعدّ تصميم الواجهة واختيار الزجاج أمرين حاسمين لتحسين أداء الطاقة وتقليل اكتساب الحرارة الشمسية. يدرس البحث الحالي فعالية استخدام الزجاج منخفض الانبعاثية (Low-E) المطلي بالنانو مقارنةً بالزجاج المزدوج العادي في أحمال التبريد للواجهات المواجهة للجنوب الغربي في مبانٍ بمحافظة السليمانية في العراق. استُخدم برنامجا *Autodesk Revit* و *Autodesk Carbon Insight Analysis* لتطوير نمذجة لثلاثة مبانٍ تجارية متعددة الاستخدامات، تختلف في أشكالها المعمارية ونِسَب الزجاج والتقسيمات الداخلية. وجرى توحيد الأحمال الداخلية وبيانات مناخ الصيف المحلي في جميع النماذج للتركيز على تأثير نوع الزجاج. أظهرت النتائج توفيرًا في الطاقة باستخدام الزجاج الفضي منخفض الانبعاثية المطلي بالنانو في دراسات الحالة الثلاث: فقد حقق مبنى Gawhary Mulk وفراً بنسبة 40.64%، ومبنى Aqary بنسبة 28.84%، ومبنى Mix Brand بنسبة 24.61%. وُجد أن المباني حققت أكبر مكاسب في الأداء عند استخدام واجهات كبيرة غير مظللة، موجهة نحو الجنوب الغربي،

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وبنِسَب نوافذ إلى جدران عالية. وبالمقارنة مع معيار ASHRAE 90.1 ، فإن المباني المزودة بزجاج النانو تلبي أو تبقى ضمن حدود كثافة طاقة التبريد الموصى بها (173.7 ك.و.س/م²/سنة)، بينما المباني ذات الزجاج القياسي تجاوزت هذه الحدود في معظم الحالات. تُثبت هذه النتائج إمكانات توفير الطاقة للزجاج المطلي بالنانو، وتؤكد على الدور الحاسم لتوجيه الواجهة، وتبرر اعتماده كإجراء سلبي لخفض استهلاك الطاقة في المباني خلال فصل الصيف.

الكلمات المفتاحية: الزجاج القياسي، الزجاج المطلي بالنانو، اتجاه المبنى، الأداء الطاقي، اكتساب الحرارة الشمسية.

پوختە:

لەم دواییانەدا، زیادبوونی خواست لەسەر وزەی ساردکەرەوە ئاڵنگاری زیاتری بۆ بیناکان دروستکردووە، بەتایبەتی لە هاویندا لەگەڵ بەرکەوتنی درێژخایەن بە تیشکی خۆر. بۆیە دیزاینی ڕووکار و هەڵبژاردنی شووشە بەرچاوە بۆ باشترکردنی کارایی وزە و کەمکردنەوەی گەیشتنی گەرمی خۆر. ئەم توێژینەوەیە ئێستا کاریگەری بەکارهێنانی Silver Low-E nano-coated glass بەراورد بە شووشەی دوو جامی ستاندارد لەسەر باری ساردکەرەوەی ڕووبەری باڵەخانەکان کە ئاراستەیان بەرەو باشووری ڕۆژئاوایە لە پارێزگای سلێمانی لە عێراق هەڵدەسەنگێنێت. بەرنامەکانی Autodesk Revit وAutodesk Carbon Insight Analysisبەکارهێنران بۆ پەرەپێدانی مۆدێل بۆ سێ بینای بازرگانی تێکەڵ، کە فۆرمی تەلارسازیان جیاوازە، ڕێژەی شووشە و دابەشکردنی ناوەوەیان جیاواز بوو. باری ناوەوە و داتاکانی کەشوهەوای هاوینەی ناوخۆیی لە هەموو مۆدێلەکاندا یەکسان کران بۆ ئەوەی تەنیا کاریگەری جۆری شووشە بەدیاربێت. ئەنجامەکان ئەوەیان نیشاندا کە بەکارهێنانی Silver Low-E nano-coated glassتوانای توانای بەدەست هێنانی وزە هەیە: بینای40.64% Gawhary Mulk ، بینای28.84% Aqary ، و بینای Mix 24.61% Brand. دەرکەوت کە زۆرترین باشبوونی کارایی لەو بینایانەدا بەدەست دەهێنرێت کە ڕووبەری گەورەی بێ سێبەریان هەبوو، ئاراستەیان بەرەو باشووری ڕۆژئاوا بوو، و ڕێژەی پەنجەرە بە دیوار زیاتر بوو. بە بەراورد لەگەڵ ستانداردی ASHRAE 90.1، ئەو بینایانەی کە شووشەی نانۆیان هەبوو سنووری چڕی وزەی ساردکەرەوەی پێشنیارکراوی (173.7 kWh/m²/year)یان کەمتر بووە، لە کاتێکدا ئەو بینایانەی کە شووشەی ستانداردیان هەبوو زۆرجار ئەم سنوورەیان تێپەڕاندووە. ئەم ئەنجامانە دڵنیایی دەدەن لە توانای بەدەست هێنانی وزەی Silver Low-E nano-coated glass، جەخت لەسەر گرنگی ئاراستەکردنی ڕووکار دەکەنەوە، و بە تێچوونێکی پاسیڤ پاساو دەدەن بۆ کەمکردنەوەی بەکارهێنانی وزەی بیناکان لە هاویندا.

کلیلە وشە: شووشەی ستاندارد، شووشەی نانۆ ڕوپۆش، ئاراستەی بینا، ئەدای وزە، بەدەستهێنانی گەرمی خۆر.

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Introduction

Since buildings are major energy consumers worldwide, they have become a central point of concern in climate action and sustainability. The built environment contributes approximately 48 percent of all energy use in the United States and 20 to 40% in Europe and other developed cities (Al-Sallal, 2014). Building-related energy services in the world cover approximately one-third of final energy demand and the related CO_2 emissions (Urge-Vorsatz et al., 2013). As a result, the industry has a high role to play in climate change and air pollution (Bilgen, 2014).

Due to the ever-growing building inventory around the world, effective design and implementation of innovative technologies are becoming the primary concerns, aiming to lessen energy consumption during operations (Al-Sallal, 2014). In summer, the problems are further complicated by raised warm temperatures and intense solar radiation. For instance, Iraq is one of the most climate-deficient states, as it is regularly affected by extreme temperature conditions of heatwaves (Al-Zaidi, 2023). However, in the Kurdistan region, the advancement of average temperatures in Sulaymaniyah has been around 1.3°C over the past decades, and elevated sun radiation have continued to rise (AbdulRahman et al., 2024). Moreover, the modifications in the speed of wind, vapor pressure, and evapotranspiration also increase the cooling requirements (AbdulRahman & Khalid, 2019). This situation explains the value of building façade design and glazing consideration to prevent excessive undesired heat during warm seasons (AbdulRahman et al., 2021).

In modern buildings, it is common to use large amounts of glass screens to allow daylight and the beauty, but still, in those buildings, glazing is one of the most significant sources of thermal vulnerability. It is proven that windows can account for 20%–60% of the whole building energy loss, depending on their thermal properties (Moghaddam et al., 2023).

As revealed by Stegou-Sagia et al. (2007), very high glazing areas can highly extend the cooling energy unless their design is shaded or coated. Despite Hee et al. (2015) abiding by the logic of the trade-off between daylighting and excessive solar gain, and validated that the immediate effect of glazing type is on energy consumption and indoor climate.

Nanotechnology has now become a possible way of optimizing glazing performance. According to El Din and Fikry (2019), it will be possible to reduce cooling loads in hot areas by using sensible decisions when it comes to glazing and coating. In addition, Li et. al. (2018) show that thermal energy storage is increased, and energy dissipated up to 4 % is lowered due to the insertion of nanoparticles into the double-glazed units in arid climatic conditions. As Jastaneyah et al. (2023) verify, metal and oxide coatings on nano-structured glass reduce the amount of thermal conductivity and also the energy required, notably, in buildings that are situated in areas where the solar radiation is very high. These results have revealed that nano-coating glazing could alleviate solar heat gain and improve façade energy performance. Sulaymaniyah will be an applicable case study to test the interventions. It has a semi-arid to Mediterranean climate that causes increasing average temperatures and a high level of solar exposure throughout the summer, which increases cooling demands (AbdulRahman et al., 2024).

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The orientation of the facade is the ultimate factor in deciding on the solar heat gain and cooling load. In tropical and temperate regions, studies have repeatedly confirmed that east- and west-facing structures are the most prone to overheating because they are exposed to low-angle solar radiation in the morning and afternoon, which is why, in many cases, such buildings are exposed to the highest possible outside temperature (Rubel and Joarder, 2024). In Europe, such parametric analyses have verified that south-facing glazing may be useful in colder climates, but at all rates west- and east-facing facades make cooling requirements worse in hotter climates (Leskovar & Premrov, 2011). Nanotechnology-based glazing, particularly low-emissivity and coated systems, has been shown to mitigate these orientation-dependent challenges by reducing solar transmittance and improving insulation (Kalefa, 2023). The southwest facade is particularly critical in Sulaymaniyah, where the highest afternoon sun occurs during the time of maximum cooling loads of the day, causing the southwest to be the most critical in terms of cooling loads. It is, therefore, this orientation that offers the most suitable and realistic premise on which the effectiveness of nano-coated glazing can be tested as compared to standard glazing in terms of minimizing heat gain and overall building energy consumption.

Literature Review

In this section, the various impacts of glazing systems in hot climate buildings on the energy consumption of the buildings are analyzed, such as constraints of using regular glass, the importance of setting the façade orientation, and the benefits of nano-coated glazing. Also, it outlines the most frequently applied simulation instruments to assess thermal performance.

Standard Glazing in Hot Climates

In the past few decades, glass has been the central figure in modern architecture. Having initially been incorporated in small-sized window openings, it has evolved to involve large open curtain walls and full-height facades, especially in commercial/office buildings. This development is influenced by not only aesthetic interests but also a desire to maximise daylight and eye contact (Cassiday, 2014). However, the spread of large glazed surfaces brings severe energy problems to the hot-climate areas. The standard double glazing (though better than single glazing) causes great heat gain internally in those places. As an example, Alwetaishi (2019) revealed that in Saudi Arabian cities, double-glazed windows had increased cooling loads even though they are being extensively used in contemporary buildings.

At the same time, Attia and Helmy (2015) revealed that the use of double glazing was not sufficient to ensure adequate prevention of solar heat gain in residential units with high levels of harsh sun, as energy levels were demonstrated as high during summer months. In terms of performance, U-values of a conventional double glazing are usually between 2.5 and 3.0 W/m 2 K, whereas their solar heat gain coefficient (SHGC) is between 0.60 and 0.70 (Alwetaishi, 2019; Cassiday, 2014). All these parameters have shown mediocre insulation and weak solar control, which is not sufficient under extreme solar exposure. The result is that glazing with characteristics of allow a lot of solar radiation to enter allows the system to be more dependent on the use of mechanical cooling. Numerous investigations also support the inefficient behavior of uncoated transparent double glazing in hot, dry climates. It is evident, as Radhi (2009) proved, that clear glass allows a high amount of radiation,

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especially in cases of covering an unshaded or west-directed facade. Bouchahm et al. (2012) also witnessed this phenomenon as they demonstrated that even double glazing is associated with proportional increases in cooling loads when greater glazing ratios are chosen.

The typical double-glazing systems also offer some quantifiable gain in comparison to the old technologies in glazing, but they are still insufficient to be applicable in the construction of buildings that are positioned in hot climatic environments. Those systems also have a chronic shortage of solar-heat control, especially high-angle orientations exposed to intense afternoon solar irradiance, which compromises the ability of such systems to suppress the consumption of energy. Therefore, the need for more resilient glazing systems becomes ever more prominent in climate-sensitive architectural design, such as nano-coated glasses.

Effect of Façade Orientation on Solar Heat Gain

Orientation of the facades makes a concrete impact on the thermal reaction of buildings in hot climatic conditions. The solar heat gain is directional with an extremely dense intensity in cases of extreme intensity, coupled with a prolonged solar exposure on the surface of the facades that are oriented towards the southwest and west. As Biyik et al. (2017) reveal, such orientations are particularly vulnerable to the afternoon radiation, at the times when the outside temperatures are the highest.

Furthermore, Zomorodian et al. (2016) observe that, in hot-arid climates, south-west directions are also significantly more likely to load as a result of extensive solar exposure and the dearth of natural shades. As a result, south-west facades are more vulnerable to overheating, hence further exacerbating the reliance on the mechanical cooling systems.

In addition, He et al. (2016) also point out that poor placement of the facade in combination with high solar invasion caused by glazing materials may significantly increase cooling energy consumption. They also provide support to the argument that orientation and glazing performance are variables that are interdependent and are supposed to be tackled together in the quest to increase the energy efficiency of a building.

Lastly, Karlsen et al. (2020) also highlight requirements of orientation-aware façade strategies, depicting that a south-west-facing façade will need specific shading and glazing to ensure the energy consumption is minimized in the hot climate. All these studies confirm that south-west orientation is the most significant parameter in building design in hot climates since it has been experienced to have high solar exposure and it directly influences cooling energy requirements.

Nano-Coated Glazing Technology

The advancement in the field of nanotechnology over the last couple of years has made it possible to come up with glazing systems with high performance that are able to reduce the amount of energy wasted in buildings under heavy solar radiation. One of the most significant ways in which that decrease is realized is via the use of low-emissivity (low-E) nano-coatings, which are often produced with silver and a range of metal oxides, added into building envelopes.

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According to Yousef et al. (2019), these coatings have been defined as ultrathin conducting/reflective layers placed on the glass substrate through physical or chemical vapour processing. The byproduct is used as a selective solar filter, reducing the infrared transmittance and largely retaining visible light transmission. This functionality reduces undesirable gain of solar heat and hence scales down the cooling demands of the building.

Furthermore, Scalisi et al. (2017) put nanostructured materials in a wider frame of the entire glazing system, record their ability to improve optical and thermal properties, and thus increase solar reflectance and reduce thermal conductance. The piece of writing produces lower U-values and solar heat gain coefficients (SHGC), which form the keystones of the performance of glazed facades.

In addition, El Din and Fikry (2019) highlight the effectiveness of reflective nano-layers, especially those produced with the use of nano-silver compounds in reducing solar absorption. The extent of interactions of reflective coatings in restricting solar heat gain in large areas of glass surface, a phenomenon that is particularly beneficial in structures characterized by high window-wall ratios, is elaborated in their investigation.

Similarly, Monis and Rastogi (2022), nano-glazed systems comprise an inseparable part of passive design systems, particularly the ones that perform well in warm climatic cities. In their review, it has been stated that these systems are capable of blocking solar gain, yet maintaining an extended transmission of daylight, thus saving energy loads and having visual transparency at the same time.

The findings of Al-Masrani et al. (2019) rely on simulations and indicate that the use of nano-coated glass in building envelopes delivers quantifiable reductions in the indoor heat levels along with the subseq/uent improvements in cooling energy needs. The test outcomes, hence, endorse the feasibility of such technologies to operate in sun-dictated surroundings.

Energy Simulation Approaches for Glazing Performance

Substantial research has been based on the simulation tools to assess building envelopes, especially glazing systems that are subjected to different climatic conditions. The most prominent ones include Energy Plus, E-Quest, Open Studio, and Autodesk Insight, which are frequently cited in scholarly sources. As an example, Ali et al. (2020) used the Design Builder, which is an Energy Plus integration, to compare nano-coated and standard glazing in a hot desert climate, highlighting the benefits of using advanced glazing in lowering the cooling loads.

Ahmed and Fikry (2019) used E-QUEST and CALUMEN software to perform the analysis of multiple glazing options on south-facing facades in the hot arid zone in Egypt and found that substantial savings in cooling and lighting energy could be achieved by implementing optimal glazing and shading. It was also possible to compare the types of glazing or rather, determine that orientation and the properties of glass have a significant impact on cooling demand in accordance with Ragab among the sources (2020).

In the meantime, Open Studio has become a general-purpose simulation application, especially in the context of passive design analyses (Fateh et al., 2019), notably in cases where several envelope designs have to be tested. That said, despite this, there remains a clear research gap: there has been

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little investigation that has specifically studied the comparison of nano-coated glazing compared to the standard glazing, in a south-west-oriented façade, specifically in Sulaymaniyah (where this orientation receives the greatest amount of solar radiation in the afternoon). The simulation of this gap will be imperative in ensuring that appropriate insights are incorporated with regard to energy-efficient building design in a hot climate setting". Section 1.2 provides details specific research gap based on the synthesized literature review.

Research Gap

Nanotechnology has made its strong case to be recognized for its potential in enhancing the thermal performance of glazing; however, there is a dearth of realistic, quantitative, simulation-based comparisons of nano-coated and average glazing with real-world building environments. In addition, façade orientation, especially the south-west-facing façade that is the most exposed to high levels of solar radiation in the afternoon hours, remains an underestimated factor in the present assessment of the advanced glazing solutions. It has also been identified to be the most exposed façade to the sun all year round, getting exposed to the greatest annual solar radiation among the simulated environments in any comparative façade analysis (Chow et al., 2005), which makes it the key benchmark against which to evaluate the energy-saving technologies that are governed by hot climates.

Although several studies have discussed the shortcomings of a traditional glazing system and the advantages of the nano-coated glass in hot climates (Scalisi et al., 2017; El Din & Fikry, 2019; Al-Masrani et al., 2019), inefficiency in the real performance of the compared systems with the specifics of the south-west facades of buildings in the hot summer climate of Sulaymaniyah has been still missing. Numerous studies prove that south-west facades are the most exposed to overheating and additional cooling needs in the afternoons due to the maximized amounts of solar radiation (Biyik et al., 2017; Zomorodian et al., 2016; Karlsen et al., 2020; Chow et al., 2005). Nevertheless, no simulation-based study has yet compared nano-silver-glazing with conventional double glazing with this orientation and this climate. By filling this research gap, it is possible to obtain a credible and context-based design alternative regarding energy-efficient and climate-responsive architectural practice.

Problem Statement

In recent years, there has been increasing interest in the potential to improve the thermal performance of building envelopes in hot climates, in part due to potentially important improvements in glazing technologies. The orientation of the façade is an important aspect as it can influence solar heat gain and energy requirements, especially in areas that receive more sunlight exposure for a long duration, such as Sulaymaniyah..

There is a lack of orientation-related evaluation of the thermal performance of various glazing types within hot-climate architecture. Ordinary glass, which is widely used in facade construction, allows a substantial amount of solar heat gain, especially on southwest-facing facades in Sulaymaniyah, and, therefore, contributes to adding cooling burden and increasing the total energy use. Though a thermally improved form of nano-coated glass has been developed, it has not yet been

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compared in a practical arid climatic environment in hot areas like Sulaymaniyah. The lack limits architects when choosing which materials should be used on the façade so as to achieve maximum energy efficiency in hot climates.

Research Questions

This study is guided by the following research questions, focusing on the impact of nano-coated glass on energy performance in hot climates.

1. To what extent does nano-coated glass reduce the cooling energy demand of south-west-oriented façades?
2. What is the impact of nano-coated glazing on solar heat gain compared to standard glazing in south-west facing building envelopes?
3. To what extent can nano-coated glazing enhance the thermal behavior of facades subjected to intense solar radiation during the summer in Sulaymaniyah?

Research Aim and Objectives

The research aims to compare and assess the energy performance of nano-coated and standard glass facades installed on south-west facing building envelopes applied on a building facade in a hot weather climate by utilizing a dynamic simulation tool. These aims are to determine the extent of their influence on cooling energy demand and locate the most effective glazing mode to improve thermal performance in Sulaymaniyah.

To achieve the aim through:

1. **Analyze** the impact of solar radiation on south-west-oriented facades in hot climates, with a focus on cooling energy demand.
2. **Define** the thermal properties of standard and nano-coated glazing systems, including U-value and SHGC.
3. **Conduct** dynamic building energy simulations comparing cooling energy consumption between standard and nano-coated glass facades under identical conditions.
4. **Quantify** the energy savings achieved by nano-coated glazing relative to standard glass.

Research Design

The current paper uses a comparative simulation model to determine the impact that nano-coated glazing and standard glazing have on the cooling energy needs of buildings that are located in a hot summer environment in Sulaymaniyah. The study focuses on three of the exemplar building types whose facades face south-west, the direction exposed to maximum radiation by the sun in the afternoon. The main aim is to determine the amount of energy that can be saved by installing nano-coated glass compared to the use of the conventional glazing system.

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Building Models and Design Process

Three representative building models were developed to reflect typical mixed-use developments commonly found in Sulaymaniyah's hot summer climate. The design process involved defining a realistic configuration where each building includes multiple functional zones. For example, the ground floor is designated as retail or commercial space, while the upper floors are modeled as office units. Each model was created in Autodesk Revit 2024 to define the building geometry, number of stories, floor area, window-to-wall ratio, and the specific façade orientation. The south-west orientation was selected because, according to Sulaymaniyah's local climate data for the Kurdistan Region, it receives the highest afternoon solar exposure during the hot summer season. directly affecting cooling energy demand.

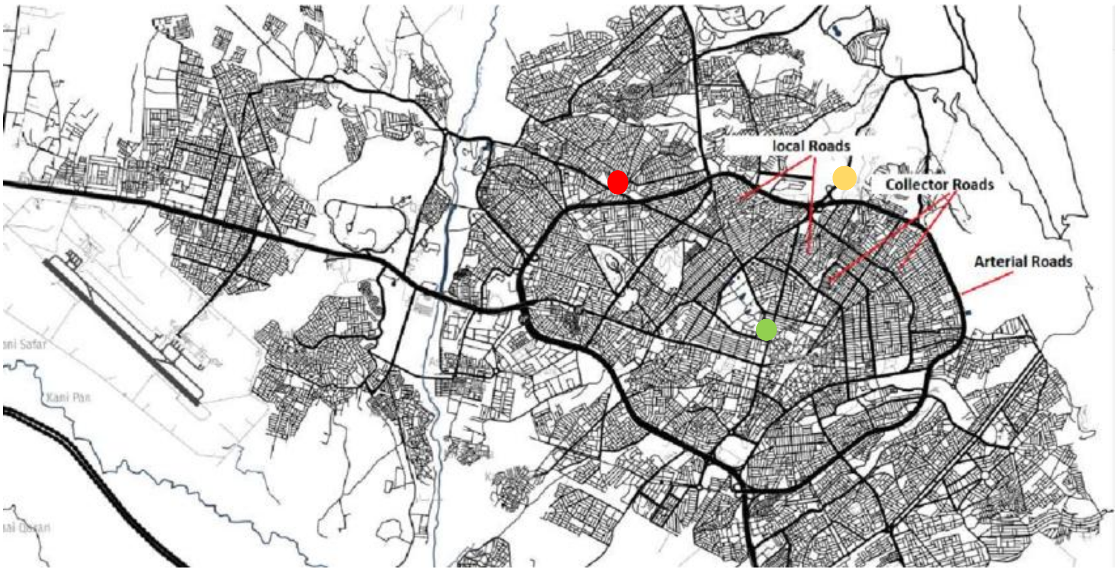

Figure 0-1 The three case studies are located on the Sulaymaniyah master plan (Source: Municipality plan)

- The yellow circle on the Sulaymaniyah master plan is the Gawhary Mulk building, which is located on Malik Mahmoud main road next to the Titanic hotel *(Figure 2-1)*.
- The red circle is the Mixed Brand building on the west orientation, located on Malik Mahmoud main road (*Figure 2-1)*.
- The green circle is the Aqary Building located on Salim Street, in front of the Rotana hotel. *(Figure 2-1)*.

The selected buildings meet three main criteria:

1. These are the common mixed-use buildings with the function of shops or real estate offices that cover the ground floor and office space on the upper levels to suit the typical building type in the urban downtown of Sulaymaniyah.
2. They work during the daylight hours, and during this period, the solar heat gain is highest, and therefore, glazing performance is vital in the cooling energy demand.

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3. They possess extensive glazed areas, large window-to-wall ratios (80 %-100 %), south-west facing *Table 2-1*, a window direction that local climate data reveal to have the greatest number of afternoons of peak summer sun.

Table 2-1: Architectural Information of the Selected Case Study Buildings (Source: Researcher's calculation based on architectural drawings).

	Building Name	Floors	Ground Floor Use	Upper Floors Use	Total Floor Area (m²)	Total Façade Area (m²)	Total Glazing Area (m²)	WWR (%)	Façade Orientation
A	**Gawhar Mulk**	GF+5	Real estate office	Offices	135	261.25	252.36	**96.6%**	South-West
B	**Mix Brand**	GF+5	Retail	Offices	400	410	390.73	**95.31 %**	South-West
C	**Talary Aqary**	GF+7	Shops	Offices	1550	1391.63	1150.64	**82.69 %**	South-West

The criteria are such that allow ensuring that the modeled constructions are realistic representations of the state of the façade that would describe urban corridors to the urban environment located either within or directly adjacent to Malik Mahmood Ring Road, Sulaymaniyah. To make these characteristics transparent, drawings of the available inventory were obtained for each target building and processed accordingly to produce the ground-floor story, a representative upper story, sections, elevations, and 3D forms to be used in the simulation. *Table 2-2.*

It should be noted that the case study buildings vary in façade and glazing areas. This variation reflects real architectural practice in Sulaymaniyah rather than standardized models. To enable meaningful comparison, the study relies on the window-to-wall ratio (WWR) as the key parameter, which normalizes the influence of absolute façade size. In addition, this diversity strengthens the applicability of the findings, since the analysis covers buildings of different scales and glazing proportions rather than a single uniform type.

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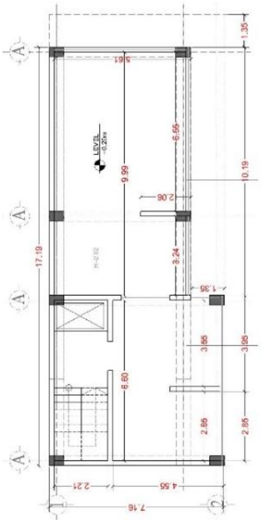
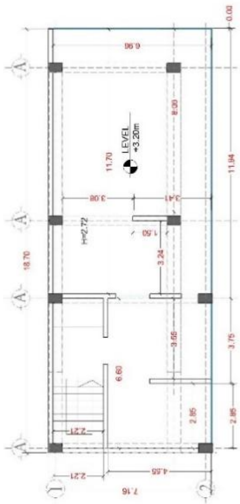
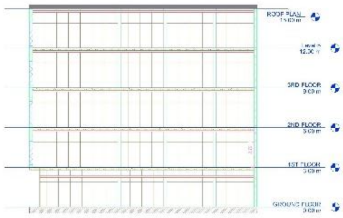
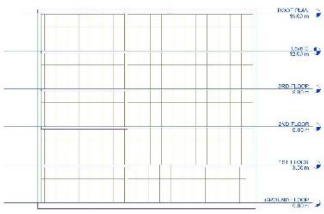
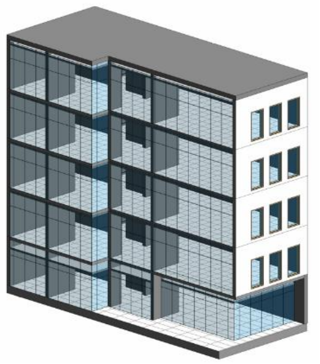
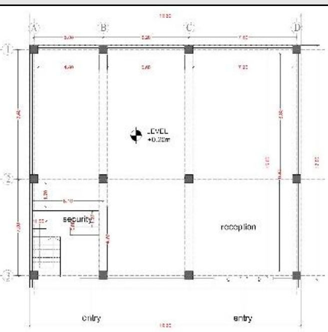
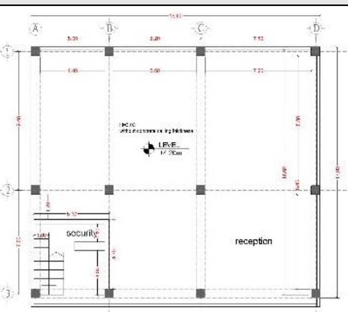
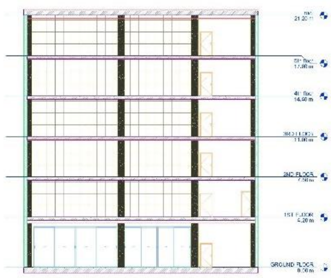
Table 2-2: Buildings Architectural Drawing Data (Source: Researcher).

	Building Name	Ground Floor Plan	Typical Floor Plan	Section A-A
A	**Gawhary Mulk** (Source: Researcher)			
		Façade	**3D (Revit model) View**	**Real Building Image**
				
	Building Name	**Ground Floor Plan**	**Typical Floor Plan**	**Section A-A**
B	**Mix Brand** (Source: Researcher)			

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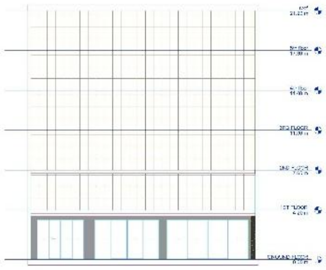
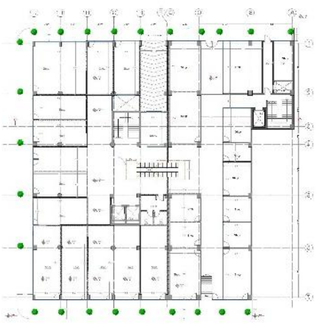
		Façade	**3D (Revit model) View**	**Real Building Image**
				
	Building Name	**Ground Floor Plan**	**Typical Floor Plan**	**Section A-A**
B	**Talary Aqary** (Source: Researcher)			
		Façade	**3D (Revit model) View**	**Real Building Image**
				

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Simulation Parameters

A dynamic energy model was carried out through Autodesk Revit 2024 which was used to model the building, and Autodesk Insight Carbon Analysis was used to simulate the building performance (Autodesk Insight was chosen because it provides integration with Revit and its capability to simulate envelope-driven cooling load performance in a very hot climate). The geometrical floor layout, total floor area, positioning, and the orientation of the facade, window-to-wall ratio (WWR), and glazing area in total were used to model each of the three representative mixed-use buildings as described in *Table 2-1*. Autodesk Insight allows data from climates and climate zones representing ASHRAE-designed climate branches (which consider the ASHRAE Standards 90.1) to generate realistic weather conditions that minutely reflect the summer climate of Sulaymaniyah.

This determines that the energy performance evaluation represents environmental situations prevailing regionally as per global standards. A pair of glazing situations was established per building: (1) a basic situation with conventional clear and uncoated 2-fold glazing; (2) a occasion situation with low-E coated 2-fold glazing of silver-based nano-material. As *Table 2.3* indicates, the normal glass of the baseline model has a U-value of 2.W/m²·K, an SHGC of 0.75 and thermal conductivity of 0.0696 W/m·K, whereas the alternative, which is a nano-glass achieves a U-value of 1.3 W/m²·K as well as an SHGC of 0.25 with a thermal conductivity of 0.0312 W/m K (Table 2-3).

Table 2-3: Glazing Thermal Properties (Source: Emek Company).

Glass Type	Description	Layer Composition	U-value (W/m²·K)	SHGC	Thermal Conductivity (W/m·K)	Thickness (m)
Normal Glass	Clear double glazing without coating	6–12–6 mm (air gap)	2.9	0.75	0.0696	0.024
Nano-Coated Glass	Double glazing with silver low-E nano coating	6–12–6 mm (air gap)	1.3	0.25	0.0312	0.024

The simulation was based on operation cooling loads in a hot summer, and the actual output was cooling energy demand (kWh) per scenario, which was the most crucial. Autodesk Revit 2024 was used to create the building models, and then they were connected to Climate Studio to carry out the simulations. The second visual output is the solar heat gain maps (temperature contour visualizations), which were produced in Climate Studio to show the internal distribution of the solar energy in each glazing condition and assist in a more intuitive interpretation of the simulation results.

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Scenario Definition and Analysis

To assess how glazing performance affects the cooling energy demand, two simulation scenarios were determined according to the type of glazing properties described in Table X. The first one (case A) is a default condition that offers uncoated standard double glazing (6 12 6mm). Scenario B, on the other hand, has the same structure of the double glazing that has been altered with silver-based nano low-emissivity (Low-E) coating, which is a high-performance glazing system used in hot climates. The two situations were modelled and simulated under identical conditions, which were different geometrical buildings, internal loads, schedule uses, and climate data of Sulaymaniyah. In this way, any possible change in the energy performance can be directly linked to the properties of glazing alone. The Autodesk Insight simulated the simulations, which produced the annual cooling energy demand (kWh/m²) of each scenario. Simulations were made regarding the operation profile of each building with 6 working days per week, and 12 hours of occupancy duration each working day, considering the typical office buildings and mixed office and commercial buildings occupancy conditions in Sulaymaniyah. Though the outcomes of the study analyzed annual consumption, the analysis done in this research gave special focus on the hot season (May-September), the time when the cooling demand in Sulaymaniyah is understood to be the greatest. Based on local climate statistics, the warm period lasts between early June and mid-September, and the average temperature is above 33°C daily in particularly in July and August ("Weather Spark," n.d.). It is usually in the most extreme and intense solar radiation during this period, and maximum volumes of mechanical cooling are involved.

Results

In this section, the simulation results of the cooling energy performance of the three buildings in the case study are provided. The statistical results were stated in the form of energy use intensity (kWh/m²/year), which allows a regular comparison between the circumstance with a normal glazing state and the circumstance with a glazing surface treated professionally using nano-coating supervision.

These findings enable a direct comparison to be made regarding the performance of normal and nano-coated glazing on the basis of energy efficiency. In every case study building, the most exposed glazed façade has been chosen through the orientation and the intensity of solar radiation during the hot summer in Sulaymaniyah as per simulation consideration. The performance of each one of the facades was assessed with a standard surface glazing and a nano-coated glazing as follows.

a. Building A Gawhary Mulk

The chosen building is found on Malik Mahmud Ring Road in roughly 35.5787 N, 45.4614 E, a commercial area of elephantine density. It has a 59.9 o face to the true north, or more specifically, to the southwest-northwest axis as observed in (Figure 3-1), and this gives it high solar radiation in the afternoon of the summertime. The southwest direction elevation, having a high window-to-wall ratio and minimum shading, was chosen as a critical test surface for the simulation since it is the elevation that has a high cooling requirement under the Sulaymaniyah hot climate environment.

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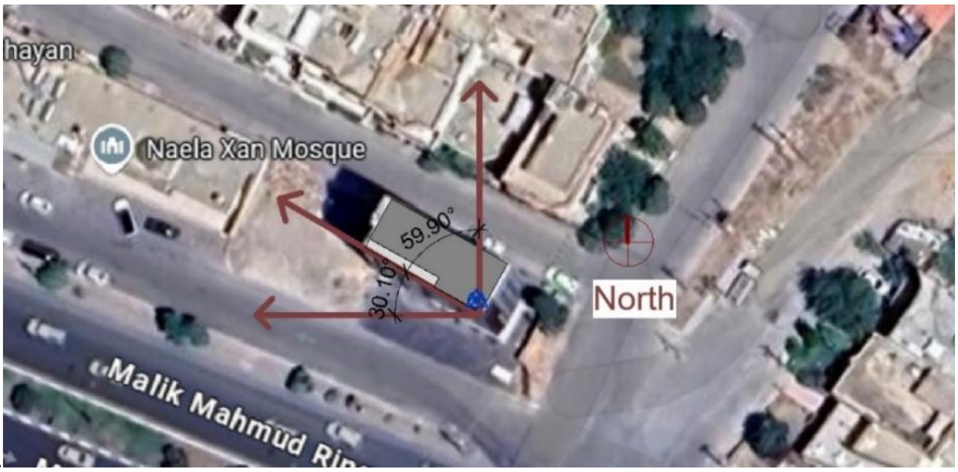

Figure 0-1 Building orientation showing the glazed façade aligned along the northwest axis (59.9° from north) (Source: Google Map).

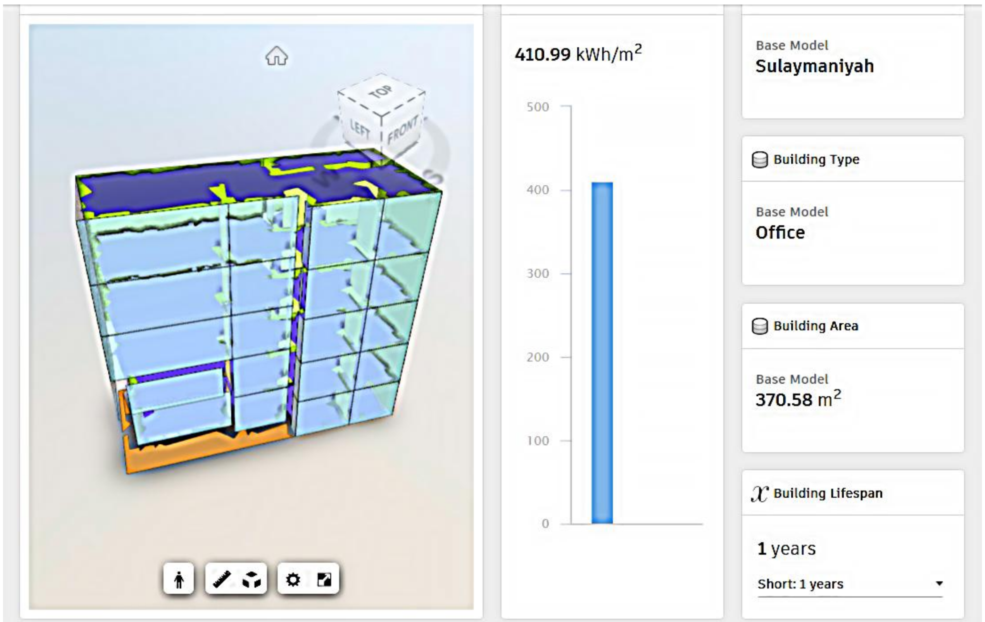

Figure 0-2 Simulated annual cooling energy demand for the Jawhar Mulk building with Normal double glazing (Source: Researcher).

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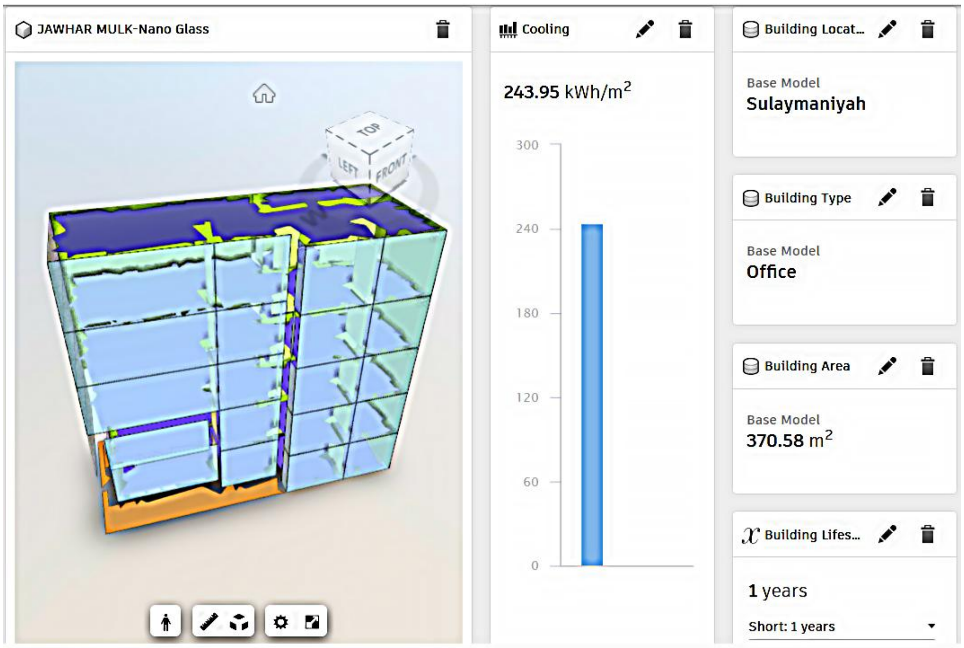

Figure 0-3 Simulated annual cooling energy demand for Jawhar Mulk building with silver-based nano low-emissivity (Low-E) coating glazing (Source: Researcher.

b. Building B Mix Brand

The chosen façade to simulate is about 68.25° oriented to true north, as illustrated in (Figure 3-4); therefore, it would be on a southwest-northwest facing solar exposure. This orientation is also under the excessive afternoon sun rays in Sulaymaniyah during the summer period, and thus it serves as a critical surface in assessing cooling energy requirements in hot climate cities. The location of this building is at 35.5816 N, 45.4136 E, which is close to 142-47 Street within a highly dense urban locality in the western city of Sulaymaniyah. It has such a southwest orientation, high glazing ratio, and low external shading that its elevation was selected as a typical case study to examine the efficacy of nano-coated glazing along with the real climatic and architectural environment.

Figure 0-4 Building orientation showing the glazed façade aligned along the west-northwest axis (68.25° from north) (Source: Google Map).

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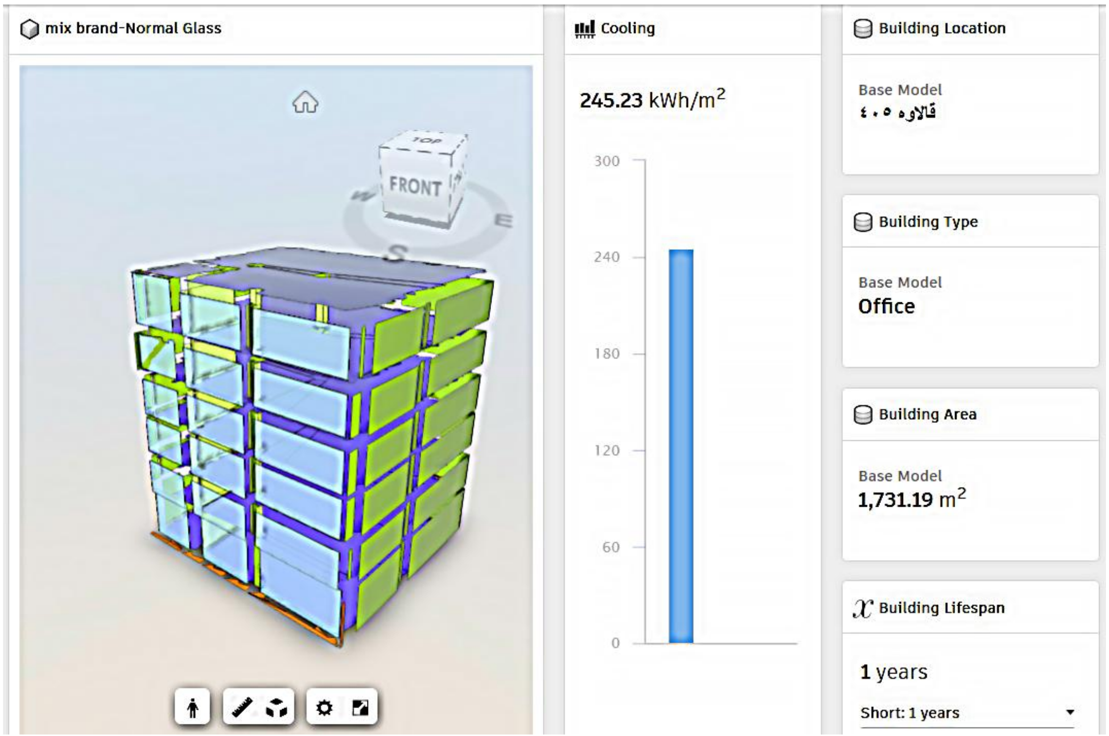

Figure 0-5 Simulated annual cooling energy demand for Mix Brand building with Normal double glazing (Source: Researcher).

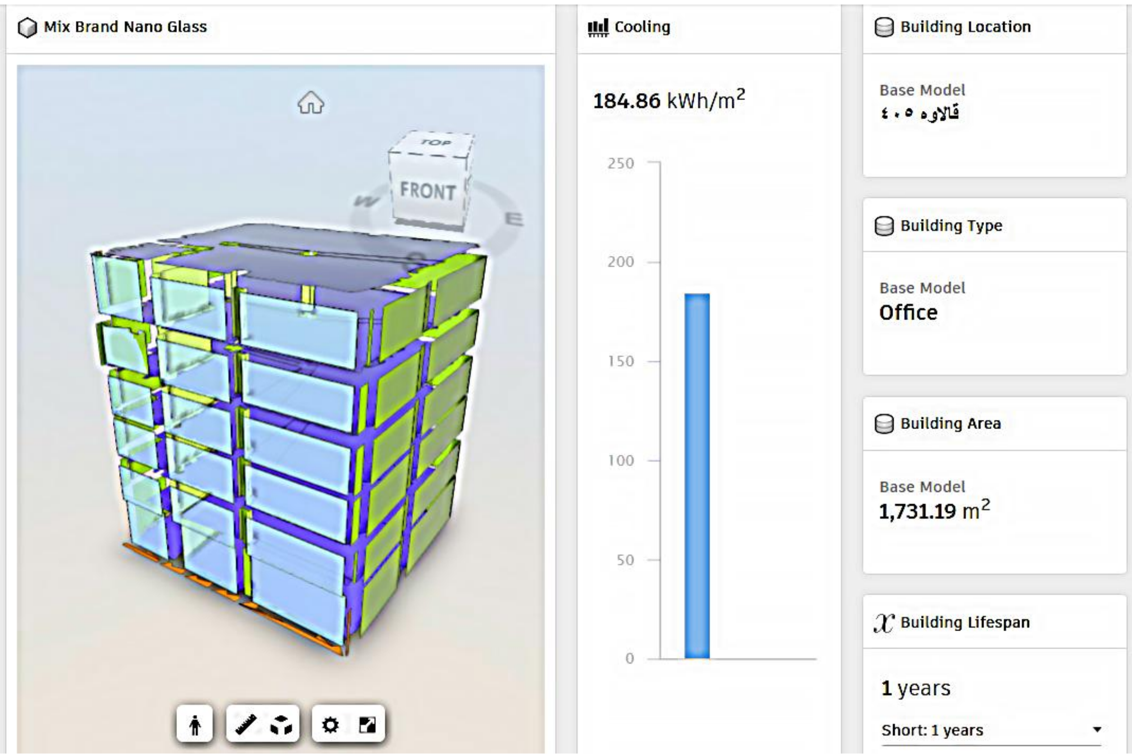

Figure 0-6 Simulated annual cooling energy demand for Mix Brand building with silver-based nano low-emissivity (Low-E) coating glazing (Source: Researcher).

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c. Building C Aqary Building

The virtual facade is set 72.25° off of true North, as illustrated in (Figure 3-7); therefore, facing the southwest direction that has heavy solar intensity in the afternoon hours of Sulaymaniyah in hot summers. The building is placed on Salim Street at 35.5575° N, 45.4295° E, as the glazed southwest elevation is most beneficial to the building in the evaluation of the cooling capacity of nano-coated glazing because of its large solar gain and low shading. The case study building had the south-east and south-west glazed elevations, but to meet the reality of the actual exposure of the building envelope, both exposed the simulation to the south-east and south-west.

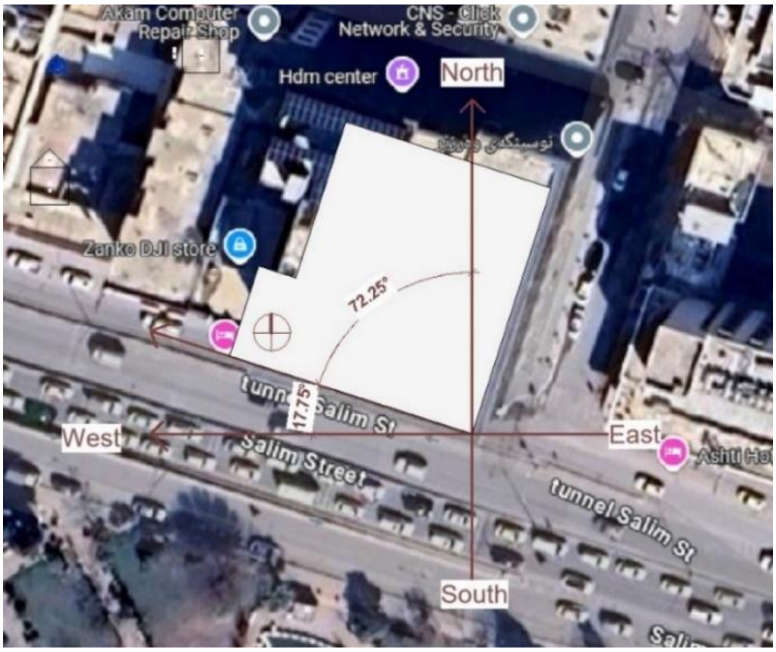

Figure 0-7 Building orientation showing the glazed façade aligned along the west-northwest axis (72.25° from north (Source: Google Map).

Although the south-east side is partially blocked by other buildings, it has a lot of morning solar radiation. The south-west facade, conversely, has full exposure and it is highly exposed to solar gain in the afternoon. In that sense, the whole building envelope was simulated to consider both sides of the solar heat gain, making the cooling energy demand analysis accurate and realistic in real site conditions.

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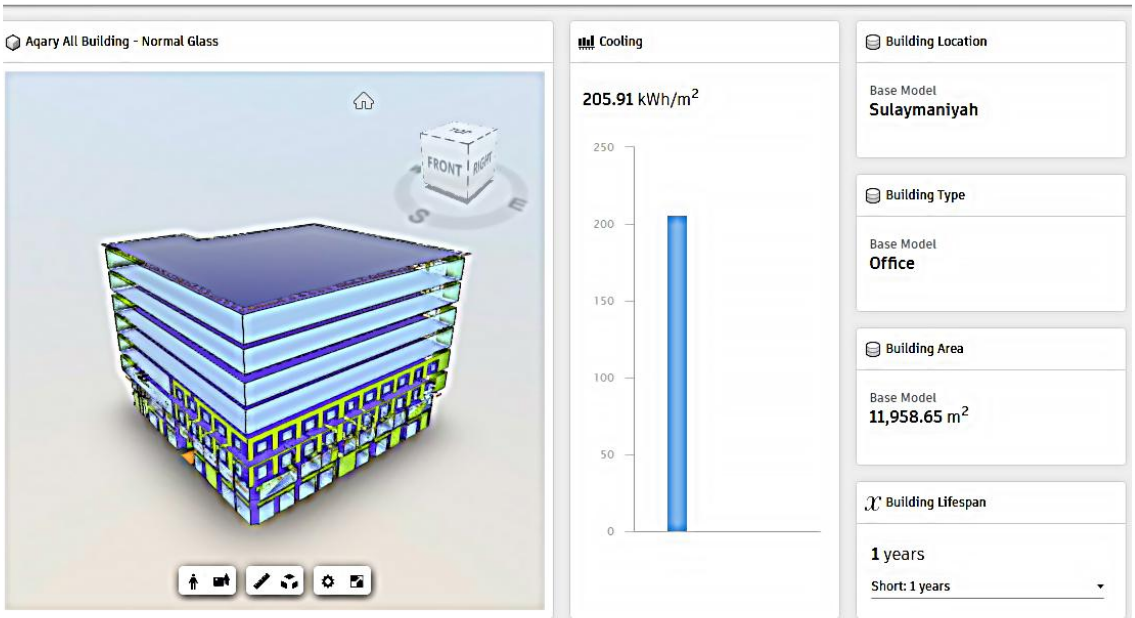

Figure 0-8 Simulated annual cooling energy demand for the Aqary building with Normal double glazing (Source: Researcher).

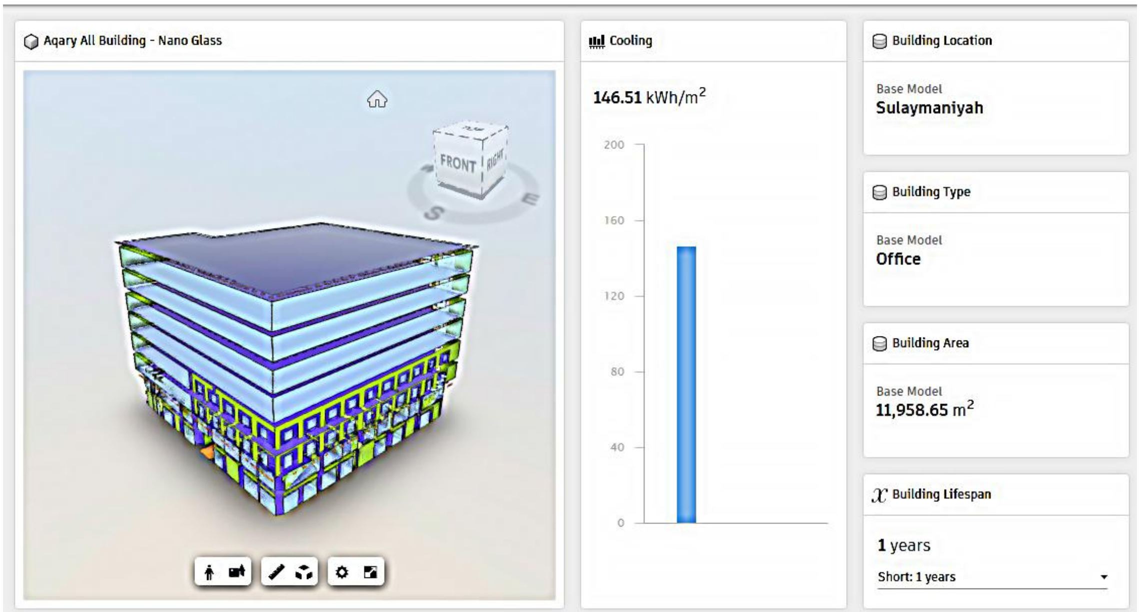

Figure 0-9 Simulated annual cooling energy demand for the Aqary building with silver-based nano low-emissivity (Low-E) coating glazing (Source: Researcher).

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***Table 3-1**. Annual Cooling Energy Demand (kWh/m²) Summary (Source: Researcher).*

	Building	Scenario A: Normal Glazing (kWh/m²)	Scenario B: Nano-Coated Glazing (kWh/m²)	% Reduction
A	**Gawhary Mulk**	410.99	243.95	**40.64%**
B	**Mix Brand**	245.23	184.86	**24.61%**
C	**Aqary Building**	205.91	146.51	**28.84%**

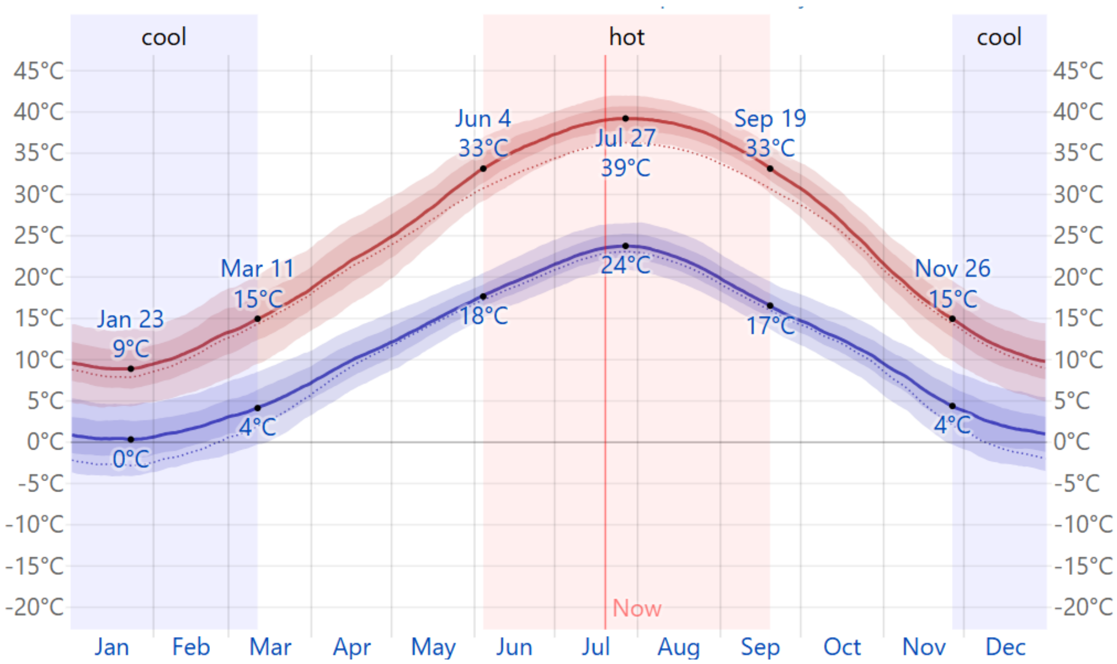

Figure 0-10 Mean (maximum and minimum) temperature daily in Sulaymaniyah illustrating the hot season in June till September. The high and low temperature (red and blue line) on average per day. These lines are the corresponding average perceived temperatures (Source: Weather Spark).

Taking into consideration the fact that about three-quarters of the total annual cooling energy consumption in Sulaymaniyah is made during the hot period of the year (June to mid-September), *Table 3-2* provides an estimate of the seasonal cooling loads per case study building, assuming both the standard and nano-coated glazing. This annual decomposition brings out the efficiency of nano-glazing in decreasing cooling energy requirement during the time when solar yield gain is maximum. The temperature curve behind this assumption has been depicted as *(Figure 3-10),* which is based on data on climatic conditions that have been provided by Weather Spark (n.d.).

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Table 3-2: *Cooling Energy Use Intensity (EUI) (kWh/m²) – Hottest Months (Source: Researcher).*

	Building	*Cooling* EUI (Standard)*(kWh/m²)*	*Cooling* EUI (Nano-Coated)*(kWh/m²)*	Reduction Achieved
A	**Gawhar Mulk**	308.24	182.96	**40.65%**
B	**Mix Brand**	183.92	138.65	**24.62%**
C	**Aqary Building**	154.43	109.88	**28.84%**

- **Heat Gain Contour (Visualization)**

The Mix Brand building was modeled in Autodesk Revit 2024, and the heat gain visualization was produced in Climate Studio v.2.1.9190.15522 to determine the spatial influence of glazing types on internal heat gain. Both cases were simulated under the same climatic conditions and operational settings for comparison. *Figure 3-11a* illustrates the simulated heat gain contour of the baseline system with conventional double glazing, showing extensive high-intensity zones, particularly on the southwest-facing façade. *Figure 3-11b* presents the distribution with silver-based nano Low-E coated glazing, where the red high-gain areas are noticeably reduced and shifted towards lower-intensity colors (yellow to blue). The color scale is used here as a visual indicator of relative heat gain intensity, with red denoting the highest solar exposure and blue indicating the lowest. These comparative maps demonstrate that high-performance nano-coated glazing effectively mitigates heat build-up within the interior environment, especially along southwest-facing façade members that are most exposed to adverse solar radiation during the hot season.

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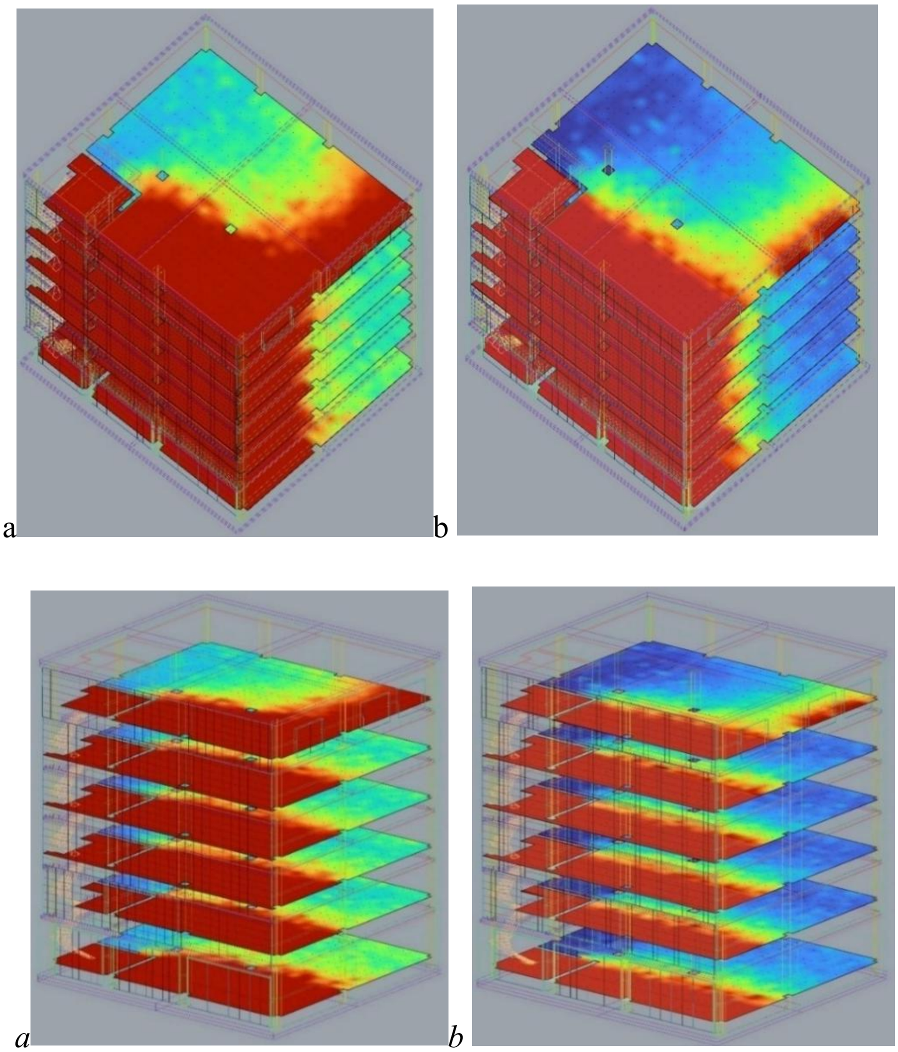

Figure 3-11 Interior solar heat gain visualization: a)standard glazing scenario, b) nano-coated glazing scenario (Source: Researcher).

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Discussion

The simulation outcomes, particularized to a building, prove that silver-based nano Low-e glazing has a huge effect on cooling energy requirement, particularly on the southwest-facing facades that have to endure intense solar radiation. All three case studies were reported to have significant increases in energy performance after the installation of nano-coated glazing, as explained in *Table 3-1*.

A cooling load reduction of 40.64%, the maximum amount in Gawhary Mulk, was expressed in kWh/m²/year: 410.99 kWh/m²/y with standard glazing *(Figure 3-2)* and 243. 95 kWh/m²/y with nano-coated glazing *(Figure 3-3)*. The compact geometry of the building and the full southwest orientation of the building have been credited a lot for this good performance, having maximum solar exposure in the afternoon with little shading. These kinds of conditions enabled the nano-coating to work at the maximum thermal stress, hence maximizing its efficiency.

Conversely, the cooling energy demand reduction in Mix Brand has been less dramatic; cooling EUI demand fell by 245.23 kWh/m²/ year *(Figure 3-5)* to 184.86 kWh/m² / year, a 24.61 percent improvement *(Figure 3-6)*. The comparatively low performance may be attributed to the increased interior volume of the building, complicated functional zoning, and already partial distribution of the facade facade-out exposure, which made the effect of direct solar gain dispersion. Aqary Building showed the middle-3 performance with its cooling EUI dropped to 146.51 kWh/m² /year *(Figure 3-9)* as compared to 205.91 kWh/m²/ year *(Figure 3-8),* which is a 28.84% decrease.

Although the largest of the three buildings, the nano-glazing performed well with partial shading and a more complicated thermal mass, substantiating its worth on a larger structure with several zones. This is corroborated by the results of the simulation given in the hottest months (June-August), as *Table 4-2*. The cooling EUI of Gawhary Mulk at 308.24 kWh/m fell to 182.96 kWh/m, sustaining a decrease of 40.65%, whereas Mix Brand and Aqary Tower recorded comparable trends in decrease, 24.62% and 28.84%.

It is due to these uniform decreases across buildings simulated using common internal loads and local weather conditions that one can be assured that the primary variable was the glazing material itself. Through the study, it is evident that nano Low-E glazing can minimize cooling load by 24% to more than 40% relative to the facade orientation, building geometry, as well as solar exposure.

Overall, the results can confirm that nano-coated glazing is a recommended strategy in southwest-facing facades and hot climates such as Sulaymaniyah city, especially with high window-to-wall ratios and a lack of external shading. The design solution can be used as an ideal passive method to reduce building operational cooling loads due to exposure to high solar radiation.

Although ASHRAE Standard 90.1 does not post any specific values of cooling energy use intensity (EUI), the task of creating an energy benchmark based on simulation is performed by "the U.S. Department of Energy (DOE)", by "the Pacific Northwest National Laboratory (PNNL)", with the use of prototype buildings, which are fully compliant with ASHRAE standards. Based on these prescriptive models, the EUI cooling site of a large office building in a hot climate is approximately 55.4 kBtu/ft². year, or 173.7kWh/m²/year (Pacific Northwest National Laboratory (PNNL), 2021).

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All three case study buildings are nano-coated glazing with simulated cooling loads even below this benchmark, as shown in *Table 3-3*, showing huge performance benefits. For example:

- Gawhary Mulk performed at 243.95 kWh/m²/ year, which is higher than the benchmark (243.95 kWh/m²/ year) by 70.25 70.25 kWh/m 2.
- Mix Brand made 184.86 kWh/m²/ year, which was only 11.16 kWh/m² above the benchmark.
- The lowest score was recorded in Aqary Building, as it achieved 146.51 kWh/m²/year, which is 27.19 lower than the standard score.

These results ensure that nano-coated glass has the potential to successfully decrease cooling loads, construct climate-adaptive and energy-efficient facades that enable fulfilling or even exceeding the international energy standards.

Table 3-3: Annual Cooling Load vs. ASHRAE Benchmark.

Building	Glazing Type	Cooling Load (kWh/m²/year)	% Reduction	Compared to DOE Benchmark (173.7)
Gawhary Mulk	Standard Glazing	410.99	—	**Greatly Exceeds**
	Nano-Coated Glazing	243.95	40.64%	**Exceeds**
Mix Brand	Standard Glazing	245.23	—	**Exceeds**
	Nano-Coated Glazing	184.86	24.61%	**Slightly Above**
Aqary Building	Standard Glazing	205.91	—	**Exceeds**
	Nano-Coated Glazing	146.51	28.84%	**Below Benchmark**

By contrasting nano-coated and normal glazing in a real condition setting, the study achieves its goal and objectives. Moreover, energy savings were correctly estimated through simulations of real buildings oriented between 59.9% and 72.25% to the true north in Sulaymaniyah and the orientation that has the greatest solar exposure in Sulaymaniyah.

Notably, the study does not just concentrate on the theoretical results, but it incorporates real case studies of modern urban architecture within a hot, dry environment through the dynamic simulation tools. The focus on high solar-exposed facades helps fill a substantial gap in the existing knowledge base and offers usable recommendations. The repeatability of the reductions on the diverse building types is a good indicator of the scalability of nano-glass, providing a solid case in front of architects and decision makers interested in energy savings in comparable conditions.

These results directly answer the research questions posed at the outset: nano-coated glazing substantially reduces the cooling energy requirement of southwest façades and lowers solar heat gain compared with standard glazing. This confirms the initial hypothesis and addresses the problem of excessive cooling loads in Sulaymaniyah's hot-summer climate.

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Conclusion

The research examined the effectiveness of silver-based nano Low-E glazing in reducing cooling energy demand for southwest-facing façades in Sulaymaniyah. The main conclusions are as follows:

- The hypothesis is confirmed, as nano-coated glazing significantly reduces cooling energy demand in hot-summer climates, particularly for southwest façades exposed to intense solar radiation.
- Across the three case studies, nano-glass achieved reductions between 24% and 41%, demonstrating its potential as an effective strategy to mitigate operational cooling loads.
- Heat gain contour visualizations showed that nano-glass substantially reduced high-intensity solar zones compared to standard glazing, lowering the extent and severity of interior heat build-up.
- Building form and façade exposure strongly influenced the performance of nano-glass, with compact geometries and fully southwest-oriented façades achieving the greatest efficiency gains.
- When compared to the DOE/ASHRAE benchmark (173.7 kWh/m²/year), the nano-coated glazing cases performed at or near international standards, with Aqary performing below the benchmark and Mix Brand only slightly above.
- The results provide a practical solution to the problem of excessive cooling loads in Sulaymaniyah's commercial buildings, proving that nano-coated glazing is a scalable passive design strategy that enhances energy efficiency while supporting global sustainability goals.

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