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

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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, a lot of recent studies have looked only at integrated Nano coatings on walls over a short period of time.

In this context, this study explores the long-term thermal behavior of building walls that 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 facility in Mansoura city in Egypt in the hot summer season. Ansys Fluent is used to simulate the long-term thermal behavior of a building wall with and without a Nano coating layer.

The results confirmed that introducing Nano coatings in the wall constructions will reduce indoor heat flux and achieve an indoor 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, the use of a 3-mm thick Nano coating on the wall results in a 52.5% reduction in the overall energy gain during the summer months.

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

Introduction

Recent studies have found that buildings accounted 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 with the goal of using Nano coating to lower energy consumption in healthcare buildings. Nano coating is regarded as the most promising high-performance material for construction applications. It presents remarkable benefits when compared to environmental coating materials in the construction industry because of its self-assembly effects (Boostani and Modirrousta,2016).

The use of Nanomaterials in construction is costly, but can be made cost effective due to gains in long term reliability. Consequently, Nanomaterials integrated into a building envelope are seen as good economic choices that save a significant amount of money while improving the efficiency of the built environment and solving future environmental concerns (Lalbakhsh,2011). Nanotechnology has the potential to radically alter our built environment and how we live; it is potentially the most transformative technology we have ever invented (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 photo catalysis demonstrate many inventive and creative design strategies with practical examples that demonstrate 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 utilized to modify characteristics such as color, reflectivity, stickiness, and a variety of other things. Compared to conventional coating materials used in the construction industry, they offer a 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, 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. The three routes of heat transmission in traditional thermal insulation materials are thermal conduction, heat flux and thermal radiation. In Nano-technology-based thermal insulation materials, one or more pathways of heat transmissions are impeded. Thus, they can reduce the heat transfer coefficient of building structures. A well-known heat transfer coefficient: Eq. (1), is as follows:

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

Here, U is the heat transfer coefficient [W/m2K]; d_i is the individual thickness of each structural layer [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 fillers of Nano size balls each of which contains 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 play 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 reduce maintenance operations as they create a suitable and hygienic environment for the patients, staff, and their families.

In this context, this study examines healthcare facilities due to the nature of their work and running on a 24 h basis, with higher 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 main objective of this study 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

The thermal performance of the building envelope plays a very important role in saving energy (Feng et al.,2016). The demand for building envelope analysis has grown. In this technique, the physical barrier between a building's internal and outer environment is assessed. New construction methods and materials, laws and regulations, rising costs of energy, and growing occupant health concerns are all contributing to this demand. In order to reduce the need for space heating and cooling, it is essential to minimize heat transfer through the building envelope. The building envelope can lower the amount of 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), U-values of envelope materials, and site-related characteristics, such as temperature and solar irradiation, are the inputs to the envelope-related energy demand (Granadeiro et al., 2013). To achieve optimum. performance of buildings, emphasis must be given to the thermal energy performance of the building envelope and sustainability. Moreover, investigations have indicated that building envelopes contribute between 50 and 60 percent of the overall heat gain in buildings and more than 50 percent of the embodied energy distribution in major building elements in residential buildings (Mwasha et al., 2011).In comparison to hot temperatures, cold regions have seen the majority of research into nanomaterials as insulation options. But that is altering. Ihara and Gao (2015) recently investigated how a translucent Nano gel granulate glazing system affected the spandrels of three cities with hot climates' office buildings. According to the results of the simulation, Nano gel facades could use less energy than double-glazed ones.

Rashawn, Farag, and Mostafa (2013) have tested the Nano thermal model and have measured the heat transfer rate in comparison to conventional building envelope materials (baseline model) under typical Egypt-Aswan weather conditions to investigate the energy performance 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 energy efficiency of building wall constructions by 40%. Abdelrady , Abdelhafez and Ragab (2021) focused on the effect of Nano gel glazing in windows and Nano VIPs in external walls on energy consumption of residential building in New Aswan City, Egypt. For comparison with Nano VIPs walls and Nano gel glazed windows, the study's base case included 120 mm brick walls and 3 mm glass windows. The Design Builder was used to simulate energy use. They discovered that the layer of Nano gel sandwiched between two layers of argon and two layers of glass significantly reduced the annual energy usage by 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. This study compares the energy consumption of conventional building materials and Nano-based materials, such as fiber-reinforced aerogel blankets used as thermal insulation and Nano gel windows, in order to assess the impact of using these new materials on the energy efficiency of buildings. As a result of using Nano-based building materials, it was discovered that total energy consumption decreased significantly, reaching 7.42% (216479 KWh) and 10.78% (137544 KWh) for cooling loads. It is concluded that using Nano-based building materials for all building envelope components, including opaque elements and coatings, will result in significant energy savings, which will lower the building's operating costs and lessen its negative environmental impact.

Ali et al, (2020) focus on coating buildings windows glass and the associational effect on energy consumption, using Design Builder as the modelling tool. A public housing building located at Sabah Al-Ahmed district, Kuwait, was selected as a test case for this study. 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 yearly electrical requirements by 9.6%, but it had a 14.5% poorer light transmission than the original house design, the results showed. These results are thought to be very significant for governmental decision-makers, particularly when taking into account building energy efficiency in upcoming public housing developments. The current study focused on applying Nano coatings on health care buildings to improve thermal performance and energy efficiency in Mansoura city in Egypt. The base case of this study explores the long-term thermal behavior of building walls that comprise Nano layers using Ansys Fluent.

Research Methods

The current investigation begins with a numerical model validation experiment. The effect of including Nano coating of different thicknesses is then investigated using numerical results. This simulation is conducted in hot summer weather conditions of Mansoura, Egypt (31° 2' 16.5588" N, 31° 22' 53.4828" E). Three different modeling approaches are applied and compared in a numerical analysis. After validating that 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 performed 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 used to simulate the long-term thermal behavior of a building wall with and without a Nano coating layer.

Theoretical basis

In this paper, different numerical simulations were carried out to analyze the thermal performance of traditional paints and Nano coating paints in summer:

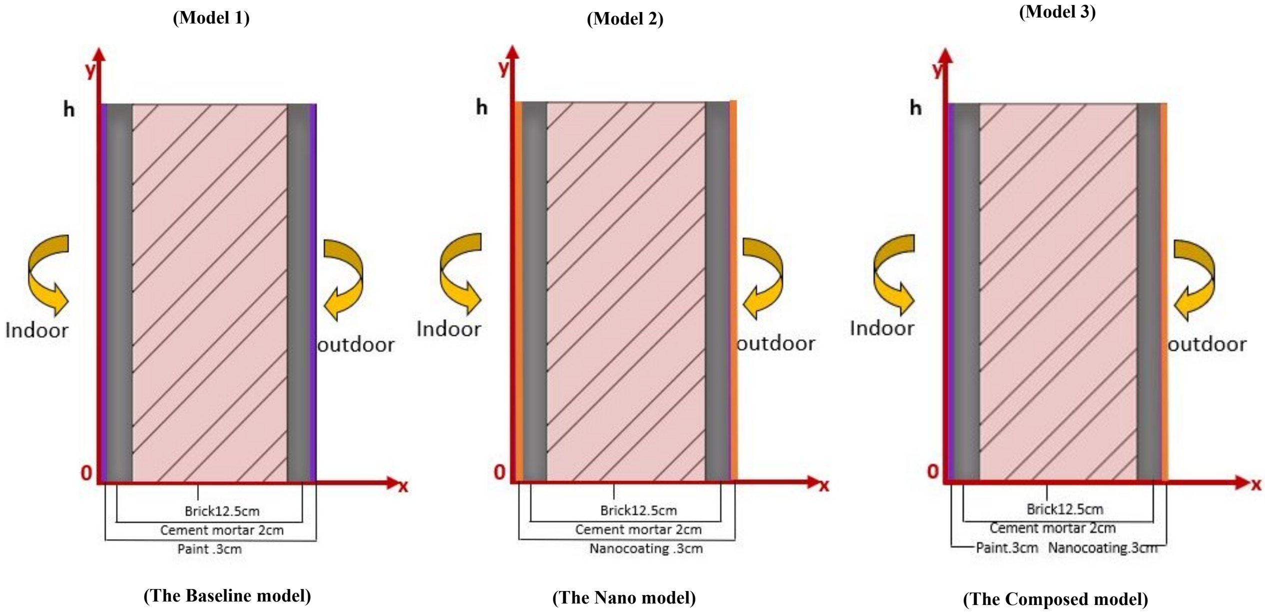

Fig. 1: Schematic of the model's materials
Source: author

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 conditions, including solar radiation, ambient temperature 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.

Following are the governing equations for each layer of the building wall:

- Following assumptions are made in building the analysis model to ensure the simulation results and simplify the complex heat transfer process between each layer:
- Heat is assumed to be transferred only in the thickness direction because heat transfer always occurs between the inner and outer surfaces, namely, one-dimensional heat transfer.
- Physical properties of other solid materials are constant.
- Thermal contact resistance between layers is negligible.

Given the differences in heat transfer between paints and other materials, mathematical models were developed to express their heat transfer. According to energy conservation, the heat transfer in the layers is described in 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):

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

On the boundary conditions, adiabatic boundaries were applied to the bottom and top surfaces (y = 0 and y = h), whereas the convective heat transfer boundaries were adopted on the outer and inner surfaces (x = 0 and x = δ) and can be expressed by Eqs. (4) and (5).

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

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

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

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

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

These two temperature recordings are assumed to be equal in this study (Li et al, 2019; Zhu et al., 2018). Consequently, the value of G is included in the numerical models using an identical transient temperature profile (t). The temperature profile, surface absorptivity, G(t), and hex(t) all influence how much the ambient temperature outside changes (t). The Sol-air temperature profile is the name of the temperature profile. Following formulas are used to calculate it:

conducted in step #3.

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

It is important to note that the following correlation (Silva,et al, 2016) is used 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 measured wind speed in m/s. In a thermally coupled boundary, the condition is imposed at the interfaces between each pair of neighboring layers with extremely little thermal contact resistance. The simulation's study framework is depicted in the 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 impact 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 in order to compare the performance of building walls with and without Nano layers.

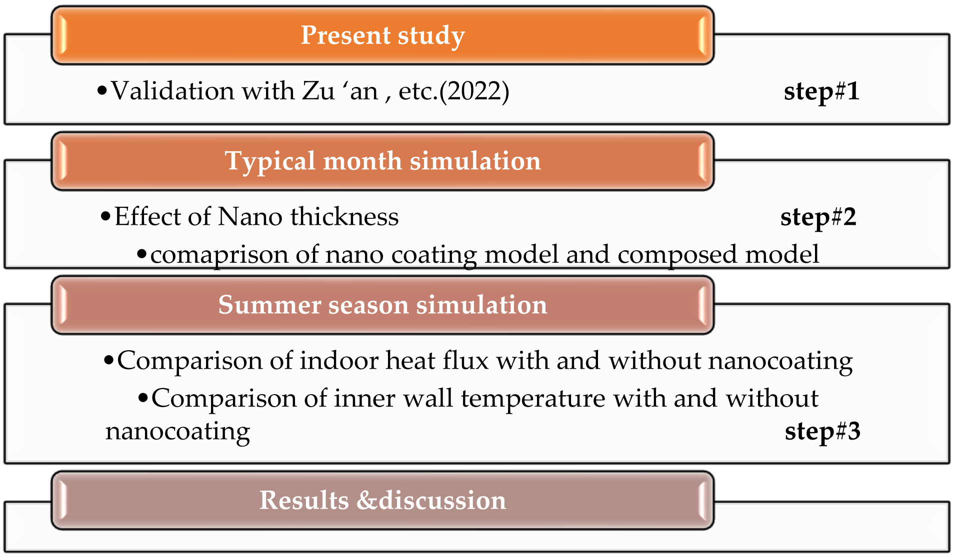

Fig. 2: Flow diagram of the study
Source: author

Model validation

Current model has been validated using literature results (Liu, et.al.,2022). The simulation period (July 30 to August 5) was used to examine the thermal behavior of the walls while maintaining an indoor air temperature of 26°C. The top and bottom surfaces of the numerical model were given 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.

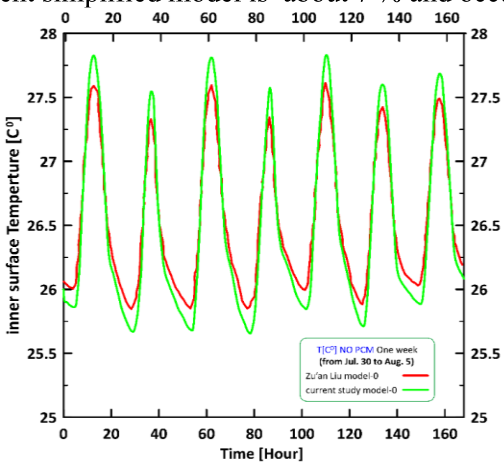

Fig. 3: Comparison of the present numerical results with the numerical simulation results
Source: Author

The overall results of this section are divided into three primary subsections. The impact of Nano thickness on the thermal performance of building wall constructions 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 nanotechnology is examined in the last subsection.

1. Effect of Nano Thickness

In this section, we discuss how Nano coating thickness affects the temperature and heat flux inside a space. Figs. (4) and (5) illustrate how the indoor heat flux and indoor surface temperature are affected, respectively, by the thickness of the Nano coating layer. Three Nano coating layers, with thicknesses of 2 mm, 3 mm, and 4 mm, are compared.The results show that raising the Nano coating thickness reduces the interior heat flux and indoor wall temperature by a small percentage. Therefore, we will not raise the thickness because it will increase the cost.

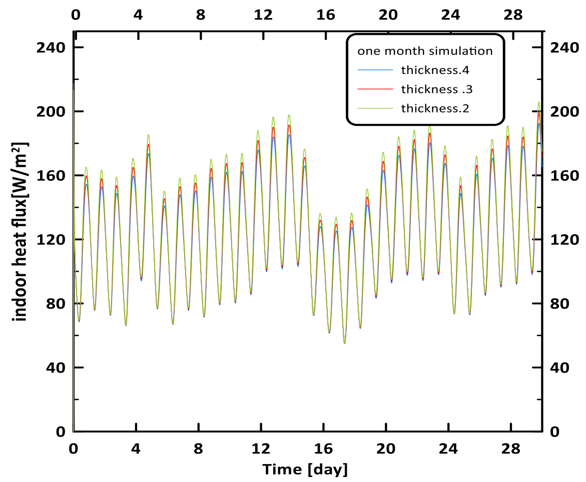

Fig. 4: Daily variation of indoor heat flux for different thickness using solidification model
Source: author

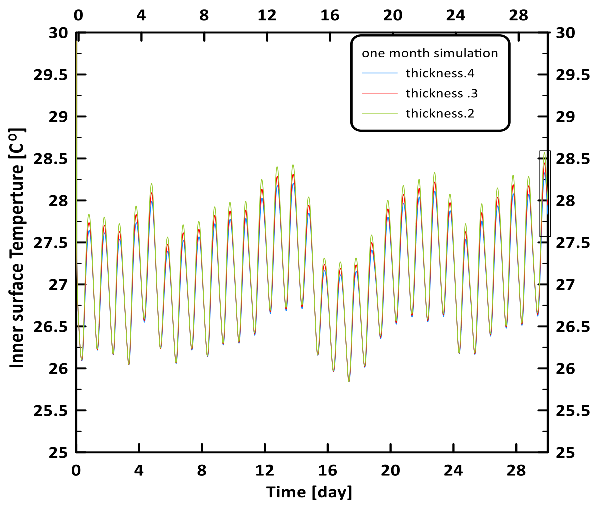

Fig. 5: Daily variation of inner wall temperature for different thicknesses using solidification model
Source: author

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 of the wall with Nano Coating was 10906.74 w/m2.day. The application of Nano coating in the wall structure results in a 48% reduction in the total energy gain throughout the summer.

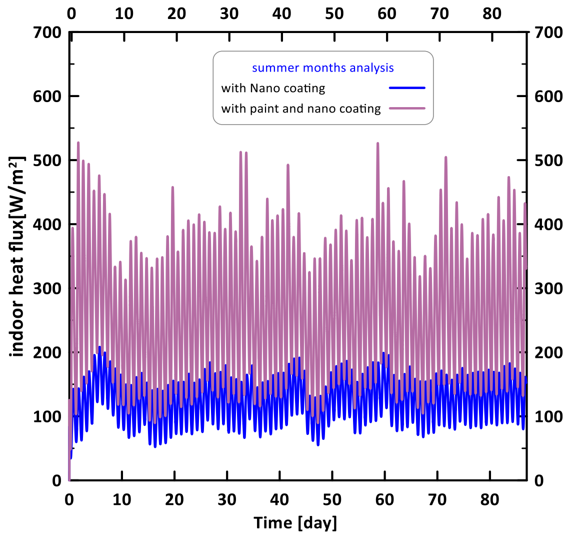

Fig. 6: Daily variation of indoor heat flux with Nano coating and composed coating
Source: author

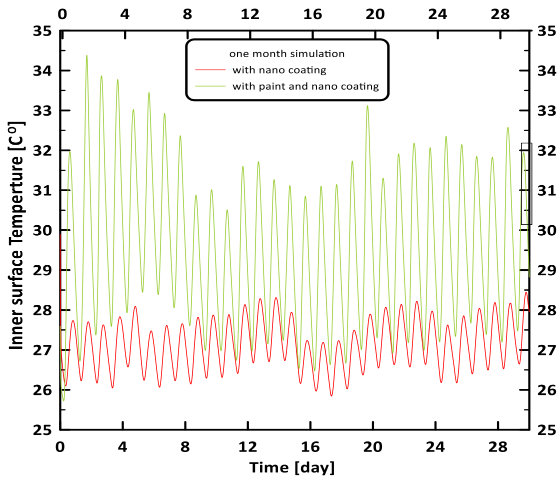

Fig. 7: Daily variation of inner wall temperature with Nano coating and composed coating
Source: author

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, the thermal benefit of using Nano in the building structure is greater. The months that are used in the simulation are June, July, and August. For these months, 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 indoor heat flux and indoor wall temperature for the 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. Additionally, 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. The application of Nano coating in the wall structure results in a 52.5% reduction in the total energy gain throughout the summer.

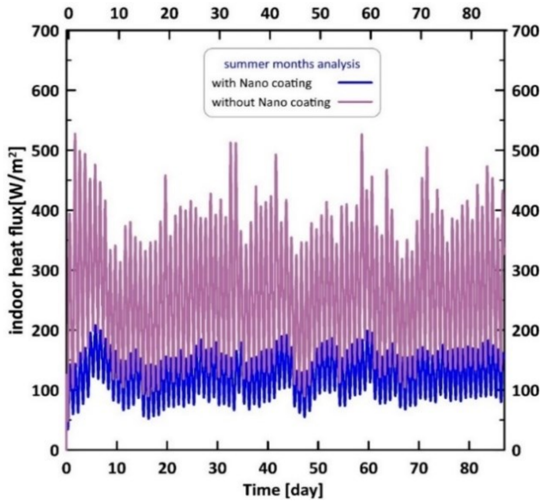

Fig. 8: Daily variation of indoor heat flux with and without Nano coating
Total energy transfer
=23000.6(W/m2). day (without Nano coating)
=10906.74(W/m2). day (with Nano coating)
Source: Author

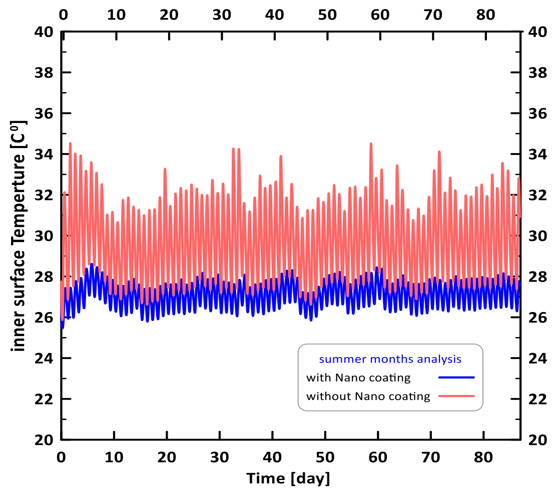

Fig. 9: Daily variation of inner wall temperature with and without Nano coating
Average indoor wall temperature=29.7°C (without Nano coating)
=27.1°C (with Nano coating)
Source: author

Conclusions

This study compared the thermal performance of building walls 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 heat flux inside and the temperature of the inside walls. According to the findings, applying Nano coating to wall constructions lowers indoor heat flux and reduces interior wall temperature closer to what is needed for indoor comfort. In order to examine the long term thermal behavior 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, according to summer models. Additionally, the overall energy transmission drops from 23000.595 w/m2/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, the overall energy usage during the summer is reduced by 52.5% so using Nano coatings can improve the thermal performance of a building, especially during the summer months, and saves energy.

The strengths is 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 to advance the use of nanomaterials in the construction of cost-effective, energy-efficient buildings. 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 nanoparticles used in thermal insulation of buildings, especially in view of the impending climate change.

Nomenclature

U	The heat transfer coefficient	(W/m^2. K)
d_i	The individual thickness of each structural layer	(m)
λ_i	The individual thermal conductivity of each structural layer	(W/m^2.k)
h_{in}	Convective heat transfer coefficient of inner surface	(W/m^2.k)
h_{out}	Convective heat transfer coefficient of outer surface	(W/m^2.k)
ρ_i	Density	(kg/m^3)
T_i	Material Temperature	(°c)
C_{pi}	Specific heat	(j/kg. k)
Ta	outdoor ambient temperature	(k)
T_{solair}	Sol-air temperature profile	(k)
U_{wind}	The unit of measurement 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

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