Applying Nano Coatings on Buildings to Improve Thermal Performance & Energy Efficiency: A Simulation of a Health Care Building in Egypt

Rowan Mohamed Mansour, Nanes EL-Sayad, & Lamis Saad El-Din El-Gizawi
Faculty of Engineering, Mansoura University, Mansoura, Egypt
rowanmansour_92@hotmail.com
Nanees_elsayyad@mans.edu.eg
lamiselgizawi@mans.edu.eg

Received	Reviewed	Revised	Published
17.06.2023	26.06.2023	16.09.2023	30.09.2023

https://doi.org/10.61275/ISVSej-2023-10-09-01

Abstract

Building energy consumption is one of the biggest challenges facing energy consumption. Therefore, modern technologies can be effectively used to reduce global energy consumption. Nano-coating is one of the modern methods that has been used to improve energy efficiency. However, many recent studies have looked only at integrated Nano coatings on walls over a short time.

In this context, this research explores the long-term thermal behaviour of building walls to comprise Nano layers. The wall's performance under various exterior weather conditions is tested with and without the Nano layer. The techniques employed were to examine it in a healthcare building in Mansoura city in Egypt in the hot summer season. Ansys Fluent is utilized to simulate long-term thermal behaviour for building walls with and without a Nano coating layer.

The results showed that introducing Nano-coatings in the wall constructions will reduce inner heat flux and achieve an inner temperature less than before using any Nano coating. Based on summer simulations, the average expected indoor wall temperature was 29.7°C for the wall without Nano coating and 27.1°C for the wall with Nano coating. Furthermore, using a 3-mm thick Nano-coating on the wall reduces 52.5% of the total energy gain during the summer.

Keywords: Nano-coating, thermal performance, energy, wall, indoor, summer months.

Introduction

Recent studies have found that buildings account for more than 40% of energy consumption worldwide (Cao, Bui and Kjøniksen, 2019). Additionally, air conditioning for buildings uses more than 50% of this energy (Al-Absi et al., 2020). As a result, numerous research initiatives have been made to use Nano-coating to lower energy consumption in healthcare buildings. Nano-coating is the highest-performance material in the building construction. It presents remarkable benefits when comparing the environmental coating materials in the construction industry because of its self-assembly effects (Boostani and Modirrousta,2016).

The use of Nano-materials in construction is costly, but can be made cost effective due to long-term reliability gains. Consequently, Nano-materials integrated into a building envelope are seen as good economic choices that significantly reduce costs while improving the built environment's efficiency and solving future environmental concerns (Lalbakhsh, 2011). Nano-technology has the ability to fundamentally modify our built environment and how we live; it is the most transformative technology we have ever created (Xiaotu, 2010).

Application of Nano-material in Architecture

As opposed to the chemical or physical principles they are built on, Nano-technology illustrates the characteristics of the Nano-particles and their applications on surfaces, such as self-cleaning and air purification. These applications, like photocatalysis, demonstrate many inventive and creative design strategies with practical examples demonstrating how Nano-coatings can increase energy efficiency. Following are a few examples of practical applications used in architecture:

- Anti-Graffiti
- Self-Cleaning
- Easy to Clean
- Air Purifying
- Anti-Fogging
- Aerogel Insulation
- Thermal Vacuum insulation (VIPs)
- Phase Change Material (PCM)
- Fire Proof
- Anti-Bacterial

The Role of Nano coating

Nano-coatings are thin layers applied to the surface of a material to enhance its surface characteristics and appearance. This broad category includes coatings that are used to increase a base material's durability or wear characteristics, offer corrosion resistance, or give other forms of protection. They can also be modified characteristics such as colour, reflectivity, stickiness, and various other things. Conventional coating materials used in the building industry offer remarkable resistance to environmental pollutants because of their ability to self-assemble.

There are many Nano-coatings for international companies, including Nano-coat, which saves energy up to 50% of air conditioning consumption, ANZ paint, which saves 20% of the energy used in interior spaces and disperses more than 80% of sunlight, and Super-Term coating provides energy from 20%–50% and reflects 95% of the sun's rays.

Nano-technology-based thermal insulation materials such as Nano $CaCO_3$ are environmentally and economically viable, as they have the potential to be produced using waste products from the cement manufacturing process, as well as generate revenue for the industry. Traditional thermal insulation materials have three ways of transmitting heat: thermal radiation, thermal conduction, and heat flux. In Nano-technology-based thermal insulation materials, one or more pathways of heat transmissions are impeded. Thus, they can reduce the building structures' heat transmission coefficient. The following is a common heat transfer coefficient, Eq. (1):

$$U = \frac{1}{\frac{1}{h_i} + \sum_{i=1}^{n} \frac{d_i}{\lambda_i} + \frac{1}{h_e}} \qquad (1)$$

U is the heat transfer coefficient [W/m2K]; d_i is the individual structural layer thickness [m]; λ_i is the individual thermal conductivity of each structural layer [W/m K]; h_i the internal convective heat transfer coefficient [W/m^{2}K]; h_e is the external convective heat transfer coefficient [W/m^{2}K].

Nano coats consist mainly of micronized metal binders from derivatives of calcium carbonate (CACO3) and nano-size ball fillers, each containing a vacuum to prevent heat and sound transfer.

Importance of Nano Coatings for Healthcare Buildings

Everyone could be a potential user of healthcare facilities. Thus, it is essential to create a healthy environment that enhances the physical and psychological health of all users. It is insufficient to improve physical, psychological, and mental well-being using healthcare and medicine alone. In fact, it is essential to focus on the final interior design from the beginning of the material selection stage to the environmental and health design, which plays an important role in the healing process. Walls play an essential role in the interior finishes of healthcare buildings. Through them, the internal temperature can be controlled; thus, energy consumption can be rationalized and cost reduced. Additionally, using self-cleaning Nano-coatings reduces maintenance operations by creating a suitable and hygienic environment for the patients, staff, and their families.

In this context, this study examines healthcare facilities according to the nature of their work and the fact that they operate at all times, with the highest energy intensity per square foot than any other building (Bawaneh et al., 2019). It chose Nano-coatings for building wall structures as a case study to raise energy efficiency in healthcare buildings by improving thermal performance and achieving thermal comfort for the patients.

The primary goal of this research was to reach the least energy consumption of the Nano coating of the building wall envelope in healthcare buildings, which is the most building in energy consumption.

Literature Review

Energy conservation greatly depends on the thermal performance of the building envelope (Feng et al., 2016). Building envelope analysis is becoming more and more common. This method evaluates the physical separation between a building's interior and exterior surroundings. New construction methods and materials, laws and regulations, rising costs of energy, and growing occupant health concerns are all contributing to this demand. Reducing heat transfer through the building envelope is essential to reduce the requirement for internal heating and cooling. Utilizing the building envelope can reduce the energy needed for heating and cooling. In colder climates and hotter climates, respectively. Regardless of temporary external conditions, a building's envelope is the primary aspect that governs and affects the quality of the inside environment (Sadineni et al., 2011).

The areas of envelope components (external walls), site-related characteristics and U-values of envelope materials, such as solar irradiation and temperature, are the inputs to the envelope-related energy demand (Granadeiro et al., 2013). To achieve optimum performance of buildings, an emphasis must be given to the building envelope's thermal efficiency and sustainability. Moreover, investigations have indicated that building envelopes contribute between 50 and 60 percent of the total heat gain in buildings and more than 50 percent of the embodied energy distribution in significant building elements in residential buildings (Mwasha et al., 2011). In comparison to hot temperatures, cold regions have seen the majority of research into nano-materials as insulation options. Ihara and Gao (2015) recently looked into how the spandrels of three office buildings in hot climates were affected by a translucent Nano gel granulate glazing system. The simulation's findings suggest that Nano gel facades might be more energy-efficient than double-glazed ones.

Rashawn, Farag, and Mostafa (2013) tested the Nano thermal model and measured the rate of heat transfer in comparison to conventional building envelope materials (baseline model) under typical Egypt-Aswan climate conditions to explore the energy efficiency of integrating building envelopes with Nano-materials. When compared to the performance of the baseline model, the results demonstrate that the addition of Nano-materials can increase the energy efficiency of building wall constructions by 40%. Abdelrady, Abdelhafez and Ragab (2021) Focused on how the energy consumption of a residential building in New Aswan City, Egypt, was affected by Nano gel glazing in the windows and Nano VIPs in the exterior walls. Nano VIP walls and Nano gel-glazed windows are being compared; the study's base case included 120 mm brick walls and 3 mm glass windows. The Design-Builder is used to simulate energy efficiency. They discovered that the layer of Nano gel sandwiched between two layers of glass and two layers of argon significantly reduced the annual energy usage to 26%. The effectiveness of five alternatives to increase building insulation and energy efficiency was examined. El-Bony (2021) used a simulation to examine the impact of employing Nano-based materials on the building's energy consumption in comparison to traditional materials, one of the primary factors affecting the construction. In order to assess the effects of using these materials on the energy efficiency of buildings, this study compares the energy consumption of conventional construction materials and Nano-based materials, such as fibre-reinforced aerogel blankets used as thermal insulation and Nano gel windows. Using Nano-based building materials significantly decreased overall energy consumption, reaching 7.42% (216479 KWh) and 10.78% (137544 KWh) for cooling loads. It has been determined that using Nano-based building materials for all building components, including coatings and opaque elements, will result in significant energy savings, lowering the building's operating costs and lessening its negative environmental impact. Ali et al., (2020) focus on coating buildings' windows glass and the associated impact on energy consumption, using Design Builder as the modelling tool. A public housing building located in Sabah Al-Ahmed district, Kuwait, was chosen as the study's test case. As the glass coating materials, commercial glaze Nano coating, Nano-ceramics, and 30% tented film were selected. For a period of one year, the modelling investigated the building's energy usage under the aforementioned glazing condition. The multi-layer Nano coating on the glass helped reduce the building's annual electricity consumption by 9.6%, and the results also showed that it had a 14.5% lower light transmission than the original house design. For government decision-makers, these findings are deemed to be extremely important, especially when considering the energy efficiency of buildings in future public housing developments. The current study focused on applying Nano coatings on healthcare buildings to raise thermal performance and energy efficiency in Mansoura city in Egypt. The base case of this research analyses the long-term thermal behaviour of building walls using Nano layers by Ansys Fluent.

Research Methods

The current investigation begins with a numerical model validation experiment. The impact of using Nano coating for different thicknesses is then investigated using numerical results. The hot summer weather of Mansoura, Egypt (31° 2' 16.5588" N, 31° 22' 53.4828" E) is used for this simulation. Three different modeling approaches are utilized and compared in a numerical analysis. After validating, the simplified model yields reliable results, a lengthy simulation is then carried out. The literature applies this simplified model (El-Abbasy,2019).

The energy simulation was carried out using Ansys Fluent software (version 2021), which is easily used in heat transfer problems involving conduction, convection, and radiation. Diagrams, tables, and charts are used to display all the results. Ansys Fluent is utilized to simulate long-term thermal behavior of a building wall with and without a Nano coating layer.

Theoretical basis

In this paper, different numerical simulations were performed to evaluate the thermal performance of conventional paints and Nano coating paints in summer:

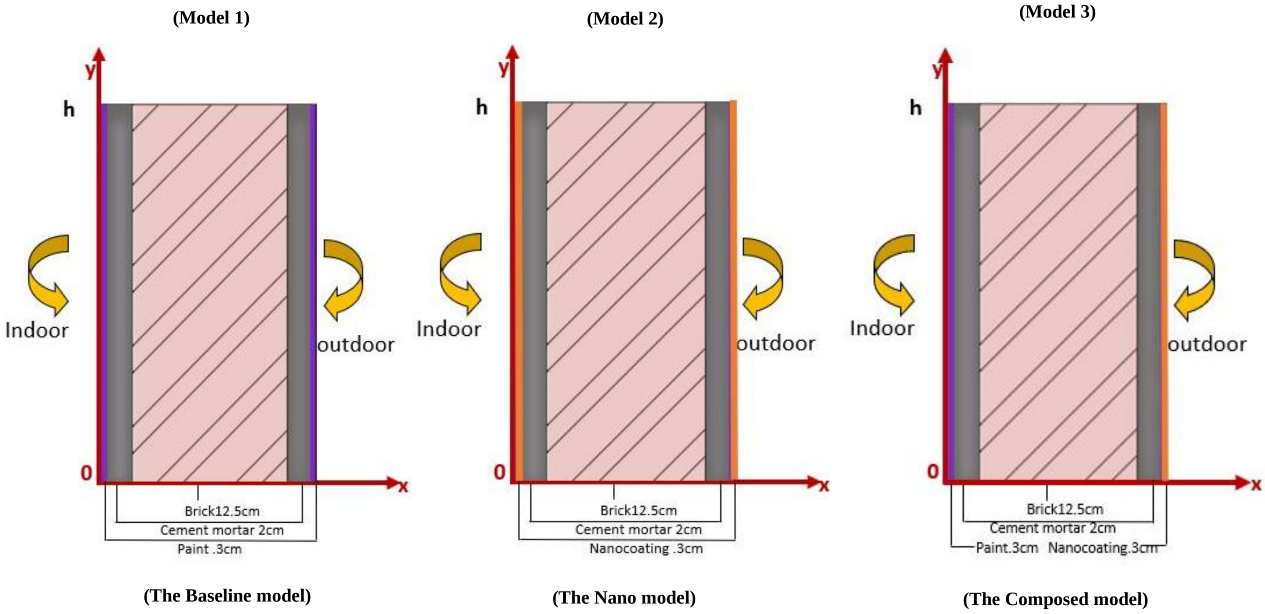

Fig. 1: Schematic of the model's materials
Source: Author

Table 1: Thermal physical parameters of wall materials.

Material	Thickness	Thermal conductivity	Specific heat	Density
Nomenclature	d	λ_i	cp	ρ
Unit	(cm)	(W/m. k)	(j/kg. k)	(kg/m^3)
Traditional paints	0.3	0.57	2835	1162
Nano coating	0.3	0.15	919	1250
Cement mortar	2	0.6	837	1858
Brick	12.5	0.72	829	1850

The transient heat conduction in the solid layers of the wall structure is combined in this model. There are five basic layers in the wall construction under investigation. The material scheme for the models is shown in Fig. 1. With time, a realistic example of the outdoor weather, including ambient temperature, solar radiation and wind speed, becomes available. These weather statistics were found on the website climate. one building. Org."

The baseline Model (1) for the traditional building materials is as follows.

- Outer layer: traditional paints-cement layers 2.3 cm thick.
- Brick masonry layer: 12.5 cm thick.
- Internal layer: traditional paints-cement layers 2.3 cm thick.

Nano model (2) (Nano coating building materials):

- Outer layer: Nano coating-cement layers 2.3 cm thick.
- Brick masonry layer:12.5 cm thick.
- Internal layer: Nano coating-cement layers 2.3 cm thick.

Composed model (3) (Nano coating and traditional paint building materials):

- Outer layer: traditional paints-cement layers 2.3 cm thick.
- Brick masonry layer: 12.5 cm thick.
- Internal layer: Nano coating-cement layers 2.3 cm thick.

The governing equations for each layer of the construction wall are as follows:

- The analytical model is constructed using the following presumptions to guarantee simulated outcomes and streamline the intricate heat transfer methods between each layer.
- Heat transmission is considered to occur solely in the thickness direction because it always takes place between the inner and outer surfaces or one-dimensional heat transfer.
- The physical qualities of other solid materials are constant.
- There is negligible thermal contact resistance between layers.

Given the differences in heat transfer between paints and other materials, mathematical models were developed to express their heat transfer. Due to energy conservation, The heat transmission in the layers is defined by Eq. (2) (Susa et al., 2016).

$$\rho_i c_{pi} \frac{\partial T_i}{\partial_t} = \lambda_i \frac{\partial^2 T_i}{\partial x^2} \quad (2)$$

For the interface between the two layers of materials, its heat is conserved, as given by the Eq. (3):

$$-\lambda_i \frac{\partial T_i}{\partial x} = \lambda_J \frac{\partial T_j}{\partial x} \quad (3)$$

The bottom and top surfaces (y = 0 and y = h) had adiabatic bounds applied to them, whereas the outer and inner surfaces (x = 0 and x =) had convective heat transfer boundaries, which can be described by Eqs. (4) and (5).

$$-\lambda \frac{\partial T}{\partial y} \Big|_{y=o} = 0,\ y=0 \quad -\boldsymbol{\lambda} \frac{\boldsymbol{\partial T}}{\boldsymbol{\partial y}} \Big|_{y=h} = 0,\ y=h \quad (4)$$

$$-\lambda \frac{\partial T}{\partial x} \Big|_{x=o} = h\ out\ (Tout – T\ w, out) + \alpha\mu\ X=0 \quad (5)$$

$$\lambda \frac{\partial T}{\partial x} \Big|_{x=\delta} = h\ in\ (T\ w, in – T\ in)\ x=\delta$$

The initial condition is represented in Eq. (6):

$$T(x,t)|t = 0 = T_0 \quad (6)$$

These two temperature measurements are assumed to be equal in this study (Li et al, 2019; Zhu et al., 2018). As a result, the numerical models employing the same transient temperature profile (t) include the value of G. The temperature profile, surface absorptivity, G(t), and hex(t) all influence how much the ambient temperature outside changes (t). The temperature profile is referred to as the Sol-air temperature profile. It is calculated using the formulas below:

Conducted in step #3.

$$T_{sol-air}(\mathrm{t}) = \frac{\mathrm{G(t)} \times \rho\mathrm{s}}{\mathrm{hout(t)}} + \mathrm{Ta\ (t)} \quad (7)$$

It is important to note that the following correlation (Silva ,et al, 2016) is utilized to determine the exterior convection heat transfer coefficient, hex(t), driven by the wind speed effect:

$$H_{out}(t) = 5.62 + 3.9 \times U_{wind}(t) \quad (8)$$

Where U wind is the wind speed in m/s. At the interfaces between each pair of adjacent layers in a thermally linked boundary with extremely little thermal contact resistance, the condition is applied. The study framework for the simulation is shown in Fig. 2. First, data from literature results made available in this work, as in step No.1, are used to validate the three proposed models. The third step then investigates the effect of Nano thickness on the thermal performance of building wall structures and compares the Nano model to the constructed model. In the third step, a long-term simulation of the summertime weather conditions in Mansoura is carried out to compare the thermal building performance between walls with and without Nano layers.

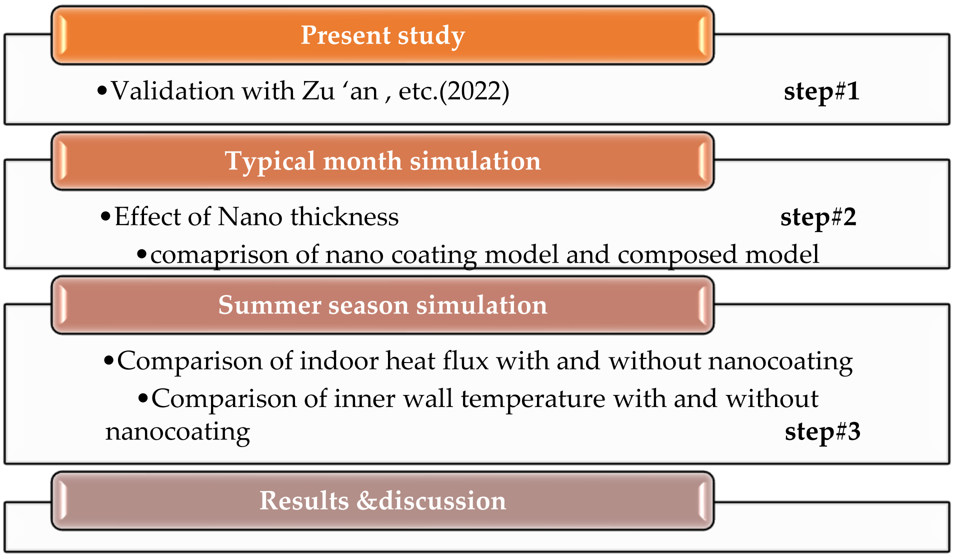

Fig. 2: Flow diagram of the study
Source: Author

Model Validation

Current model has been validated using literature results (Liu et al., 2022).

The simulation period (July 30 to August 5) examined the thermal behaviour of the walls while maintaining an inner air temperature of 26°C. The top and bottom surfaces of the numerical model received adiabatic bounds, with connective heat transfer coefficients of 8.7 W/m2. k for the inner surface (h in) and 19W/m2. k for the outer surface (h out). Figure (3) contrasts the present value of the numbers with the numbers obtained from Zu 'an, etc. The highest relative difference for the solid brick wall, between the numerical results in Zu 'an etc. and the current simplified model is about 7 % and occurs at the 80 hour mark.

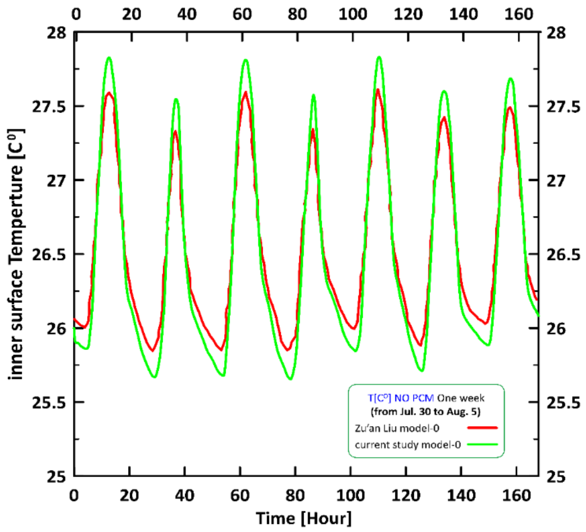

Fig. 3: Comparison of the current numerical results with the numerical simulation results
Source: Author

The overall results of this section are divided into three primary subsections. The impact of Nano thickness on the thermal performance of building construction walls is examined in the first subsection. The Nano model and composite model are contrasted in the second subsection. The building wall's long-term simulation with and without nano-technology is examined in the last subsection.

1. Nano Thickness's Effect

In this section, we discuss how the thickness of Nano coating affects the temperature and heat flux inside a certain region. The effects of the thickness of the Nano coating layer on the inner heat flux and inner surface temperature are shown in Figs. (4) and (5). Three Nano coating layers, measuring 2 mm, 3 mm, and 4 mm in thickness, are compared. Results indicate that increasing the Nano coating thickness decreases the interior heat flow and indoor wall temperature. As a result, we will not increase the thickness because it will increase the cost.

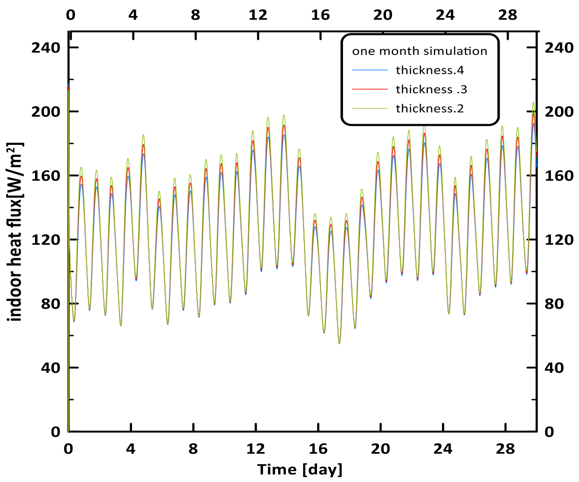

Fig. 4: Daily variation of inner heat flux for different thicknesses using solidification model
Source: Author

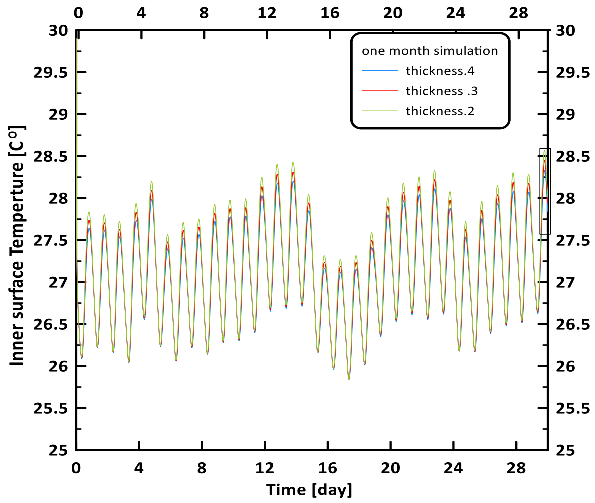

Fig. 5: Daily variation of inner wall temperature for different thicknesses using the solidification model
Source: Author

2. Comparison between Nano model (2) and composed model (3)

The approach treats Nano coatings and traditional paints as solid materials with variable specific heat capacity as a function of temperature in this subsection. To make this comparison, we simulated the two models for one month in terms of interior heat flow and indoor wall temperature, and the results were compared, as shown in Figures (6) and (7). The results show that the total energy for the wall without Nano coating was 21000.3 w/m2.day. The total energy for the wall with Nano Coating was 10906.74 w/m2.day. Using Nano coating in the wall structure reduces 48 % of the total energy gain during the summer.

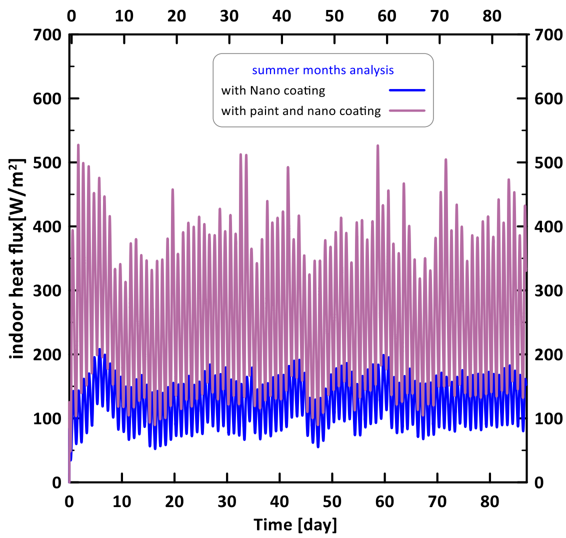

Fig. 6: Daily variation of inner heat flux with Nano coating and composed coating
Source: Author

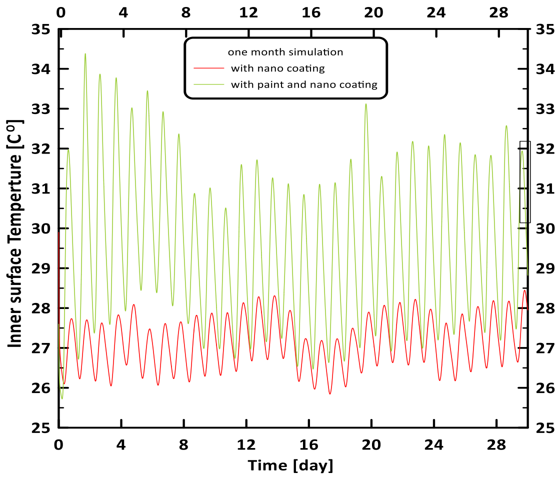

Fig. 7: Daily variation of inner wall temperature with Nano coating and composed coating
Source: Author

3. Long-term simulations

The climate in Mansoura, Egypt, during the summer, is the focus of this subsection. When compared to a wall without Nano, utilizing Nano coating in the building structure will improve thermal performance more. The months that are used in the simulation are June, July, and August, during which the maximum ambient temperature, wind speed, and solar radiation reached 42.7°C, 13 m/s, and 1004 W/m2, respectively.

The daily variation in inner heat flux and inner wall temperature for summer months are depicted in Fig. (8) and (9) accordingly. The findings demonstrate that with Nano coating, indoor heat flow and daily anticipated interior temperature are significantly lower than without coating.

For the three months, the expected average indoor temperature was 27.1° C for the wall with Nano coating and 29.7° C for the wall without Nano coating. The total energy for the wall with Nano coating is lower than for the wall without it, falling from 23000.595 to 10906.74 w/m2.day.Using Nano coating in the wall structure reduces 52.5% of the total energy gain during the summer.

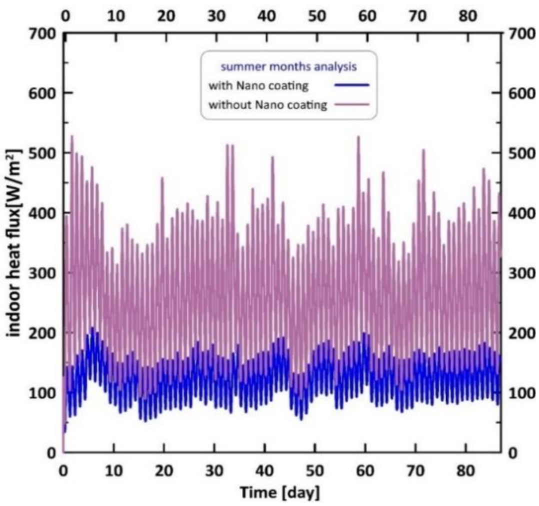

Fig. 8: Daily variation of inner heat flux with and without Nano coating
Total energy transfer
=23000.6(W/m2). day (without Nano coating)
=10906.74(W/m2). day (with Nano coating)
Source: Author

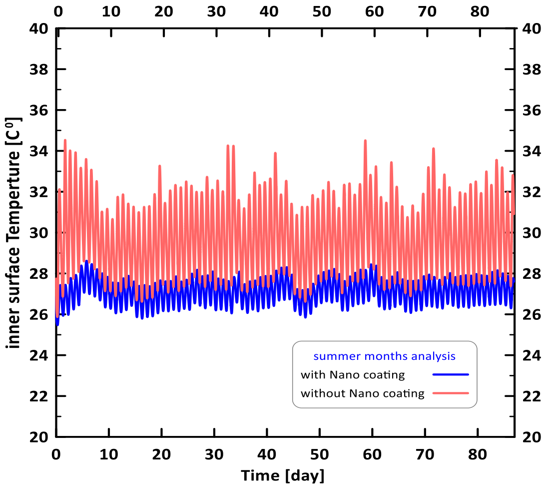

Fig. 9: Daily variation of inner wall temperature with and without Nano coating
Average indoor wall temperature=29.7℃ (without Nano coating)
=27.1℃ (with Nano coating)
Source: Author

Conclusions

This study compared the thermal performance of building wall structures painted with conventional paint with Nano coating. Walls with and without the Nano coating layers were compared in various outdoor weather scenarios. It is contrasted with a single thermal model. To test the model, the research used data from the literature. Additionally, it contrasted standard paints with Nano coatings with various thermal characteristics and thicknesses. The evaluation is based on a comparison of the inner heat flux and the inner wall temperature. According to the findings, applying Nano coating to wall constructions lowers indoor heat flux and reduces inner wall temperature closer to what is needed for indoor comfort. In order to examine the long-term thermal behaviour of the wall with and without Nano coating, a model is finally run throughout the summer.

The results show that adding Nano coating to the wall construction reduces indoor heat flux and reduces the temperature of the interior wall to a level closer to that of the interior air. The average projected inside wall temperature for a wall without a Nano coating was 29.7°C, compared to 27.1°C for a wall with a Nano coating, due to summer models. Additionally, the overall energy transmission drops from 23000.595 w/m^2.day for the wall without a Nano coating to 10906.74 w/m2/day for the wall with one. By using a 3-mm thick Nano coating in the wall's structure, all of the energy usage during the summer is reduced by 52.5%. Using Nano coatings can improve a building's thermal performance and reduce energy consumption, especially in the summer.

The strengths are using the Ansys Fluent program, which is characterized by high accuracy in calculating energy efficiency and thermal performance in any weather in long-term simulation and an interesting topic in Nano-coatings in HealthCare buildings, which need to save energy because it is working 24 hours every day.

This study leads the way in using nano-materials in construction to increase a building's energy efficiency. In order to determine whether using these materials in the present and the future is feasible, more in-depth economic studies must be conducted on the development of nano-particles used in the thermal insulation of buildings, particularly in view of the impending climate change.

Nomenclature

U	The heat transfer coefficient	(W/m^2. K)
d_i	The individual thickness for each structural layer	(m)
λ_i	The individual thermal conductivity for each structural layer	(W/m^2.k)
h_{in}	Convective coefficient of heat transfer for inner surface	(W/m^2.k)
h_{out}	Convective coefficient of heat transfer for outer surface	(W/m^2.k)
ρ_i	Density	(kg/m^3)
T_i	Material Temperature	(^{o}c)
C_{pi}	Specific heat	(j/kg. k)
Ta	outdoor ambient temperature	(k)
T_{solair}	Sol-air temperature	(k)
U_{wind}	The measurement unit for wind speed	(m. s^{-1})
G	The solar radiation incident on the horizontal surface.	
α	Wall absorptivity	
h	Wall height	(m)
t	time	(s)

Subscripts:

X	wall thickness direction
Y	wall height direction
Win	inner surfaces
Wout	outer surfaces
i	representatives Nano material or traditional paint

References

Abdelrady, A., Abdelhafez, M.H.H., Ragab, A. (2021) Use of Insulation Based on Nano-materials to Improve Energy Efficiency of Residential Buildings in a Hot Desert Climate. Sustainability ,Vol. 13, 5266. DOI:10.3390/su13095266.

Al-Absi, Z.A., Hafizal M., Ismail, M., Mardiana, A. & Ghazali, A. (2020) Peak indoor air temperature reduction for buildings in hot-humid climate using phase change materials, Case Stud. Therm. Eng., Vol. 22, no. October, pp. 100762 . DOI:10.1016/j.csite.100762.

Ali et al., (2020) Nano-coating: An Energy Efficient Solution Towards Reducing Buildings Electrical Consumption In The State Of Kuwait. Advances in Science and Engineering Technology International Conferences.DOI:10.1109/ASET48392.9118309.

Bawaneh, K., Nezami, F.G., Rasheduzzaman, M. & Deken, B. (2019) Energy consumption analysis and characterization of healthcare facilities in the United States, Energies, Vol. 12, pp. 19 . DOI: 10.3390/en12193775.

Boostani, H. & Modirrousta, S. (2016) Review of Nano coatings for building application Procedia Eng., Vol. 145, pp. 1541–1548 . DOI: 10.1016/j.proeng.04.194.

Bozsaky, D. Thermal insulation with nano-technology based materials, Internationals Symposium "Event materials": Material technology und Event innovation (online). at:https://www.researchgate.net/publication/289128493_Thermal_Insulation_with_Nanotechnology_Based_Materials (accessed March 3 2022).

Cao, V.D., Bui, T.Q. & Kjøniksen, L. (2019) Thermal analysis of multi-layer walls containing geopolymer concrete and phase change materials for building applications, Energy, Vol. 186, pp. 115792 . DOI: 10.1016/j.energy.2019.07.122.

CMB-ChemicalsforModernBuilding,CMBGROUP (online).Available at: https://www.cmbegypt.com/cmb/datasheets/en/pdf/1-Construction%20 Paints/4-Exterior%20 Paints/Nanocoat.pdf /(accessed March 3 2022)

El-Abbasy, R.A. (2019) Review article nano-technology applications in interior design of hospitals, Int. J. Eng. Res., Vol. V8, no. 07, pp. 313–319.DOI: 10.17577/ijertv8is070160.

Elbony, F.A.(2020) Nano-technology and energy efficiency in buildings Nano based insulation materials . journal of the Egyptian society of engineer s,Vol.59,no.1,pp.28-33.

Feng, G., Shaa, S. & Xu, X. (2016) Analysis of the building envelope influence to building energy consumption in the cold regions , Procedia Engineering ,Vol.146 ,pp. 244 – 250.DOI: 10.1016/j.proeng.2016.06.382.

Granadeiro, V., Joa,˜o C., Vı´tor, L. & Jose, D. (2013) Envelope-relatedenergy demand: a design indicator of energy performance for residential buildings in early design stages. Energy Buildings,pp. 215–223.

GreenNanotechnology,INTERBUILDTODAY(online).Available at:https://ibtoday.expertsudan.com/2019/07/31/nano-technology-3/ (accessed March 3 2022)

Ihara, T., Gao, T. & Jelle, B.P. (2015) Aerogel granulate glazing facades and their application potential from an energy saving perspective. Appl. Energy,Vol. 142,pp. 179–191.

Lalbakhsh, E. (2011) Nano-material for smart future buildings , Int. Conf. Nanotechnol. Biosens., Vol. 25, pp. 80–83.

Li, Y. et al. (2019) Heat storage and release characteristics of composite phase change wall under different intermittent heating conditions," Sci. Technol. Built Environ., Vol. 25, no. 3, pp. 336–345. DOI: 10.1080/23744731.2018.1527137.

Liu, Z., Hou J., Huang Y., Zhang J., Meng X. & Dewancker, B.J. (2022) Influence of phase change material (PCM) parameters on the thermal performance of lightweight building walls with different thermal resistances, Case Stud. Therm. Eng., Vol. 31, no. January, pp. 101844 . DOI: 10.1016/j.csite.2022.101844.

Mwasha, A., Williams, R. & Iwaro, J.(2011) Modeling the performance of residential building envelope; The role of sustainable energy performance indicators. Energy Buildings ,Vol.43,pp. 2108–2117.

Rashwan, A., Farag, A. & Moustafa ,W. S. (2013) Energy performance analysis of integrating building envelopes with nano-materials, Int. J. Sustain. Built Environ., Vol. 2, no. 2, pp. 209–223. DOI: 10.1016/j.ijsbe.2013.12.001.

Sadineni, S., Madala, S. & Boehm, R. (2011) Passive building energy savings: a review of building envelope components. Renewable and Sustainable Energy Reviews ,Vol.15 ,pp. 3617–3631.

Silva, T., Vicente, R., Amaral, C. & Figueiredo, A. (2016) Thermal performance of a window shutter containing PCM: Numerical validation and experimental analysis, Appl. Energy, Vol. 179, pp. 64–84. DOI: 10.1016/j.apenergy.2016.06.126.

Soliman, M.H., Meselhy, M.S. & Qotb, M.Y. (2020) Nano-technology design framework for healthcare architecture as a building technology strategy, Vol. 9, no. 5, pp. 2753–2763.

SUPERTHERM®NEOtechCoatingsAustralia,SUPERTHERM (online).Available at :/2020/03/Super-Therm-USA-brochure.pdf (accessed March 3 2022).

Susa, M., Maldague, X., Svaic, S., Boras, I. & Bendada, A. (2008) The influence of surface coatings on the differences between numerical and experimental results for samples subjected to pulse thermography examination, no. September 2016..DOI: 10.21611/qirt.2008.12_11_16.

Xiaotu, L. (2010) Building physics , China Build. Ind. Press. Beijing . D
OI: 10.1007/978-3-319-57484-4.

Zanshare Made in China Thermal Insulation Nano Coating Building Exterior Wall Waterproof Paint., Made in China (online).Available at :,https://zanshare.en.made-in-china.com/product/vFHGuLtVHJpd/China-Zansh.are-Made-in-China-Thermal-Insulation-Nano-Coating-Building-Exterior-Wall-Waterproof-Paint.html (accessed March 3 2022).

Zhu, L., Yang, Y., Chen, S. & Sun, Y. (2018) Numerical study on the thermal performance of lightweight temporary building integrated with phase change materials, Appl. Therm. Eng., Vol. 138, pp. 35–47. DOI: 10.1016/j.applthermaleng.2018.03.103.