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The Effect of Exterior Wall Color on Thermal Performance of Building

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ABSTRACT

An experimental study of four colors of ordinary dye (white, yellow, Tibny, and blue) on the external wall of the apartment building was carried out in the current work to find out the range of its effect on the heating load in the winter season compared with a dark color of cement wall at 24hr. In the southern wall were made two openings, the opening dimensions were 1 meter high and 0.3-meter width. Two types of walls are built in the two openings. The first wall was made of bricks and was covered with a layer of cement (Ficus) 1 cm in thickness, while the second wall was also made of bricks covered with cement (Ficus) with a thickness of 1 cm and painted with different colors. The results showed that the heating load is not affected by the change of the facade color of the buildings, where the difference in the external and internal temperatures of the colored wall compared to the black wall was approximately equal during the winter season during minimum temperature surface at night.

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دراسة تأثير اللون الخارجي للجدار على الأداء الحراري للمبنى

حسن كريم عبدالله قسم الهندسة الميكانيكية/ كلية الهندسة / جامعة واسط / العراق.
رنا قاسم فرج قسم الهندسة الميكانيكية / كلية الهندسة / جامعة واسط / العراق.

الخلاصة

تم إجراء دراسة تجريبية لأربعة ألوان من الصبغ العادي (أبيض، أصفر، تبني، أزرق) للجدار الخارجي للمبنى السكني في العمل الحالي، لمعرفة مدى تأثيره على حمل التدفئة في موسم الشتاء مقارنة مع اللون الداكن (الاسمنت). أجريت التجارب في جامعة واسط (مدينة الكوت، خط عرض 32.5 شمالاً) في الشتاء، من خلال صنع غرفة نموذجية من السندويش بنل. كانت أبعاد الغرفة (2 م طول و2 م عرض و2.4 م ارتفاع) وتم شق فتحتين في الجدار في الاتجاه الجنوبي، وكانت أبعاد الفتحة (1 م ارتفاع و0.3 م عرض). تم بناء نوعين من الجدران في الفتحين. الجدار الأول تم بناءه من الطابوق ومغطى بطبقة من الأسمنت (اللبخ) الداكن اللون بسمك 1 سم، والجدار الثاني مبني من الطابوق المغطى بالأسمنت (اللبخ) بسمك 1 سم وتم طلاءه بألوان مختلفة. اظهرت النتائج أن حمل التدفئة لا تتأثر بتغير لون الواجهة للمباني حيث كان الفرق في درجات الحرارة الخارجية والداخلية للجدار الملون مقارنة بالجدار الأسود متساوٍ تقريبًا عند اوطأ درجة حرارة والتي تكون في الليل في موسم الشتاء.

الكلمات الدالة: الألوان، الجدار الخارجي، اللبخ، الواجهة.

1. INTRODUCTION

The present study tries to show the effect of the different external colors of the building on heating and cooling load. In Iraq, the weather is very hot. The ambient temperature is above 50 °C, so the external colors have an important effect on reflecting or absorbing the solar radiation, which increases or decreases the heat gain through the wall. The work includes two parts, the first was done in this research for the winter season, and the second part will be under study for the next summer. This study aims to reduce the heating load in the winter season building (Synnefa, Saliari, et al.) [1]. This study describes the effect of the cold roof (which has high reflectivity of solar radiation compared to the initial roof) on thermal comfort; the study was conducted on a school building that was non-cooled in Athens. A white elastomeric coating with a solar reflection of 0.89 was applied to the roof of the building. The results showed that the air temperature in the classes decreased by 2.8 ° C and the annual cooling load decreased by 40%. On the other hand, the heating load increased by 10%. (Dias et al.) [2] studied the effect of cool dyes on the thermal performance and the amount of energy required for the building was studied. The case study was on a building in Portugal where cool dyes containing 92% TSR (total solar reflection) and 0.90 on emission were used, and it was found that the use of cool coating leads to a null annual cooling load while in winter, the heating load was increased about 30% comparing with building without dying. This study showed that when cool white dyes were used on the roofs and the facades of buildings, in the summer week, there was a decrease in maximum temperature to about 5 °C. In contrast, in the winter week, the minimum temperature decreased between (0.8 °C and 1.5 °C). (Azarnejad et al.) [3] The effect of visual reflection of building facades on thermal behavior in Vienna has been investigated in several parts, including the disclosure of the relationship between the temperature of the corresponding surfaces and the visual reflection of the building's facade. Several buildings were chosen in a variety of facade colors. The results indicate that the effect of visual reflection of the facades of light-colored buildings greatly affects the internal temperature of the building as the cooling load decreases to about 40% compared to buildings with polystyrene insulation. (Cheng et al.) [4] indicated the effect of the color of the outer wall of the building as well as the thermal mass on the internal temperature of the building in the Chinese University of Hong Kong (CUHK) in humid and hot climates. where white and black colors were used. The results showed that the degree of internal heat in a dark room without a window is more than) 10 °C(in a room with white color. Abdullah [5] deals with the effect of colors on the external walls of buildings; where two sets of the experiment were done in June 2011 at UTM Skudai in Malaysia., where the first experiment studied different colors of paints, including white and yellow, and brown for the outer walls of buildings while using orange and dark brown and green in the roof of the building. the results showed that the lowest surface temperature at the white color at the maximum hour of the sun was 35.4 ° C while recording the orange color on the roof's surface, the lowest temperature in the sun rush hour. It was 37.4 ° C.(Synnefa, Santamouris, and Livada) [6] 14 types of cool dyes were used on the exterior wall of the buildings, which were selected from international markets to test their ability to reduce the ambient temperature. They were used in 2004 from August to October for 24 hours. Infrared emission and spectral reflection were measured in the models where the results showed that white reflective dyes could work on reducing the temperature of the building surface by 4 ° C in a hot summer climate and reduce the temperature at night by 2 ° C.(Yu et al.) [7] In 2003, in the summer, a study was carried out on models of buildings at Xi'an Jiaotong University where the results showed that the difference between the internal temperature of the building and the external surface temperature was found the highest between the white dye and cement plaster dye, followed by pink dye and then lead color and blue is smaller. The results showed that the high-albedo materials facing the wall could reduce 150.3 watts of cooling load per day in the summer season and reduce the heat load in the winter season by 69.5 watts, where in summer temperature decrease to 3.53 °C and winter increase by 2.81°C whenever high-albedo dyes are used on the outer wall of the building, (Uemoto et al.) [8] The thermal behavior of cool colored dyes and compare them with ordinary dyes and the same colors were studied where the selection of yellow, brown and white color applied to the fiber cement roof. The results showed that the composition of cold dyes is more reflective than normal colored dyes, and the surface temperature when exposed to infrared radiation is (10 °C) lower than normal dyes and more possible. (Synnefa, Santamouris, and Apostolakis) [9] studied the thermal behavior and solar spectral properties of 10 samples dyed with cool-colored pigment at Kapodistrian University and Athens University in Athens. Cool colored dyes were used and compared with conventional dyes. The surface temperature of the coating was measured when applied to concrete construction in 2005 for 24 hours from August to December. The results showed that the cool dyes retain a lower surface temperature (10.2°C) than conventional coatings, but this difference was diminished during winter and better avoided heating penalization.(Coser et al.) [10] a study was conducted on paints that contain infrared reflective dyes (cool paints) and compared them with conventional paints, where eight models were made, four of which were painted with cool pigments (black, yellow, brown 1, and brown 2) and four painted with the same colors but with conventional paints.The results showed that the best is the cool yellow, which records the lowest temperature because of higher solar reflectivity. In contrast, the highest temperature difference between cool and traditional paint was the cool brown2 point, where the temperature difference was (2.7°C).(Han et al.) [11] evaluating the energy performance in a mathematical model for roof structures in a different color. The authors showed a decrease in cooling load of up to 9.3% when the roof color changes from black (solar reflection value of 15%) to white (solar reflection value of 52%).

2. THE PRESENT WORK

The experimental work consists of building a practical room to investigate the effect of coating color on a temperature difference for the room model for 24hr. Present work was carried out at the university of Wasit (Al Kut city) in a room model built to be in direct contact with solar radiation in the winter in the south direction (February 2020). different colors of coating (white, Tibny, yellow, blue) were used to show the temperature difference compared with the black wall (cement)

3.ROOM MODEL

A small room is a model used for this study where all the walls of the room and the ceiling are built from a sandwich panel with thermal conductivity (0.034) W / m.K and a thickness of 5 cm to prevent heat leakage from the outside to the inside or the opposite of all walls. The southern wall contains two openings that were under study. The size of the room (width 2m, length 2m, height 2.4m). Dimensions of the opening (1 m high and 0.3 m wide). The walls of the room are all exposed to external conditions directly. The first wall was built from bricks, covered with a layer of cement (ficus), and the second was the same as the first but was dyed in different colors, Fig.1.

Fig.1 Room model

The floor of the room was made from a wooden board with a thickness of 17mm. All the room walls were directly exposed to the external conditions and faced four directions north, south, east, and west.

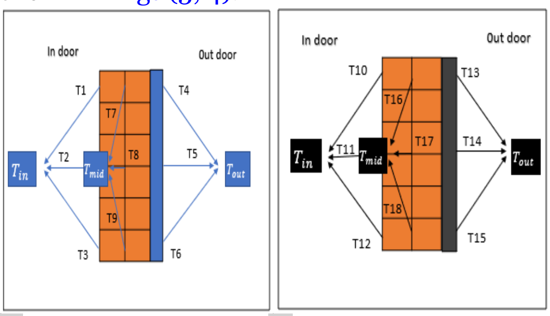
3.1 Exterior wall color

Four different colors of ordinary dyes were used to paint the room's outer wall model, which are (white, yellow, Tibny, and blue). The wall was coated on the layer of cement (ficus) in the south direction Fig. 2

Fig. 2 wall with different colors of dyes (White, Yellow, Tibny, Blue).

3.2 Temperature measurement

TP-01 K Type Thermocouple was used to measure temperatures where three wires were installed on each of the wall's outer surfaces, the middle, and the inner surface. The distance between the wires was distributed evenly to record the average temperature for each surface. A wire TP was installed to measure the room temperature in the middle of the room. A wire was also installed outside the room in the shade to measure the ambient temperature, as shown in Figs (3, 4).



a- the wall with coating **b**- the wall without coating

Fig. 3 Shows the (TP-01) location on the wall with and without coating.

Picolog data logger TC-08 model measures a wide range of temperatures. This device consists of eight channels. The thermocouples are connected to measure the temperatures using thermocouples (TP-01) with an accuracy of temperature measurement of about (± 0.2)°C.

3.3 Solar power meter

The type of solar energy meter used in this research is (TES-1333R). Made in China, this device is used to record solar radiation in W/m² during the day during experimental work

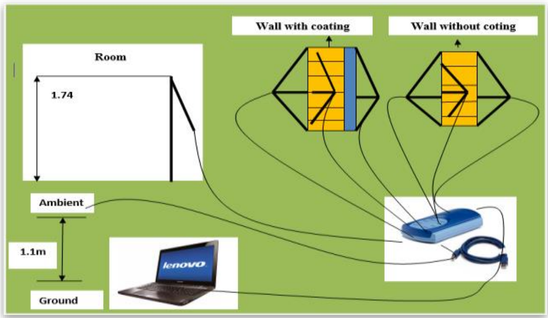


Fig. 4 Indicate to connection temperature measurement equipment.

3.4 Heating unit

To make the room temperature constant at 24 ° C during all times of experiment, a heating unit used inside a room consists of a fin and electric heater of 3500Wusing with a control temperature system.

4. RESULTS AND DISCUSSIONS

Fig.5 [a] shows the external surface temperature of white and black (cement) walls (T_{wo}, T_{bo}), solar radiation (Ir), and ambient air temperature (T_a) for (17-Feb-2020). At 7 am. the sunshine and solar radiation increase during the morning until they reach a maximum value of 700 w/m² at mid-day 12 pm, then decrease to its zero value at 6 pm; this variation has the main reason for the increase or decreases in the wall temperature. The figure shows the temperature variation of the outside surface of white and black walls approximately in the same shape of solar radiation intensity, but it's clear that the black surface temperature(T_{bo}) increased rapidly from 17 ° C at 7 am to the maximum value 41.5 ° C at 12 pm,i.e., at the same time of maximum solar radiation due to its high absorptivity for radiation, then start decrease as (Ir) decrease, after sunset its continuous decrease to minimum value 14.5 ° C at 6 am. because of the outside air temperature during night period decrease to its minimum value at 6 am. While the outside surface temperature of white (T_{wo}) has the same variation as a black wall but in different values. The maximum temperature (T_{wo}) is 26.5 ° C at 12 pm; this low temperature compared to the black surface temperature due to its high reflectivity to solar radiation, i.e., its maximum temperature is about 37% less than the black surface, which means in summer days may be increased to more than double value, so that will be effected on thermal load of a building, this is the main purpose of this study. (T_{wo} & T_{bo}) decreased during the night period to a minimum value of 14.5 at 6 am, due to a decrease (Ta) reaching a minimum value of 11 ° C. The ambient temperature (T_a) varied at the same rate as surface temperature but with lower temperature, starting from 17 am then increasing during the day to a maximum value of 23 ° C at 3 pm., then decreasing to a minimum value of 11 ° C at next morning at 6 am because the earth emitted power to the night sky (night sky temperature is about -50 ° C at outer space of 15 Km level)[12]. Fig.5 [b] shows the mid-temperature gradient of white and black wall surfaces (T_{wm} & T_{bm}), the variation in temperature for both walls took place at the same rate but was the lowest in the white wall because of low absorptivity compared with black(cement)wall.

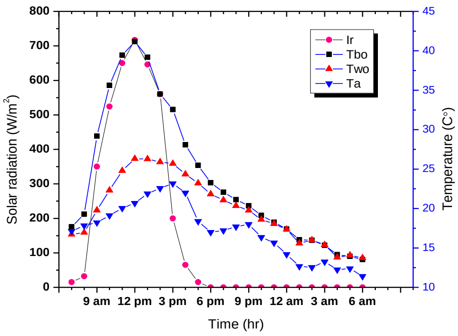


Fig.5. [a] solar radiation, ambient temperature, and outer surface temperature gradient of the wall without and with white coating.

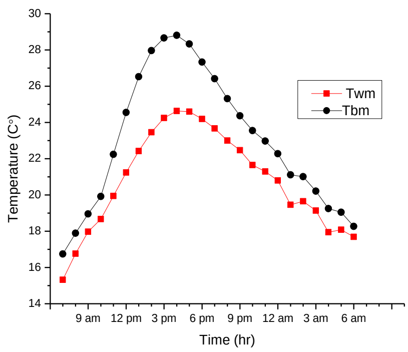


Fig.5. [b] mid surface temperature gradient of a white and black wall at (17-Feb-2020).

Fig.5 [c] shows the comparison of the inner temperature gradient of white and black (cement)walls (T_{wi} & T_{bi}) and room temperature (T_r), which is approximately constant between (23 ° C to 26 ° C) by controlling the heating unit at 24 ° C. (T_{wi} & T_{bi}) during the day begin to increase to values above the room temperature, while starting to drop to below room temperature at night, this means that heat will be lost through the wall from inside the room to the outside to reach the minimum value to 18.6 ° C at 6 am for both (T_{wi} & T_{bi}), this means black wall was lost heat more than a white wall. Fig.5 [d] indicates the comparison between the difference between the outer and inner surface temperature gradient of the wall without coating and the wall with a white coating (ΔT_{bo-i} &ΔT_{wo-i}), where the maximum value of (ΔT_{bo-i}) was (18.8 ° C) at 12 pm, while the maximum value is (ΔT_{wo-i}) was (3.7 ° C) at the same time, i .e, about 80% less than (ΔT_{bo-i}).While at night start decrease the difference between (ΔT_{bi-o}) and (ΔT_{wi-o}) to reach the minimum value to zero at 6 am, where the minimum value was (5° C) for both (ΔT_{bi-o}) &(ΔT_{wi-o}).

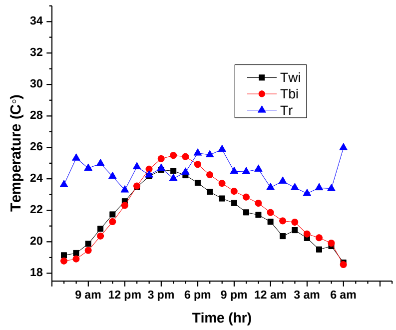


Fig.5. [c] inner surface temperature gradient of the wall without coating, with a white coating and room temperature.

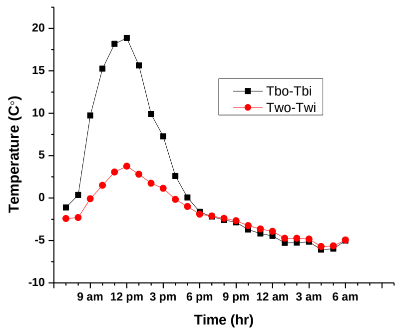


Fig.5. [d] Comparison between the wall without coating temperature difference and a white coating at (17-Feb-2020).

Fig.6 [a] indicates the outer surface temperature of yellow and black (cement) wall (T_{yo}, T_{bo}), solar radiation (Ir), and ambient air temperature (T_a) for (23-Feb-2020). The solar radiation (Ir) begins from (30 W / m2) at 7 A.m. and reaches the highest value at 12 p.m. (765 W / m2), then it reaches the lowest value, which is zero at 6 p.m., while starts the ambient temperature (T_a Fig.6 [b] shows mid surface temperature gradient of black and yellow walls (Tym & Tbm), which take the same rate of variation, but the yellow wall was the lowest temperature gradient because of low absorptivity compared with the black wall.) to increase from 14.8 ° C at 7 A.m. to reach its highest value of 23.6 ° C at 3 p.m. with the decrease in solar radiation. The gradient of the outer surface temperature of yellow and black walls takes the same shape as solar radiation, where (Tyo, Tbo) start increase from (14,17) ° C respectively at 7 am to reach maximum value (51 ° C for Tbo and 34.5 ° C for Tyo) at 1 pm, i.e., the maximum value of (Tbo) is 32% more than (Tyo) due to high absorptivity of a black wall compared with a yellow wall, then decrease with decrease solar radiation to reach minimum value (16 ° C) at 6 am. for black and yellow walls due decrease ambient air temperature during the night to reach minimum value (15.5 ° C) at next morning at 6 am.

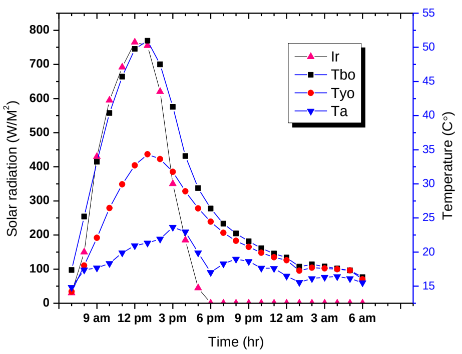


Fig.6. [a] solar radiation, ambient temperature, and outer surface temperature gradient of the wall without coating and with white coating.

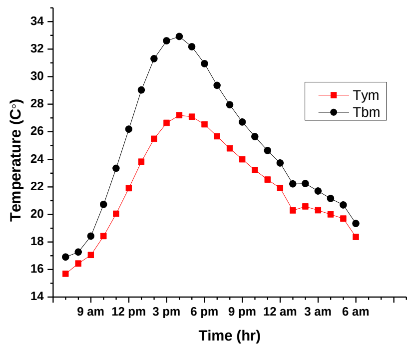


Fig.6. [b] mid surface temperature gradient of a yellow and black wall at (23-Feb-2020).

Fig.6 [c] indicates the comparison of the inner surface temperature gradient of the black and yellow walls (T_{bi} & T_{yi}) and room temperature (T_r), where it's approximately constant between (23 ° C to 26 ° C) by controlling the heating unit at 24 ° C. (T_{bi} & T_{yi}) start increase from (17.5,16.5) ° C respectively at 7 am to reach values above room temperature during the day then start to drop to below room temperature at night, this means that heat will be lost through the wall from inside the room to the outside to reach minimum value 19.5 ° C at 6 am for both black and yellow walls, this means black wall was lost heat more than a yellow wall. Fig.6. [d] shows a comparison in different temperatures between the outer and inner surface temperatures of black and yellow walls (ΔT_{bo-i} &ΔT_{yo-i}), where the maximum value of (ΔT_{bo-i}) was (27 ° C) at 12 pm. During night start decrease the difference between (ΔTbi-o &ΔTyi-o) to reach zero at 6am ,where the minimum value was (3.36 ° C) for each (ΔTbi-o &ΔTyi-o). In comparison, the maximum value of (ΔTyo-i) was 10 ° C simultaneously, i.e., about 63% less than (Tbo-i).

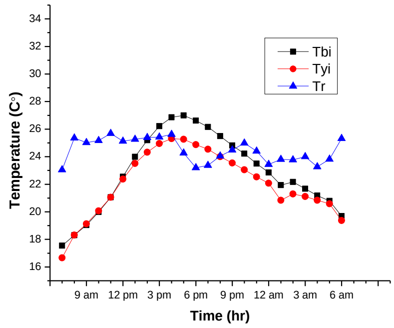


Fig.6. [c] inner surface temperature gradient of the wall without coating, with yellow coating and room temperature.

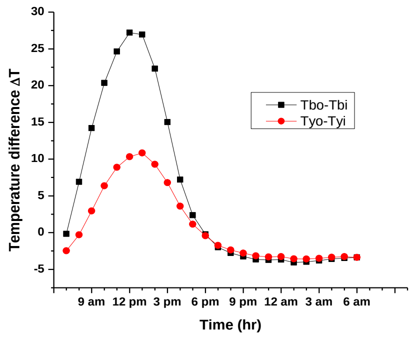


Fig.6. [d] Comparison of the temperature difference of the wall without coating and yellow coating on (23-Feb-2020).

Fig.7 [a] indicates the outer surface temperature gradient of black and tibny walls (T_{bo} &T_{to}), solar radiation (Ir), and ambient air temperature (T_a) for (27-Feb-2020). The solar radiation (Ir) begins from (15 W / m2) at 7 am and reaches the highest value at 12 pm. (670 W / m2), then it reaches the lowest value, which is zero at 6 p.m., while starts the ambient temperature (T_a) to increase from (13.3 ° C) at 7 A.m. to reach its highest value of (18.3 ° C) at 3 p.m. with the decrease in solar radiation. (T_{bo} &T_{to}) were varied at the same shape of solar radiation, where the start increase from (14,13) ° C at 7 am respectively to reach maximum value for (T_{bo}) was (41.5 ° C) at 1 pm., while the highest value of (T_{to}) was (26.5 ° C) at the same time, i.e., it's about 36% less than (T_{bo}) due to high absorptivity of a black wall compared with tibny wall, then decrease with decrease solar radiation to reach minimum value(13 ° C) at 6 am for black and tibny walls due to decrease ambient air temperature during the night to reach minimum value (12.5 ° C) at next morning at 6 am. Fig.7 [b] shows mid surface temperature gradient of black and tibny walls (T_{bm} &T_{tm}), which variations take the same shape, but the tibny wall was the lowest due to low absorptivity compared with the black wall.

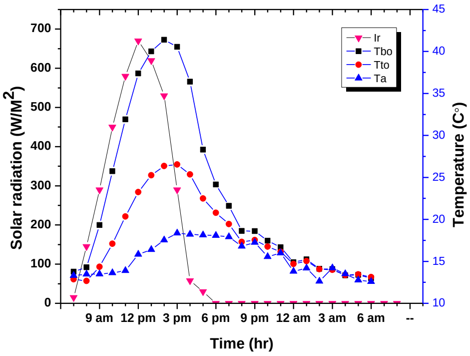


Fig.7. [a] solar radiation, ambient temperature, and outer surface temperature gradient of the black wall and wall with tibny coating.

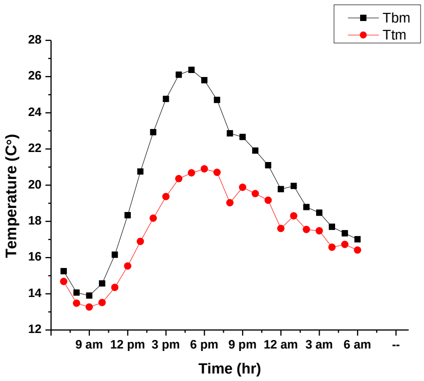


Fig.7. [b] mid surface temperature gradient of tibny and black walls at (27-Feb-2020).

Fig.7 [c] indicates the comparison of the inner surface temperature gradient of the black and tibny walls (T_{bi} & T_{ti}) and room temperature (T_r), which is approximately constant between (23 ° C to 26 ° C) by controlling the heating unit at 24 ° C. (T_{bi} & T_{ti}) start to increase from (15,14.5) ° C respectively at 7 am to reach maximum values (21.5,20) ° C respectively at 6 pm then begin to drop to below room temperature at night, this means that heat will be lost through the wall from inside the room to the outside to reach minimum value (18 ° C) at 6 am for both black and tibny walls , this means black wall was lost heat more than tibny walls. Fig.7 [d] indicates a comparison in different temperatures between the outer and inner surface temperature of black and tibny walls (ΔT_{bo-i} &ΔT_{to-i}), where the maximum value of (ΔT_{bo-i}) was (23 ° C) at 1 pm. During night start decrease the difference between (ΔTbi-o &ΔTti-o) to reach minimum value which is zero at 6am ,where the minimum value was (5 ° C) for each (ΔTbi-o &ΔTti-o). In comparison, the maximum value of (ΔTto-i) was (8 ° C) at the same time, i.e., it's about 65% less than (Tbo-i).

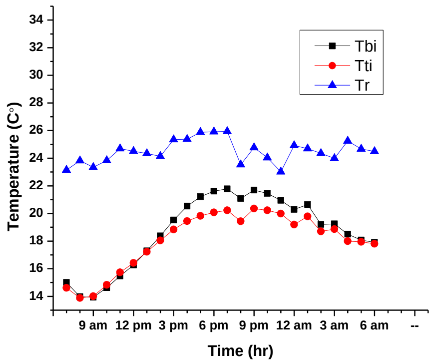


Fig.7. [c] inner surface temperature gradient of the wall without coating and with tibny coating and room temperature.

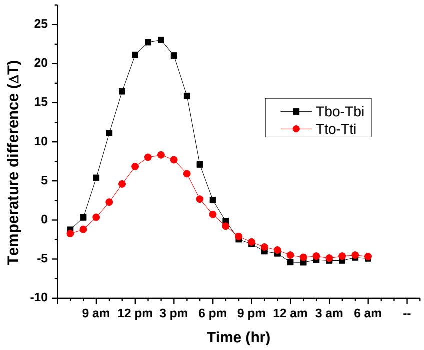


Fig.7. [d] Comparison between the temperature difference of the wall without coating and with tibny coating at (27-Feb-2020).

Fig.8 [a] shows the external surface temperature gradient of blue and black (cement) wall (T_{Bo}, T_{bo}), solar radiation (Ir), and ambient air temperature (T_a) for (29-Feb-2020). The solar radiation (Ir) begins from (27 W / m2) at 7 A.m. and reaches the highest value at 12 P.m. (775 W / m2), then it reaches the lowest value, which is zero at 6 pm, while starts the ambient temperature (T_a Fig.8 [b] shows mid surface temperature gradient of black and blue walls (Tbm &TBm), which variation takes the same shape for both walls, but the blue wall was the lowest due to low absorptivity compared with the black wall.) to increase from (10.8 ° C) at 7 A.m. to reach its highest value of (21.4 ° C) at 3 p.m. with the decrease in solar radiation. The outer surface temperature gradient of blue and black walls takes the same shape as solar radiation, where (TBo, Tbo) start to increase from (12,13) ° C respectively at 7 am to reach maximum value (45.3 ° C for Tbo and 29.5 ° C for TBo) at 1pm ,i.e. the maximum value of (Tbo) is 34.8% more than (TBo) due to high absorptivity of a black wall compared with blue wall, then decrease with decrease solar radiation to reach minimum value(15 ° C) at 6 am. for black and blue walls due decrease ambient air temperature during the night to reach minimum value (13.5 ° C) at next morning at 5 am.

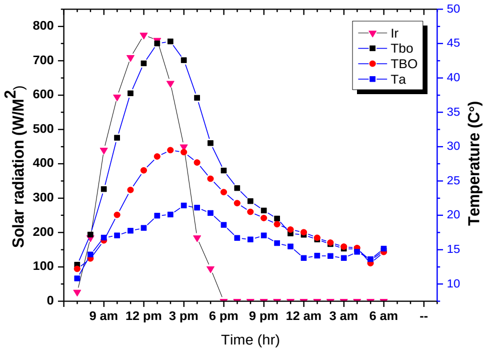


Fig.8. [a] solar radiation, ambient temperature, and outer surface temperature gradient of the black wall and blue-black.

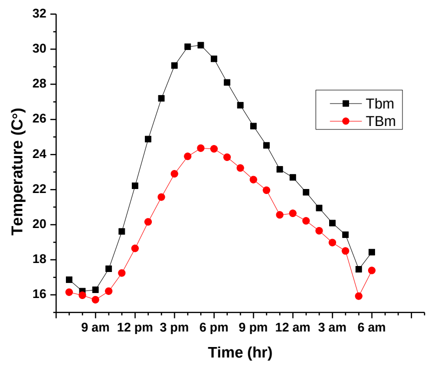


Fig.8. [b] mid surface temperature gradient of blue and black walls at (29-Feb-2020)

Fig.8 [c] indicates the comparison of the inner surface temperature gradient of the black and blue walls (T_{bi} & T_{Bi}) and room temperature (T_r), which is approximately constant between (23 ° C to 26 ° C) by controlling the heating unit at 24 ° C. (T_{bi} & T_{Bi}) start to increase from (18 ° C) at 7 am to reach maximum values (25,23.5) ° C respectively at 6 pm then begin to drop to below room temperature at night, this means that heat will be lost through the wall from inside the room to the outside to reach minimum value (17.5 ° C) at 5 am for both black and blue walls , this means black wall was lost heat more than tibny wall. Fig.8 [d] indicates a comparison in different temperatures between the outer and inner surface temperature of black and tibny walls (ΔT_{bo-i} &ΔT_{Bo-i}), where the maximum value of (ΔT_{bo-i}) was (24 ° C) at 1 pm while the maximum value of (ΔT_{Bo-i}) was (8 ° C) at the same time, i.e., it's about 65% less than (T_{bo-i}). During the night start decrease, the difference between (ΔT_{bi-o} &ΔT_{Bi-o}) reached a minimum value which is zero at 6 am, where the minimum value was (4.7 ° C) for each (ΔT_{bi-o} &ΔT_{Bi-o}).

Fig.8. [c] inner surface temperature gradient of the wall without coating and with blue coating and room temperature.

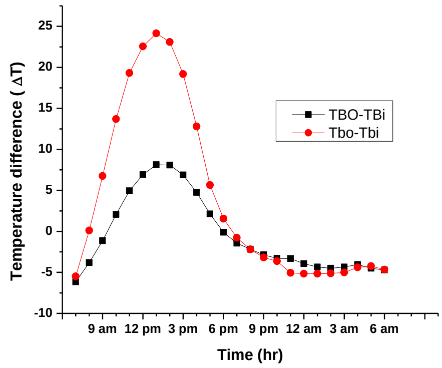


Fig.8. [d]Comparison of the wall temperature difference without and with a blue coating on (29-Feb-2020).

5.CONCLUSIONS

This study arose from the need to show the thermal performance of buildings in the winter season. The study was conducted to assess the effect of buildings facade's colors on heating load. The results showed that the heating load is not affected by the change in the facade color of the buildings, where the difference in the external and internal temperatures of the colored wall compared to the black wall was approximately equal. The author recommended using colored dyes for the interior walls of the new building and for the oldest with insulating materials to reduce heat loss and energy consumption by reducing heating load.

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