THERMAL PERFORMANCE OF NANOMATERIALS OF A MEDIUM SIZE OFFICE BUILDING ENVELOPE

With a Special Reference to Hot Arid Climatic Zone Of Egypt

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Abstract. Global warming is becoming a huge threat in the 21st century. The building is the main contributor to energy consumption and greenhouse gas emissions which play an important role in global warming. Using new technologies provides a step towards a better-built environment. Nanotechnology is an emerging technology that provides innovative materials that integrate with the building envelope to enhance energy efficiency and decrease energy consumption in buildings. Many Nano products are a promising candidate for building thermal insulation and increasing the building's efficiency. This paper aims to reach minimum energy consumption by investigating Nanomaterials thermal performance on a building's envelope in a hot arid climate. An office building in Cairo, Egypt is chosen as a case study. The paper presents an empirical/applied inquiry that is based on a computer simulation using *Design Builder* software. Energy consumption is calculated for different cases; the base model of the office building without using nanomaterials, and several nano models using nanomaterials. The results indicate that the use of Nanomaterials can enhance the thermal performance of the office building and save about 13.44 % of the annual energy consumption of the building.

Keywords: *Office Buildings, Building envelope, Energy consumption, Nano insulation materials.*

ملخص. في القرن الحادي والعشرين، التهديد الكبير هو ظاهرة الاحتباس الحراري. المباني هي المساهم الرئيسي في استهلاك الطاقة وانبعاثات غازات الاحتباس الحراري التي تلعب دورًا مهمًا في ظاهرة الاحتباس الحراري. لذلك، فان استخدام التكنولوجيات الجديدة يعطي خطوة نحو بيئة مبنية بشكل أفضل. تقنية النانو هي تقنية ناشئة في هذا الوقت *وتوفر مواد مبتكرة تتكامل مع بناء الغلاف الخارجي للمبني لتعزيز كفاءة الطاقة وتحقيق خفض كبير في استهلاك طاقة المبني*. تم إجراء دراسة تجريبية، تستند إلى محاكاة الكمبيوتر، باستخدام برنامج Design Builder لمبنى إداري يقع في القاهرة، مصر. وتم بناء نموذج المبنى في برنامج Autodesk Revit. ثم إجراء مقارنة بين استهلاك الطاقة وأحمال التبريد بين نموذج مبنى المكاتب الأساسي مع المواد التقليدية ونموذج النانو باستخدام Nano VIP في السقف وNano aerogel glazing system و Nano Aerogel based renderingفي الجدران. والحصول على نسبة الانحراف حوالي 5٪ بين نموذج الحالة الأساسية وفواتير المرافق للمبنى في عام 2017. تشير النتائج الي أن استخدام مواد النانو مع غلاف المبني يعزز الأداء الحراري للمبني في المناخ الجاف الحار ويظهر أن تكامل مواد النانو مع غلاف المبني يعطي قيمة قياسية علمية وتجريبية منخفضة لانتقال الحرارة . يتم تقليل استهلاك الطاقة بنسبة % 13.44من استهلاك الطاقة السنوي للمبني باستخدام مواد النانو.

الكلمات المفتاحية: *استهلاك الطاقة، الغلاف الخارجي للمبني، المباني الإدارية، تكنولوجيا النانو، مواد العزل بالنانو.*

1. Introduction

Global warming has become a serious threat to mankind. Ratings show that there is an annual increase of 1.8% per year of the impact of global warming through 2050, as such, energy conservation is becoming an imperative issue (Akeiber et al., 2016). The building envelope must have thermal protection as it causes great heat loss (Cui, et al. 2015). New technologies such as "nanotechnology" can solve many problems in the building sector (Atwa, 2015). There is a growing interest in the applications of nanomaterials because of their positive impact on thermal properties and energy efficiency (Boostani, 2016). One of the purposes of this paper is to highlight the benefits of nanomaterials in energy conservation.

2. Nanoarchitecture Applications and Energy Saving

Nanotechnology has many applications in architecture like air purification, water purification, lighting, solar energy, and design. The meaning of nanoarchitecture can be confirmed in nanomaterials and energy sectors (Casini, 2016a).

In the materials sector: 1. Creating Nanostructured materials by adding free or embedded Nano objects with the composite of traditional materials, both solid and liquid as, cement, metals, ceramics, paints to make them nanocrystalline. 2. Using nanocoating for surface treatment of traditional products like glass, ceramic, textiles materials, wood, and PV cells. 3. Modifying the surface structures of conventional products to make them nanostructured. 4. Creating new Nanoporous material such as insulation materials.

In the energy sector: Nanotechnology can provide many benefits across the entire supply chain, from production to distribution (power transmission and heat transfer), storage like; Phase Change Materials.

3. Research Methodology

3.1. SCOPE AND LIMITATIONS

The case study is an office building located in Dokki area, Giza, in Cairo, Egypt. Thermal and energy performance are the key performance criteria. This paper focuses on the effect of Nanomaterials applied on the building envelope that could save more energy. The case study is a comparison between the energy consumption of an office building with and without using nanomaterials.

3.2. METHODS AND TOOLS

The Practical approach comprises two main activities: **First**, Analyzing the case study, measuring energy consumption and heat transfer through the building envelope by using traditional and Nanomaterials. **Second,** Comparing the conventional building envelope materials (base case model) with the Nano thermal models under typical Egyptian-Cairene weather conditions. Autodesk Revit is used to build up the model as it is very efficient, accurate and automatically updates floor plans, elevations, and sections. Design-Builder is used for the simulation process, The Design-Builder program has excellent features including rapid (building modeling, HVAC system built-up), easy to learn, perfect visualization effect and it is support from the ministry of energy of the United States. [Zhao et. al., 2017].

4. Base Case Parameters

The case study is Almoez tower [FIGURE 1], an office building in Cairo, Egypt. The base case parameters are shown in [TABLE 1], [TABLE 2].

Figure 1. The typical floor plan of the study building (left) and Tower sections (right) [http://www.almoez.com/]

TABLE 1. Areas of the tower sections

Total Section Area	The Area	Floors	Tower Sections
1801 m²	335 m²	Ground Floor	Comercial Section
	723 m²	First Floor	
	723 m²	Second Floor	
7114 m²	153 m²	Ground Floor	Administrative Section
	6498-722x9 m²	9 Typical Floor	
	463 m²	Roof	
1310 m²	655 m²	Basement 1	Car Parking
	655 m²	Basement 2	
10225 m²		Total Built up Area	

[http://www.almoez.com/]

TABLE 2. The base case parameters

Office building main parameters	
Location	Giza, Egypt
Building area	655m^2
Occupancy schedules	8:30-3:30
Holidays	Friday & Saturday
No. of occupants	77 per floor
System description	
Electric supply	380V, 3Ph, 50Hz- 220V, 1Ph, 50Hz
Lighting For example, level 9 For example, level 10	LED panels 60*60, LED spots R20 150 (4*18W) lighting fixture- 77(1*26W) spot lighting- 2 (2*36W) lighting fixture -7(exit sign)- 3(1KW) hand dryer. 155(4*18W) lighting fixture- 91(1*26W) spot lighting 2(2*26W) lighting fixture -5 (exit sign) -3(1 KW) hand dryer.
HVAC	VRV HVAC systems - Average Cop:4.9 (heating) Average ERR:4.73 (cooling)
Winter set point	21-22 C
Summer set point	23-24 C
Total capacity	177 tons
Physical characteristics of the building	
Wall U-value for wall	250 mm brick (1.983 watts/m. sq.…k)
Roof U-value for roof	-240 mm reinforced concrete slab -20 mm thermal insulation (blue polystyrene). -20 mm water insulation (BITUMODE Gamma) -100 mm inclined concrete slab (0.401 watts/ m^2…k)
Floors	240 mm reinforced concrete slabs
Glazing All Windows U-value for the window Shading co-efficient Curtain wall U-value for curtain wall	curtain walls elevation (total length of facade 60.5m) single glazed/solar reflective glass 3 watts/ m^2 C 0.811 Double glazing system, Color: blue, 2 layers of glass between them a layer of argon gas. 3.094 watts/ m^2 k
Equipment used per one level	
83 PC (computers)	The unit load:0.8, Operation rate:100%, Total load per day:431.6 KW
8 Dryers	The unit load:1.6, Operation rate:60%, Total load per day:49.92 KW
8 Heaters	The unit load:2.4, Operation rate:70%, Total load per day:87.36 KW
2 Faxs	The unit load:0.4, Operation rate:70%, Total load per day:3.64 KW
3 LCDs	The unit load:0.4, Operation rate:100%, Total load per day:7.8 KW
2 Scanners	The unit load:0.4, Operation rate:60%, Total load per day:3.12 KW
3Coppiers	The unit load:0.8, Operation rate:80%, Total load per day:12.48 KW
13 Printers	The unit load:0.4, Operation rate:100%, Total load per day:33.8 KW

[Applied data is provided by the appointed planning consultant]

5. Validation Tests

The paper will focus on:

1. Glass (non-structural materials).
2. Effective insulation solutions: Vacuum Insulation Panels (VIPs).
3. Highly efficient thermal energy storage materials as Phase Change Materials (PCM).

5.1. SIMULATION FRAMEWORK

Energy simulations give architects some help in their design practice [Tian et al., 2018]. The variables that affect the simulation are the Physical characteristics of the building materials. [FIGURE 2] shows the simulation framework.

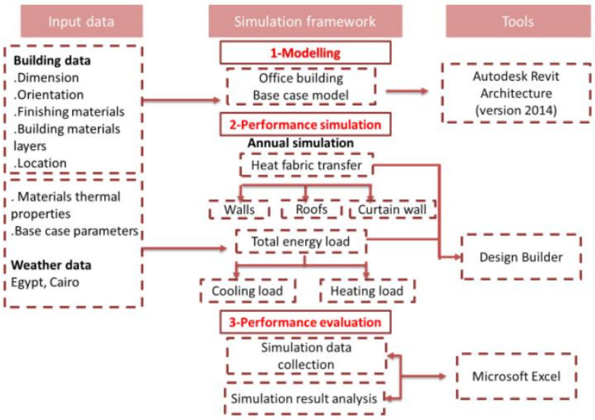

Figure 2. Main simulation process framework and supporting tools.

5.2. BASE CASE SIMULATION MODEL [A]

The input data used for the simulation of model [A] using traditional paint for walls, foam- polyurethane for roof insulation, and a double-glazing system with argon gas in between.

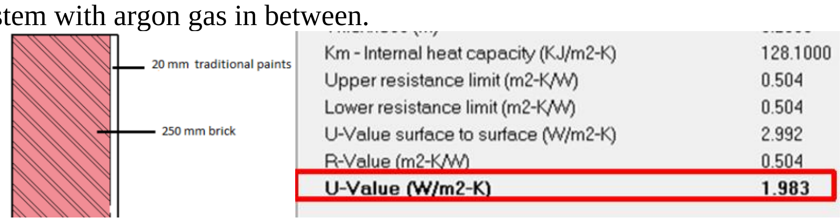

Figure 3. Exterior wall layers and input Simulation data for base case wall

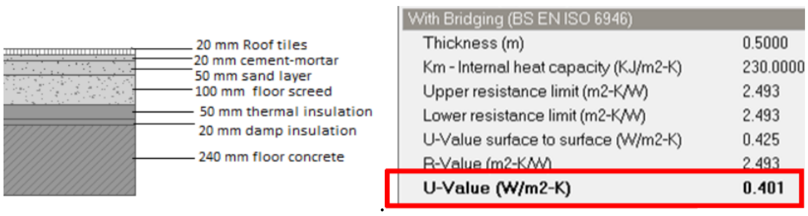

Figure 4. Roof layers and input Simulation data for base case roof.

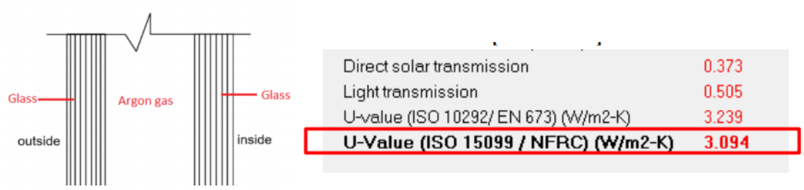

Figure 5. The double-layer glazing with Argon gas in between and input Simulation data for base case curtain wall.

From the simulation, the total energy consumption of the base case Model [A] (using traditional materials) is 2356328.89 Kwh = 235.94 Kwh/m^2, and Cooling load: 18837.58 wh/m^2.

5.3. UTILITY BILLS

The utility bills data in 2018 was used to standardize the base case of the existing building, which can be compared with similar buildings or with target values. The total energy consumption of the base case from utility bills is 247.7 Kwh/m^2. However, after using Design Builder simulation software the calculation is 235.94 Kwh/m^2, leading to a deviation gap of 5%.

5.4. NANO CASE SIMULATION

The following [Table 3] shows the different models used in the simulation.

TABLE 3. Thermal insulation models

Options	External wall	Roof	Curtain wall
Model A	Traditional paints	foam- polyurethane	double glazing
Model B	Nano paints	foam- polyurethane	double glazing
Model C	Traditional paints	Nano VIP	double glazing
Model D	Traditional paints	foam- polyurethane	Nano gel glazing
Model E	Nano paints	Nano VIP	double glazing
Model F	Nano paints	foam- polyurethane	Nanogel glazing
Model G	Traditional paints	Nano VIP	Nanogel glazing
Model H	Nano paints	Nano VIP	Nanogel glazing

5.4.1. Nano Model [B]: Exterior walls

The input data used for simulation of model B are shown in [FIGURE 6].

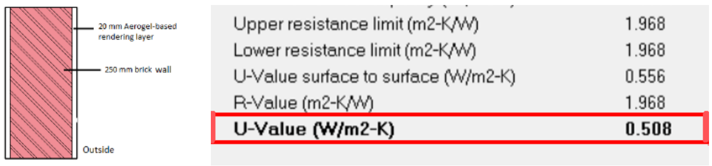

Figure 6. Exterior Nano wall layers and simulation input data for wall with Aerogel-based rendering of model B.

From the simulation: the total energy consumption is 234.01 Kwh/ m^2 and the Cooling load is 82557.04 wh/ m^2.

5.4.2. Nano Model [C]: Roof

The thermal resistance of VIP is about 10 times higher than the same thickness of conventional polystyrene (Bozsaky, 2016.).

The input data used for simulation of model C are shown in [FIGURE 7].

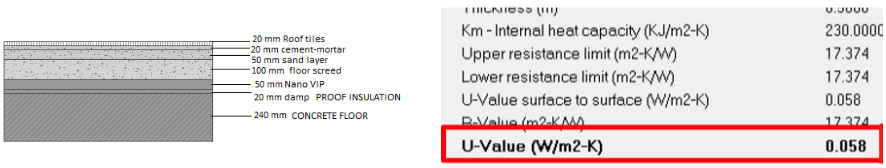

Figure 7. Nano Roof layers and Simulation input data for the roof with Nano VIP of model C.

From the simulation: the total energy consumption is 232.08 Kwh/ m^2 and the Cooling load is 87715.5 wh/ m^2.

5.4.3. Nano Model [D]: Curtain walls

The input data used for simulation of model D are shown in [FIGURE 8].

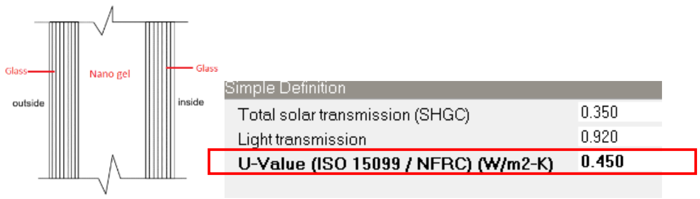

Figure 8. Nano Aerogel glazing two layers of glass-filled by Nano gel and Simulation input data for curtain wall with nanogel glazing of [model D].

From the simulation: the total energy consumption is 210.63 Kwh/m^2 and the Cooling load is 85006.25 wh/m^2.

5.4.4. Nano Model [E]: Aerogel plaster for external walls with Nano VIP for the roof.

From the simulation: the total energy consumption is 230.69 Kwh/m^2 and the Cooling load is 88886.55 wh/m^2.

5.4.5. Nano Model [F]: Aerogel-based rendering for external walls and nanogel glazing.

From the simulation: the total energy consumption is 208.71 Kwh/m^2 and the Cooling load is 80095 wh/m^2.

5.4.6. Nano Model [G]: Nano thermal insulation and nanogel glazing.

From the simulation: the total energy consumption: 206.24 Kwh/ m^2 and the Cooling load is 81739.2 Wh/m^2.

5.4.7. Nano case study Model [H]: Aerogel plaster for external walls with Nano VIP for roof and nanogel glazing.

From the simulation: the total energy consumption is 204.22 Kwh/m^2 and the Cooling load: 75006.3 wh/m^2.

6. Discussion and Conclusions

6.1. MONTHLY VARIATION IN COOLING

Models [A], [B], [C], and [E] show higher consumption to cooling load compared with the other options and reduced by using Nano gel glazing in Models [D], [F], [G] and [H], in [Figure 9].

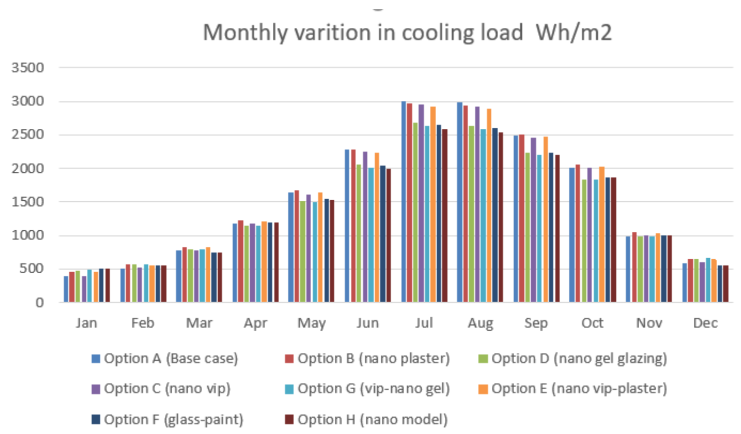

Figure 9. Monthly variation in cooling load.

6.2. THE ANNUAL ENERGY CONSUMPTION

In [Figure 10], it is noticed that models [B] and [C] save in annual energy consumption only 0.82% and 1.64% respectively, while model [D] saves about 10.7%.

In models [G] and [F], there is a saving in energy by 12.6% and 11.5% respectively, and in model [E] the saving is about 2.22% only.

The Model [H] makes a saving of 13.44% in annual energy consumption.

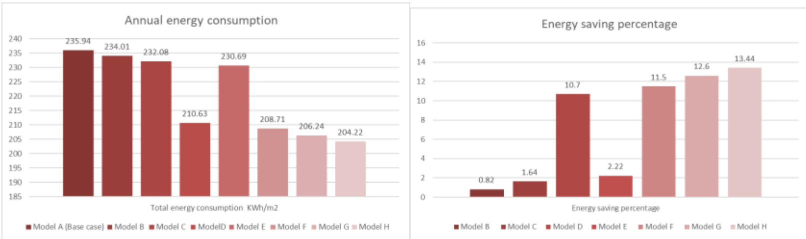

Figure 10. Annual energy consumption of various insulation models and Energy-saving percentages.

6.3. THERMAL TRANSMITTANCE COEFFICIENT

The study concludes that the U-value of Nano aerogel-based rendering caused an energy reduction by almost 3.9 times less than the traditional paint. Nano VIP caused an energy reduction by almost 7 times less than traditional insulating material and Nano gel glazing is caused an energy reduction by almost 7 times less than double glazing [FIGURE 11].

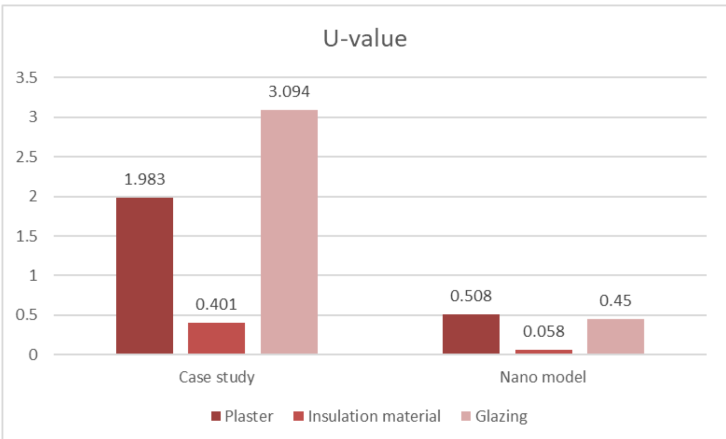

Figure 11. U-values

6.4. THE HEAT TRANSFER THROUGH WALLS, ROOF, AND CURTAIN WALLS

The thermal performance of Nano aerogel-based rendering in walls reduces the heat exchange through the outer envelope in Models [B], [E], and [F] by 68.18%, 66.5%, and 62.7% respectively compared to model [A] [Figure 12a].

By using (VIP) in roof, the heat transfer was reduced by 82%, 81.5% and 81.4% in Models [C], [G], and [E] compared to model [A] [Figure 12b].

The heat exchange process through the Nanogel glass is reduced in models [D], model [G] and model [F] by 30.4%, and Model [H] by 33.7% [Figure 13].

Figure 12a. Heat transfer through walls and *b* Heat transfer through roofs.

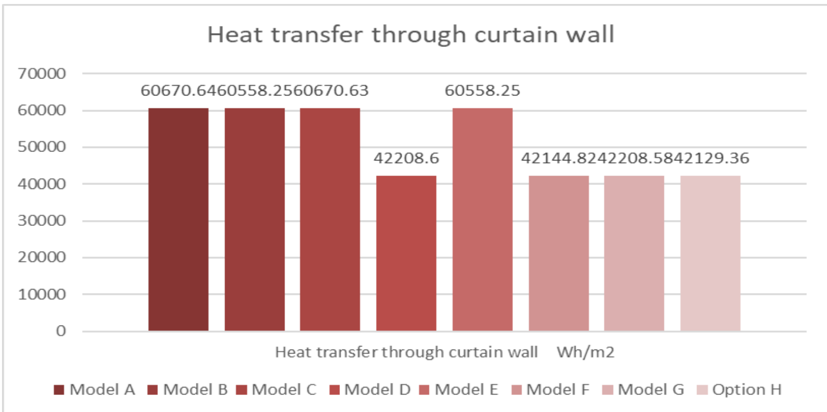

Figure 13. Heat transfer through the curtain wall.

Finally, by using nanomaterials we can reduce the cooling energy demand and total energy consumption of the building.

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