Cooling Load Reduction by Ambient Wetting Technique. (Experimental study)

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Abstract

The increase of the building temperatures above the normal thermal comfort specifications is due to the external layer of traditional building walls in summer seasons exposed to huge heat waves. In order to counteract that, a moist external air gap has been constructed around the building to help eliminate the direct ambient effects on the walls of the buildings. A simple wooden structure has been constructed to support the fiberglass mesh window screen that lies about 600 mm from the wall spanning its entire dimension (2×1) m. Three spray water nozzles were installed on the external layer of the wall. Nozzles directed towards the mesh window screen fiberglass to create a foggy layer.

The traditional wall (240 mm common bricks) of the building was covered with 4 types of materials that are available locally: face bricks 120mm thickness, tile bricks 40 mm thickness, limestone 40 mm thickness, and solid cement bricks 40 mm thickness. The external covering layer is 50 mm away from the traditional wall; this has been utilized as the external air gap that allows the ambient air to move using a fan. The fan gets its energy from a photocell.

The study was performed in Baghdad city (latitude angle 33.2 N°) during the summer season (May through September) 2019 one day for each month, from 6 AM to 7 PM, That testing room was maintained standard comfort level at 26.5˚C, 50% RH.

The researcher found out that the electrical energy consumed within natural ambient air for a traditional wall was 316 kWh, the four another studied cases in this research recorded consumption of 224 kWh, 258 kWh, 248 kWh and 302 kWh. When the water spray nozzles pump was operating to humidifying the ambient air in the external gap, a drop in the electrical energy consumed was noticed, 60 kWh, 52 kWh, 102 kWh, and 143 kWh for studied cases. Achieved energy-saving, was 162 kWh, 206 kWh, 144 kWh, and 159 kWh. Saving percentages were recorded for studied cases 72%, 83%, 58%, and 53%.

According to the results of this study, tile bricks are the best cover material out of the 4 used in the study. The most electrical reduction (206 kWh) and the highest percentage (83%) were seen with tile bricks.

Key Words: Cooling load Reducing; humidifying ambient air; Exterior air gab; double skin building; ventilated wall

1. Introduction

The electrical power used for Cooling buildings during the summer seasons in the hot climate area is considered of great importance. The importance comes from the direct effect of ambient conditions on electrical power consumption. It's estimated that 70% of the total annual expenditure of electrical power for a residential unit is used for cooling purposes [1]. Therefore, it is crucially important to reduce the environmental impact on buildings in order to reduce the heat transferred from outside to inside the buildings. This in turn will help decrease the amount of power spent on cooling down the building and overall reduction in annual usage of electricity.

The researchers focused their efforts on two aspects of the topic. The first aspect focuses on reducing the Heat transferred through external walls, therefore the building and finishing materials properties (thermal conductivity, number of layers and it's thickness) must be applied firstly, the formulating integral linear programming to obtained the best combination [2], and used a Waste plastic in the concrete mix to reduce its Thermal conductivity and density values [3], or using the thermal insulation layer and recorded the best thickness for reducing energy consumption. That thickness depends upon the calculation method (total equivalent temperature differences, cooling load temperature differences, and numerical solutions) or particular techniques, and also vary with types of insulation and light, heavy weight building materials, the better thickness in range (30-100) mm [4], better insulation thickness board in range (60-80) mm for Thermal Conductivity of (0.039) watt/m. Kelvin, and maximum energy saving (51%) [5]. The increasing reflectivity factor of an external surface by facade recovering with unclassical configuration aluminum sheets [6], or using the cool building surface applications, which reduce the energy consumption in the range 2%-70% according to types of cool techniques, the experimental was carried out Mediterranean Sea area [7], while, the white and light color materials were important to cope with surface at Arabian gulf area [8]. The use of phase change materials in building or finishing materials to reducing the heat transferred and/or peak load shifting out of working periods, the volumetric heat capacity of sensible, latent, and thermochemical energy storage materials is the perfect criterion, and the value in the range (250 - 1510) MJ/m^3, and the reduction of energy consumption up to 80% depend upon many parameters [9, 10], or using polymer materials to coat the aggregate surfaces in concrete mix [11], or using intelligent composite materials with change phase [12], while, using the foam geopolymer with the concrete mix to deformation concrete building materials, which low thermal conductivity and the electrical energy reducing by 4% [13], and using nanotechnology (and nanoscience and nanoengineering) in the concrete mix to improve the concrete [14] or concrete building material performance by sustainable material [15]. In that way, using recycled plastic (polyethylene, polyvinyl chloride, and polypropylene) as coarse aggregate instead of limestone aggregate in the concrete mix to reduce the density and heating energy by 21% and the value of UA in the range 333 - 480 [16], while, using the Waste plastic fiber reinforced coarse aggregate concrete to improve the compressive strength [17], and found that, the concrete building materials used polyurethane foam and data palm can reduce indoor cooling demand by 47% [18], using lightweight concrete blocks as substitution of bricks by using clay bricks as a small in size and require a lot of concrete as masonry materials in joining each brick and plastering thrum from both the face, to produced lightweight blocks is low cost and reducing in weight by ratio 40% and less than 70% reduction in sound and thermal properties [19]. The using polystyrene foam plastic board as a porous material in composite building materials, the cost of that materials is reduced by about 30%, the weight also required by 40% [20], or used other waste materials like glass, polyethylene terephthalate, tile and sanitary ceramic, clay bricks, tires and rubber, metal, concrete waste, or agricultural waste (almond and coconut shell or rice husk) [21].

The building structure ventilation was used to decreasing the air inside room temperature from 31°C to 22 °C when using natural air [22], or using a double-skin external wall and using reflective surface inside gap [23], or passes humidifying ambient air through that gap [24], or using natural ventilation [25].

The second aspect focuses on energy consumption reduction is using the application of vertical greenery shading systems to improving the building energy performance by decreasing the external surfaces temperature in order to reduce energy consumption by 3% [26] and as a case study-Baghdad city / Iraq, the benefit of this system is reduced the indoor temperature by 4 °C [27], also as a case study Vietnam, the benefits of using vertical greenery was reduced the temperature differences of outdoor indoor by 8 °C, and the energy saving by 35% [28], and the Phoenix city / USA as a case study, the heat removal due to evaporation by vertical Greenery was 350 kWh/m^2 [29], and the energy-saving in the cooling period was 59% in Mediterranean sea countries [30], while, as a case study-Malaysia, the annual saving in electricity construction about 756kWh/year and the annual energy saving 18% [31], the indoor temperature reducing about (1-4) °C and reducing the energy by 0.7% in north Cyprus [32], while the solar control techniques to give the suitable shading for building facade in range 5% - 77%, [33], the numerical results about the Greenery affected with energy-saving were obtained [34].

Applying a greenery system as wall cover leads to limited benefits in preventing direct sun rays from reaching the wall because the effects only last for a short period of time compared to the length of day time and the number of hours the sun rays hit the wall. It was concluded that using the greenery system leads only to 4 degrees reduction in the temperature of the room in which walls are covered (in conjunction with wall orientation and building material used) leading to 28% energy saving. Therefore, the researchers recommended to create an external gap to separate the direct ambient air from the wall. The air in this external gap is moist and when it moves it creates a hygro-thermal condition that allows and guarantees less heat transfer into the building.

2. Material and methods

The temperature of the building space changes with the effect of several external and internal factors, the environmental effect through the building surfaces exposed to the different ambient temperatures (external walls, windows, and roofs), and internal factors like (occupancy people, rate and quality of lighting, devices, and equipment are inside the space) in addition, air infiltration from the building space and the rate of ventilation to be provided, The space temperature change from the designed value (which is recommended with the international thermal comfort level and which is appropriate to the nature of the activity inside the building), therefore requires treatment of air temperature to return it to the designed temperature which that is done by working air conditioning units for longer periods of time (which consume electrical energy during work), leads to higher energy consumption in the building. Reducing energy consumption rates is requiring to study all internal and external effective factors and because of the location of our study in Baghdad / Iraq, which is affected by the semi-desert climate, where the environment has a significant influence higher than the internal influences, so the focus has been on attempts to reduce heat transfer from the surfaces of the walls and roofs which exposed to the environment, without changing the nature of the use of the building and its attic, the rest of the effects were considered constant because their change is slight during the hours of one day [35], therefore the focus was on the test wall and thermal insulation of the rest of the surfaces, and the traditional wall was covered with materials available in the Iraqi market, which is the most efficient in reducing heat transfer through it [36].

In order to achieve the goals of this research, a room on the third floor of a building in Baghdad city has been set up for thermal testing. The room on latitude 33.2 °N with dimensions of (2×1×1) m, open to the influence of the environment during the whole year as shown in (Fig. 1). All the internal surfaces have been covered using polystyrene board (thickness 200 mm), with exception of the testing wall (2×1) m. The room is supplied with a 3.5 kW window type air conditioner to save the standard thermal comfort inside the room (26.5) °C [37].

The testing wall was constructed using common bricks (240mm thick) (case 1) and covered with one of the following materials in each test: facing brick (120mm thick) (case 2), tile brick (40mm thick) (case 3), limestone (40 mm thick) (case 4), and cement brick (40 mm thick) (case 5), the details as shown in (Fig. 2) (Thermal properties of covering materials shown in table 1) (which is the highest insulation material used in Iraq) [36]. The covering material was set to be 50 mm away from the wall, the 50 mm is the thickness of the iron frame, which used to support the cover material. This 50 mm space was used as an air gap by creating a small gap beneath the cover material

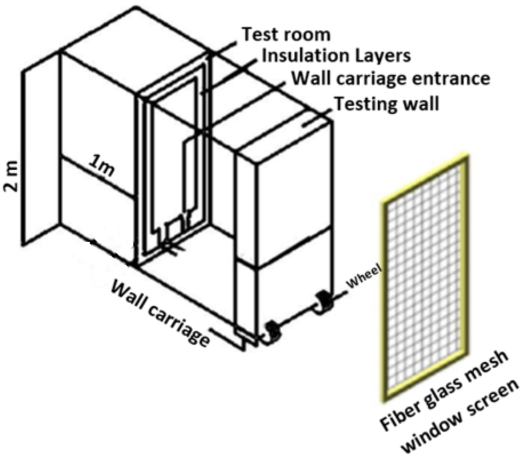


Fig. 1: Schematic illustrations the details of testing room

that ends in the top part of the wall where 2 fans were installed (each fan has a 150 mm diameter, 20 watts) creating vacuumed move the air in this gap to outside, using photocell to give the power to ventilation fans, and operating the Control circuit which used in humidifying ambient air as shown in (Fig. 3).

In addition, the interior surface temperature of test wall (Ti) and indoor air temperature (Tr) were recorded by using a pre-calibrated thermocouple, while the external surface temperature of test wall (To) and ambient air temperature at shading area (Tsh) were measured directly by using an intelligent self-thermometer.

Temperatures and measurements were recorded every 21st day of the month from May to September (summer months). The hourly temperature behavior for the studies walls (with and without humidifying) for June is demonstrated in (Fig. 4) as an example. For the steady state heat transfer conditions, at study state conditions, the environment effective was transferred to building space directly, no additional heat storage in element of building wall materials, therefore all the input heat was cussed raise that temperature level in that space, therefore, the free convection heat transfer coefficient (h) between the interior surface of the test wall into the room environment can be calculated as [38]:

$$h = 1.31\ (T_{i-r})^{1/3}$$

Then, the cooling load for test wall (Q), will be equal to [36]:

$$Q = h.A.\Delta T_{i-r}$$

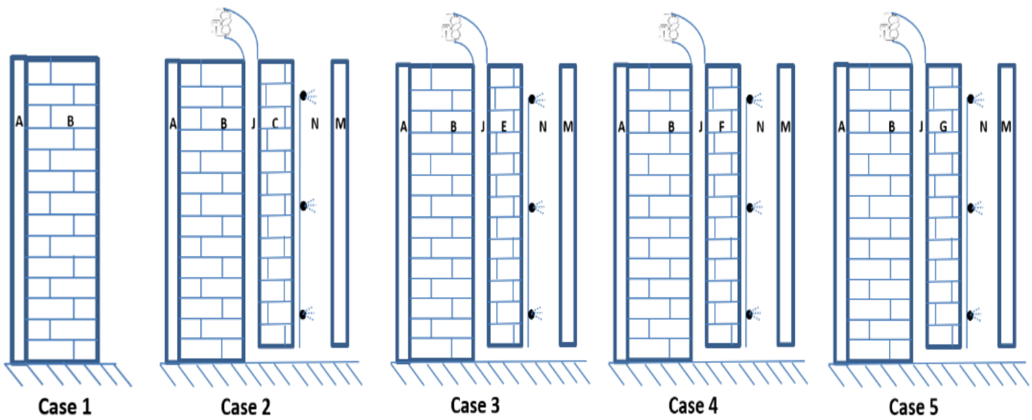


Fig. 2: Types of studied walls (A Gypsum 25 mm, B Common rick 240mm, C Face brick 120 mm, E Tile brick 40mm, F Limestone 40mm, G Solid cement brick 40mm, M Window screen / mesh, N External air gab and humidification System, J Ventilation duct 50mm)

Table 1: Thermal properties of covering materials

Basic building Materia	Case	External covering Material	Total wall thickness mm	Overall heat transfer coefficient (U) w/m^2. °C	Water absorption %	Time lag (hr)	Decrement factor
common brick 240 mm	1	Without covering	265	2.1	-	2:10	0.200
	2	Face brick 120 mm	385	1.726	4	3:40	0.410
	3	Tile brick 40 mm	355*	1.711	3.2	5:40	0.512
	4	Limestone 40 mm	355*	1.907	7.8	3:10	0.323
	5	Solid cement brick 40 mm	355*	2.059	6.1	2:50	0.211

* Included air gap 50 mm between basic and cover material

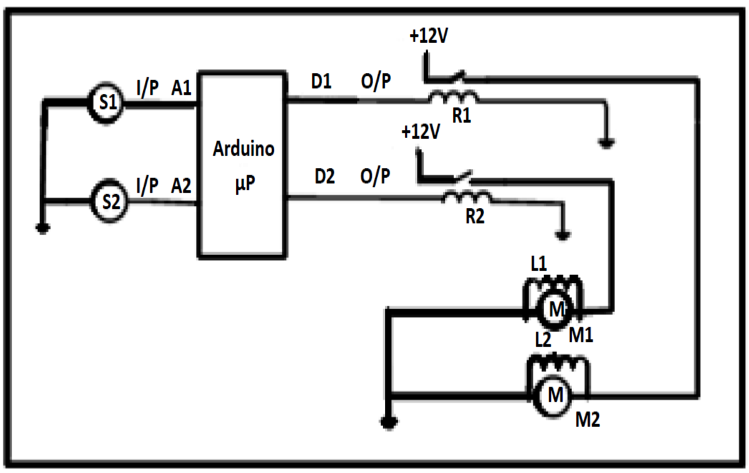


Fig. 3: Control circuit which used in humidifying ambient air (S1, S2 moisture sensors, R1, R2 water pumping relay and M1 water pump, M2 stand by pump)

The thermal properties of that drilled cement mortar finishing materials (density, (ϕ) Time lag and decrement factor (DF)) was obtained as:

Density was measured in building materials laboratories/ institute of technology/ Baghdad, while, Time lag and decrement factor was calculated as illustrated in (table 1), from (Fig. 5), as [38]:

$$\phi = t_{[T_{in}(\max)]} - t_{[T_{out}(\max)]}$$

Where, $t_{[T_{in}(\max)]}$ and $t_{[T_{out}(\max)]}$ are the time of day when the inside and outside surface temperatures reach maximum.

$$DF = \frac{T_{in}(\max) - T_{in}(\min)}{T_{out}(\max) - T_{out}(\min)}$$

Where, $T_{in}(\max)$ and $T_{in}(\min)$ are the maximum and minimum inside surface temperatures, $T_{out}(\max)$ *and* $T_{out}(\min)$ are the maximum and minimum outside surface temperatures.

2.1 Electrical enesrgy sources

Two kinds of electrical energy were supplies in this work, firstly, alternative energy- 220 V (Ac) from mainline (national net electrical energy), to operating the window type air conditioner unit, and electrical energy consumption has recorded as a wall using an energy analog instrument that connects directly to the line. Secondly, photocell of (500×500) mm dimensions, 60-watt, 12 V D.C, to operate the two vacuumed fans and water pump.

2.2 Humidification System

This study focused on determining the effect of humidifying for ambient air by using a special system which consists of a water tank (50 L capacity), 18 watt-12 V (Dc) water pump, 3 water spray nozzle-gauge 002 (water volumetric rate 3 L/h), plastic pipe 6 mm diameter to carrying composite water from the pump to spray nozzle and electrical control circuits.

The position of that spray nozzle on the external layer of the wall facing the fiberglass mesh window screen leads to the entrapment of fog waves between the wall surface and mesh. While, the position of moisture sensor on the mesh, for water conservation, the control circuit was used to operating the water pump responsible for pricing water to spray nozzle.

When the ambient air existing in the external gab, the moisture sensor was measured its relative humidity less than saturation level, closed the control electrical circuit, and was operating the water pump and fog waves deformed until the moisture of ambient air was reached to the saturated stage, opened the control circuit.

3. Results and Discussion

The thermsssal behavior has been obtained and documented in (Fig. 5), which shows the variation of temperature values for external surface (To), interior surface (Ti), and ambient temperature (Tsh), for a different type of wall coverings during one day (21st) for each summer months/2019. While (Fig. 6), shows the temperature differences through the outside and interior side for each recorded material with and without humidifying ambient air. (Figs. 7,8), (Figs. 9, 10) shows average temp. and electrical energy consumption, saving percentage.

3.1 Type of walls Studie

Due to a variety of building materials in the Iraqi construction residential building, double shells (skin) Facade Wall are the focus more thermal sufficient [36]. As shown in (Fig. 2), the Wall is made of two layers, the inner one is made of traditional System (regular) common brick 240 mm thick, while the external layer has been changed. Fore times (face brick 120 mm thick, tilt fired brick 40 mm thick, limestone 40 mm thick and solid cement brick 40 mm thick) which are the highest value of energy-saving from total recovery

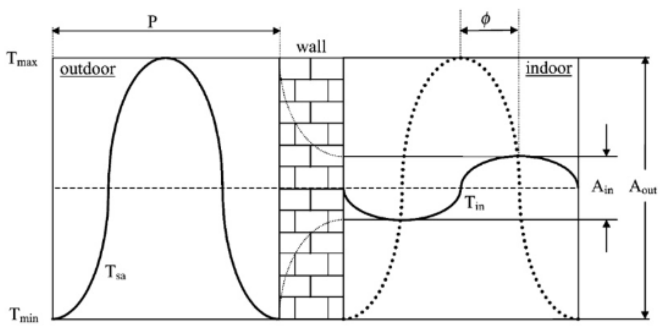
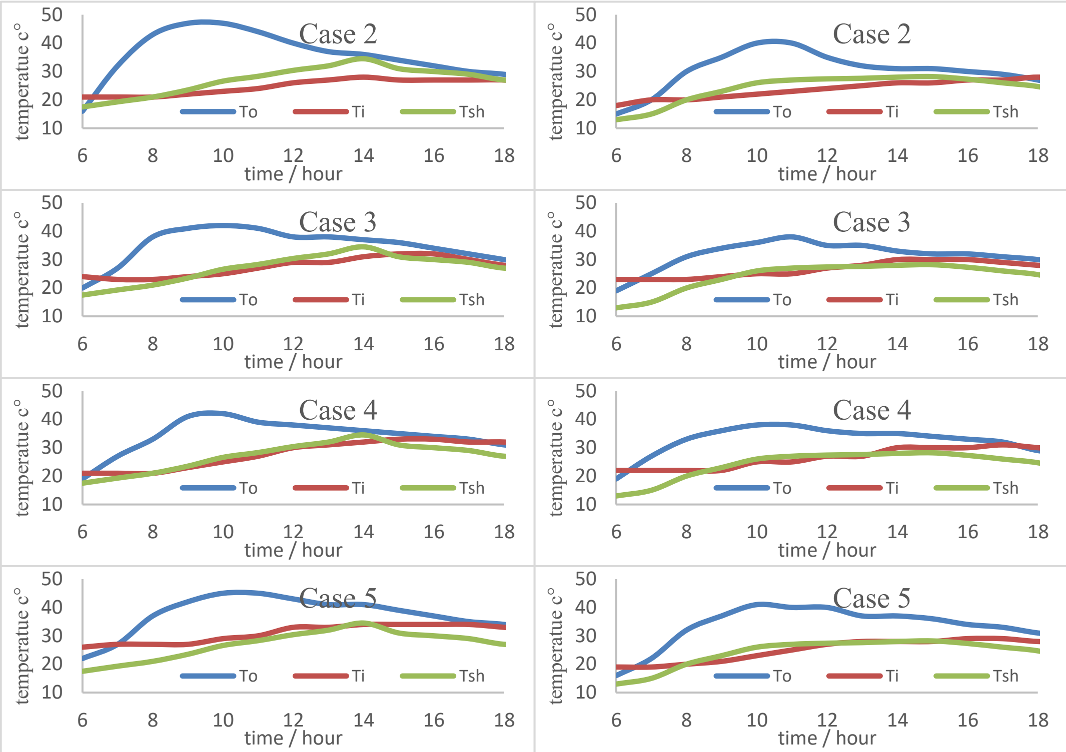


Fig. 4. Time lag and decrement factor calculation.



Without humidifying. With humidifying

Fig. 5: Thermal behavior of Studied walls with and without humidifying ambient air (To external surface temperature, Ti Interior surface temperature, Tsh Ambient air temperature)

materials using an Iraqi construction [36], 50 mm air gap has been established (between two layers) it's come from using angles iron for the fixed second layer, in which ambient air moves through it from down to up to remove any moisture that right has been transferred from an external layer in case it did not reach the inner layers.

3.2 Water spray nozzles tested

Three sizes with the lowest water consumption (as shown in table 2) have been tested as shown in (Fig. 11) (referred to as 00, 001, and 002) [39], and shows the air moisture percentage within the external air gap when the three types of water sprays used.

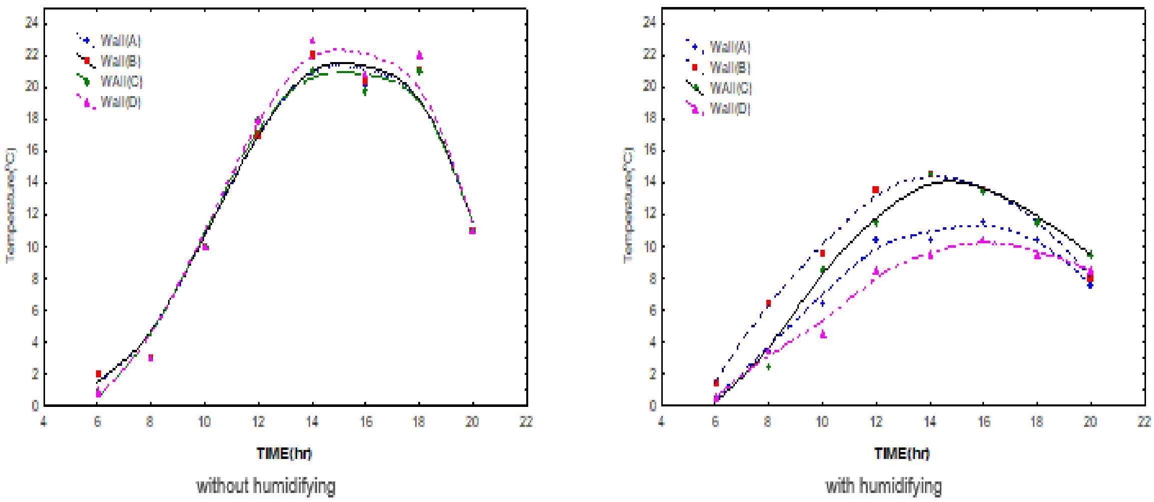


Fig. 6: Temperature differences between external and interior surface (ΔTo-i) for all walls (To external surface temperature, Ti Interior surface temperature, Th Ambient air temperature)

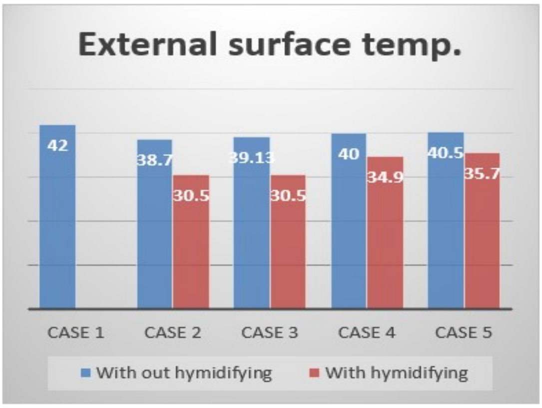


Fig. 7: Annual average for external surface temperature for Studied walls (T0), with and without humidifying ambient air

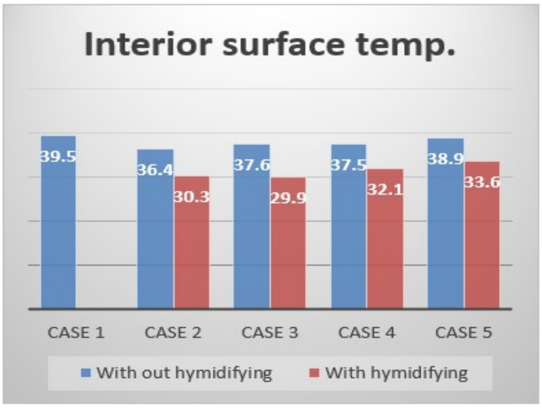


Fig. 8: Annual average for interior surface temperature for Studied walls (Ti)with and without humidifying ambient air

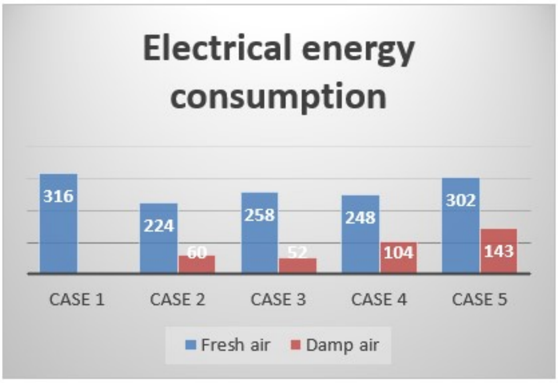


Fig. 9: Annual electrical energy consumption for cooling purposes with and without humidifying ambient air

The study shows that reducing the opening of the nozzle (size 002) leads to spreading the water droplets in fog like manner; due to the small size of the droplets which leads to delays in reaching the ground. This leads to a higher chance of the air particles in the external gap. When increasing the size of the nozzle opening (size 001), the water droplet's size becomes larger and therefore falls sooner into the ground which leads to a shorter time to be absorbed by the air particles in the external gap leading to a decrease in the percentage moisture of the air. In comparison, using nozzle opening (size 00) leads to a much bigger water droplet size and therefore a much lower chance of being absorbed by the air particles in the external gap.

In conclusion, three nozzles with an opening (size 002) were installed on the wall (average water consumption 3L/H).

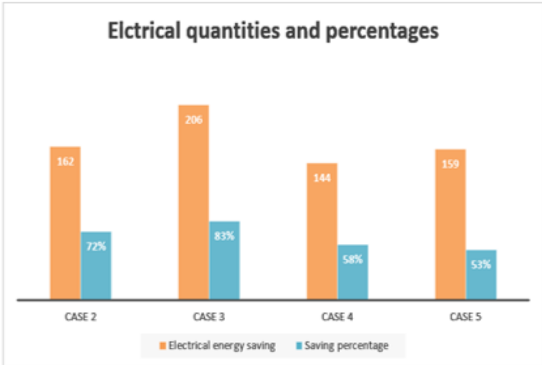


Fig. 10: Annual electrical energy saving and saving percentage for Studied walls

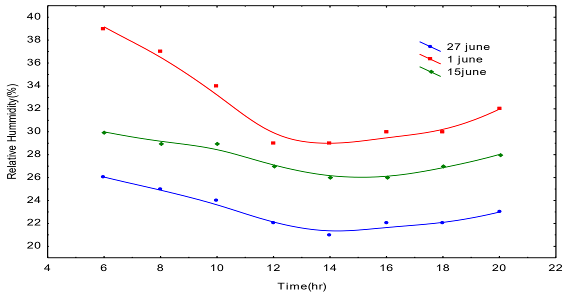


Fig. 11: Water spray nozzle testing for 00, 001, 002 size at 27st, 15st and 1 Jane

Table 2: Water spray nozzle specifications [39]

Nozzle No.	Water Dispenser L/h
002.	3
001.	5
00.	10
01.	20
02.	25
03.	30
04.	35
05.	40

3.3 Wall surface temperatures

The ambient air temperature has been affected directly on the wall temperature value, (Figs. 5, 6) shows the external surface temperature (To), and the interior temperature (Tr) withered varied through a time of day with and without humidifying and can notice clearly decreases that temperature by using humidifying. (Fig. 7) represents the value of external and interior surface temperature differences with and without humidifying the air, and also shows that temperature differences for all wall Studied with and without humidifying, the lowest temperature differences occurred at wall case 3.

(Fig. 8) shows the average temperature value is 38.7 °C, for the external surface for case 2, which dropped to 30.5 °C, when ambient air was humidifying. This indicated that increasing the moisture content of air allows for humidifying behavior to occur.

The average temperature for all Studied cases was recorded at 39.13 °C, 40 °C, 40.5 °C, respectively. When adding the moisture to the air, these temperatures dropped to 30 °C, 34.9 °C, 45.3 °C, respectively. The average temperature of the interior surface that faced room air, was 36.4 °C, 37.6 °C, 32.6 °C, and 38.9 °C, respectively for studied cases 2, 3, 4, and 5, but that temperature value dropped to 30.3 °C, 29.8 °C, 32.1 °C, and 32.6 °C respectively in presence of moisture in the ambient air. The temperature differences between interior and the standard room temperature was 9.9 °C, 11.1 °C, 11 °C, and 12.4 °C, for Studied cases, but become were 3.8°C, 3.3 °C, 5.6 °C, and 7.1 °C for studied cases.

3.4 Electrical energy

The electrical energy consumed for cooling purposes through summer months within natural ambient air for a traditional wall (case 1) was 316 kWh as shown in (Fig. 9), the four another studied cases in this research recorded consumption of 224 kWh, 258 kWh, 248 kWh and 302 kWh. When the water spray nozzles pump was operating to humidifying the ambient air in the external gap, a drop in the electrical energy consumed was noticed, 60 kWh, 52 kWh, 102 kWh, and 143 kWh for studied cases. Achieved energy-saving shown in (Fig. 10), was 162 kWh, 206 kWh, 144 kWh, and 159 kWh. Saving percentages as shown in (Fig. 10) were recorded for studied cases 72%, 83%, 58%, and 53%.

3.5 Materials covered perfect

(Fig. 6) shows that the wall in case 3 achieves the highest reduction in surface temperature difference, which leads to a reduction in the amount of heat transferred from ambient to inside the room. This, in turn, leads to a reduction in turn leads to reduction of electrical energy consumed for cooling purposes and achieving the highest saving percentage due to lower heat transferred coefficient when compared to other cases.

4. Conclusions

- It is possible to construct the carrying walls (low heat transfer coefficient (U)) from a double-shell (skin) building system which was contained on the opened air gap.
- The facade shading by greenery System was good hence, and the energy-saving percentage not more than 28% from annual electrical energy consumption for cooling.
- In the Iraqi constitution market was founded huge covering materials, and the more perfect to reduce the cooling load was face bricks 120 mm, tilt fire brick 40 mm, limestone 40 mm, and solid cement brick 40 mm.
- External air gap deformation was a good solution to avoid the direct ambient effectiveness on building
- The external building surface temperature (gap) were recorded in the range (38.7 - 40.5)°C.
- The interior surface temperature (gap) was recorded in the range (36.4 - 38.9)°C.
- When using the humidifying the air in that external gap, the external surface temperature reducing to (30.5 - 35.7)°C, while the interior surface temperature was also reduced to (30.3 - 33.6)°C.
- The humidifying air in that external gap was more efficient for energy-saving for cooling in range (144 - 206) kWh and the energy-saving percentage was in range (53 - 83) % according to which consumed at the traditional wall.

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