Reducing the cooling load of an residence building by humidifying ventilation air (experimental and numerical study)

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Abstract. The study investigates the benefit of utilizing the waste water which washed the walkway of residential buildings to humidity the ventilation air that supplied to the building. The water will collect in a concrete channel section (100 * 100 mm) in contact with the wall of the building towards the drainage network. The side adjacent to the wall contains (5mm) diameter holes ending with an air gap located behind the external wall metallic finishing. The ventilation (environmental) air (naturally or forcibly) passes through the holes to the air gap through the holes. This causes the temperature to decrease and the moisture content of the air is increased. The moving air passes through the gap towards the environment through the openings at the top of the wall. The study is carried out Baghdad city (latitude 33.2 ° North) using two types of external finishing material (Aluminum sheets) reflector and plates coated with thermal dyes. Also, employed an air gap or an air gap with thermal insulation thickness (50 mm) placed behind the plate. As well as the case of the air gap is open to the environment during day and night or closed day and “open at night” with an exhaust fan that worked by solar energy. The results showed that in the case of the air gap behind the external finishing material with thermal insulation, the fan operates during the day hours of the day and the area (1 m²), the cooling load required during the summer is (306 kW-hr / m² -cooling season). While the cooling load of the common wall is (609 kW-hr / m² -cooling season). Thus, the savings rate is (49.8%) when used this technique.

1. Introduction
The climate, in Iraq, is so hot during summer. The constructed buildings often used conventional wall which consisted of bricks, cement and gypsum plaster which causes large heat transfer affecting by the environment across building surfaces (environment exhibition). Leading to a rise in air temperature inside that building to a higher level than that specified by thermal comfort requirements. Therefore, it is crucial for resorting to using air conditioning units, which consume electrical power when operated for the purpose of controlling air temperature and bring it back to the level internationally recommended. Residential buildings in Iraq are the main consumer of electric power produced where consumption exceeded (60%) from power produced throughout Iraq [1]. Annually, the largest proportion of that power goes to operate air conditioning units (Number of units purchased for the years 2011-2016 are 30 million) [2] and the citizen defrayed the cost of these units consumes. In addition to that it is added a load on the national electricity network and increased carbon gases emissions from plants that producing electricity. Therefore, reducing amounts of heat transfer into the building through walls means reducing capacities of refrigerating units and decreasing in electric demand and air emissions. Photovoltaic cells have an important function in minimizing building energy demand when provided electrical power into the building and air gaps were used to reduce the impact of building’s integrated photovoltaic on cooling.
and heating loads. Wang et al. [3] analyzed two types of air gap between the solar cells and the building roof, ventilated air-gap and non-ventilated (closed) air gap. In summer, the PV ceiling with ventilated is appropriate and produces low cooling load and high PV transformation efficiency. The PV ceiling with non-ventilated air gap leads to low heating load and high electrical PV output. The width of the ventilated air gap facade buildings was analyzed numerically in difficult climate condition by [4]. Air velocity was tested for (40mm, 150mm and 300mm) gap width, it is found that the temperature profiles at (40mm) gap are more uniform and average speed is higher than others. The heat transfer coefficient value for single layer wall is high to obtain comfortable building. So that Ouedraoge et al. [5] analyzed using two-tier wall to reduce heat transfer coefficient. From results heat transfer coefficient decrease at (38.75%) and this percent can be improved when air gap employed between two wall layer at (47.48%).

[6] performed an experimental study to estimate the assistance of thermal insulation to reduce the cooling load. Extruded polyethylene insulation layer with a reflected alu-foil covered the external surface of the tested room. The results present that the annual economy in cooling energy will be about (30%) compared to the traditional blinding. The high reflective ceiling was utilized by Mohamed et al. [7] in Iraqi houses to reflect solar radiation then diminish heat transfer into a building and air conditioning capacity at the hottest day. Several building orientations were tested to find the more energy consuming direction. The higher reduction in energy request obtained is (25% and 24%) in July and August respectively, total annual reduction energy demand is (solar reflective=0.8) and (thermal emissivity=0.9). The south-west direction was chosen the most energy dense consuming (21805.39 kWh). Also, Mohamed et al.[8] studied the impact of using a reflective ceiling, radiant screen and interior radiation control painting to minimize space cooling of Iraqi residence and electricity requirements. Reflective ceiling has the highest reduction in cooling load about (14%) and (17.4%) reduction in annual energy requirement. The influence of surface finish on the energy requirement was investigated by [9].

A modified coating on the envelopes of the constructed building was used to enhance energy efficiency of the attic with the inclined roof. Thermal properties of this coating was high reflectivity and high emissivity (cool paints) for external finishes with low emissivity inside surfaces. Thermal efficiency has been reduced (60%) in cooling requirements when used cool paint on the outside surface of envelope and heating requirements will be reduced up to (12.5%) with employed low internal emissivity coating. The same technique was introduced by [10]. The suggestion coating are: red tile cool paint (reflectivity for solar radiation \( \rho = 0.79 \), emittance \( \varepsilon = 0.89 \) ), white cool plaster on external vertical walls surface (\( \rho = 0.88, \varepsilon = 0.9 \)) and low emissivity plaster on internal building surfaces (\( \varepsilon = 0.62 \)). The coating on the external surface reduced cooling the energy demand of (34%) and increased of (9.5%) at heating compared with conventional coatings, these actions were suitable for the hot climate. Internal acts were adequate in both summer and winter, energy requirements for cooling and heating decreased at (6.6%) and (17.8%) respectively. The influence of thermal insulation, reflective surface, ventilated wetted air gap façade residence and thermal painting are investigated in this paper experimentally and numerically to decrease energy requirement for Iraqi residence following page setup measurements.

2. Specialization of Iraqi citizen:

The majority of Iraqi citizens live in Separated residential houses at (78% percent) of living places in Baghdad [11] and they wash external walkways almost twice a day [12]. Washing water goes to the sewage network. The aim of this work is collected this water before drainage and utilized to wetting surrounding air that passed through an air gap to diminish its temperature. This water accumulates in a concrete channel with a cross- section area (100mm*100mm) and builds up vicinity to the wall such as drainage pipes as shown in Figure 1. Channel’s wall on the side of the room wall contains (8) holes in diameter (50mm) and (100mm) distance between two sequent holes from center to center. Accumulated water leads to wetting channel and reducing its temperature, when air passing through it heat exchange occurs between air and channels surface. Wetted surface takes off heat from hotter air which results to decrease air temperature and increase its humidity. Wetted air will be passed through air gap suggested in this research.
3. Experimental setup:
The experimental Room is built with dimensions (1*1*2 m), located on the third floor of a building constructed in Baghdad (Latitude 33.2° north) and exposed to the surrounding environment as shown in Figure 2. From inside, all room walls and ceiling insulated by polystyrene sheet (200mm thickness) except the tested wall (1*2 m) which orientated to the east. The tested wall is a movable part for the purpose for adding modifications. Air conditioning unit (ACU) has a refrigeration capacity (0.5 TR) employed to obtain standard comfortable condition (26.5 °C and 65% relative humidity) [13]. The electric power meter, in (kW.hr), was employed to measure the quantity of consumed electrical power from (ACU).

The two calibrated thermocouple and digital thermometer are used to measure both temperatures for air room (Tr) and the internal face of tested wall (Ti). Moreover, the intelligent auto digital thermometer was used to measure the environment temperature in the shade (Tsh) and the external face of the tested wall (To). The experimental readings are recorded in summer season (May to October on 2017) from 6:00 AM to 6:00 PM for twenty-one days.

Room wall constructed of (25mm) gypsum plaster, (240mm) brick and (20mm) cement with rough external surface. Table (1) illustrated the thermal properties of Iraqi material that used in this paper [14]. Suggested improvements to reduce the cooling load of the test room and energy requirement are:

Reflective surface: When the thermal radiations strike the reflective surface they are sent back from the surface and do not pass through it which make less heat transfer through the wall. There are unlimited alternatives to the building material packaging available in Iraqi markets used to restoration and covering building facades.
The aluminum sheets cauterized with a low price and high form ability, so they choose in this work. Aluminum reflective sheets, [ANS H35.(2001)] and (0.8 mm thickness), are added to the external surface of the tested wall on distance (50mm) as shown in Figure 3. Two types of sheets used: the first is the ordinary polished sheets and the second is the sheet dyeing with matt thermal paint (1mm thickness). The sheets installed on an iron structure at a distance (50 mm) from the wall. The thermal insulation, 25mm in thickness, settled on the cement layer to decrease heat transfer rate into room space.

Figure 3. External view of modified wall

Air gap: An air gap is formed between the tested wall and reflective surface (50mm) width. The top end of the air gap is joined with elbow duct to allow wetted air passing over room ceiling; three fans with (0.4 m/s ) velocity are placed in the duct to suction air. Experiments are conducted in the case of forced and natural flow of air in the gap.

Two form of air gap are tested. One of them is closed air gap that closed the air exit slots through a day and opened at night. The other is ventilated air gap (opened air exit) which is opened through a day and night in two case natural and forced flow air through the gap. Fans assist air to pass through the wetted concrete channel and enhance heat transfer between them. The Photovoltaics cell with (40*60 cm) produced (15 W) is used to operate the fans. The different kinds of modified wall suggested in this paper are illustrated in Figure 4.
Free convection heat transfer coefficient between the internal surfaces of tested wall into room environment can be calculated from [15]:

\[ h = 1.31 (\Delta T_{i-r})^{1.3} \]  \hspace{1cm} (1)

then the cooling load will be equal:

\[ Q = h \cdot A \cdot (\Delta T_{i-r}) \]  \hspace{1cm} (2)

To obtain the energy saving due to modification in conventional wall, (E) which is the electrical energy consumed to preserve the comfortable condition in tested room must be recorded.

\[ \text{Energy saving} = \frac{\Delta t_E}{E} \% \]  \hspace{1cm} (3)

In this study, the quantity of heat transfer through walls is uncertainty analyzed and the maximum present obtained is (3.2\%).

4. Numerical analysis:
Using (ANSYS-FLUENT 15) [16] to study temperature distribution and air flow through the modified wall which suggested to diminish heat demand. The fluid properties are assumed constant except for the density variation, which treated according to Boussinesq approximation. The present flow is considered
steady, laminar, incompressible and two-dimensional. The viscous incompressible flow and the temperature distribution inside the enclosure described by the Navier–Stokes and the energy equations, respectively [17]:

\[
\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0
\]

Continuity equation (4)

\[
U \frac{\partial U}{\partial X} + V \frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \frac{1}{Re} \left[ \frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2} \right]
\]

X- component of momentum equation (5)

\[
Y \frac{\partial V}{\partial X} + V \frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + \frac{1}{Re} \left[ \frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2} \right] + Ri \theta
\]

Y- component of momentum equation (6)

\[
U \frac{\partial T}{\partial X} + V \frac{\partial T}{\partial Y} = \frac{1}{Re Pr} \left[ \frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2} \right]
\]

Energy equation (7)

And the parameters Re, Ra and Pr are defined as:

\[
Re = \frac{u_i L}{\gamma} \quad \text{Ra} = \frac{g \beta (T - T_i) L^3}{\gamma^2} \quad \text{Pr} = \frac{\gamma}{\alpha}
\]

(8)

In the wall region, continuity and momentum equations (1,2&3) are not taken in the solution owing to the absence of fluid and motion in this region. The solving energy equation in (ANSYS FLUENT – 15) can be used to obtain the temperature distribution. The equations (1, 2, 3&4) are settled to determine velocity, temperature profile and heat transfer rate in air gap.

The boundary conditions shown in Figure 5 are:

Inside the air gap
At the inlet   U=0, V=0, \theta=0
Convective boundary condition (CBC) at the outlet   P=0
At all wall boundaries   U=0, V=0, \frac{\partial P}{\partial n} = 0
At the solar heated right wall   \theta=1
At the left, top and bottom walls   \frac{\partial \theta}{\partial X} \bigg|_{X=0} = \frac{\partial \theta}{\partial Y} \bigg|_{Y=1,0}

Figure 5. Schematic Diagram of the Boundary Conditions
For the walls shown in Figure 6, computational domain produced by utilizing pre-treatment software GAMBIT was used. Mesh generation into (170591) triangle cells or (161720) nodes was assigned to have high solution accuracy and uniform pressure and temperature distribution. The SIMPLE algorithm which used a relationship between velocity and pressure corrections was employed with 2nd order upwind to solve momentum and energy equations. At the hot wall, the average Nusselt number (Nu) defined as:

$$Nu = \frac{1}{H} \int_{0}^{H} \frac{\partial \theta}{\partial X} |_{X=1} dY$$  \hspace{1cm} (9)

The bulk average temperature in the cavity is defined as:

$$\theta_{av} = \frac{1}{V} \int \theta dV$$ \hspace{1cm} (10)

Figure 6. Mesh computational domain of the present study

5. Results and discussion

In this work, there is an experimental and numerical investigated of the effect of suggested walls on heat transfer and cooling load. In the experiments, the wall temperature recorded of both external surface and internal surface during day hours. Figure 7 illustrates the hourly thermal behavior for air gap and reflective surface wall, air gap and thermal painting surface wall with and without thermal insulation in the gap at natural and forced air movement.

(a)  
(b)  
(c)
The average value of \((T_o, T_i, \text{and} \ T_{sh})\) are used to calculate the cooling load, electrical energy consumed, and saving energy for the wall (1) to the wall (13). The experimental results obtained which shown in the Table (2) can be discussed as follows:

5.1. The temperature of the internal face of the wall (\(T_i\)):
The effect of the environment will be inverted on the temperature of the air inside gap, heat transfer rate through the wall component then the temperature of the internal face of the wall (gypsum plaster). For a conventional wall this temperature will be \((49.1 \ ^\circ C)\) and \((47.55, 45.65 ^\circ C)\) at utilization reflective surface with closed air gap through the day and with opened air gap through the day (wall 2 & wall 3) respectively. Due to the temperature difference of wetted concrete and air occupied the gap, convection currents have occurred in a natural way which leads to diminishing \((T_i)\). When the upper aperture of the gap is opened the hotter air will be raised toward this aperture and created pressure permeated in the gap resulting air drawing through the concrete openings which are wetted and saturated with washed water. This process conducted at the disposal of accumulated heat in the gap and decrease \((T_i)\). In other words, the presence of wetted concrete is contributed in diminishing heat transfer to room space and cooling load needs to maintain comfortable condition. To enhance air movement through concrete passage and gap, three small fans were used with \((15 \ W)\) needed to operate each one and this power was supplied from photovoltaic cells fixing on the room roof. More heat transfer from room space to moving air across the modified wall (wall 3) and \((T_i)\) was gone down into \((44.9 ^\circ C)\). Average temperature difference between \((T_i)\) and the external surface of the wall temperature \((T_o)\) is \((6.56 ^\circ C)\) for the conventional wall. Moreover, these differences for the reflective surface wall are \((8.11 , 10.01 , 10.76 ^\circ C)\) with a closed air gap, opened air gap and opened air gap (forced circulation) (wall 1, wall 2&3), respectively.

Figure 7. Illustrate thermal behavior of the suggested modified wall
5.2. Temperature difference inside air space ($\Delta T_{i-r}$):
The amount of heat (cooling load) that the ACU must be drawn from room space is related with ($T_i$) and standard comfortable temperature ($T_r$) which has been counted on (26.5 °C) [13]. ($\Delta T_{i-r}$) is (22.6 °C) for the conventional wall (wall 1) and (21.05 , 19.45 ,18.4°C) for the reflective surface wall with a closed air gap, opened air gap and opened air gap (forced circulation) (wall 2, wall 3 & wall4) respectively. Then the cooling loads required are (179 ,162.8 ,143.6 and 134.2 kW/m²) for a conventional wall, a reflective surface wall with a closed air gap, opened air gap and opened air gap (forced circulation) respectively.

5.3. Existence of thermal painting on the reflective plate:
Utilization thermal painting on a reflective plate is increased wall thermal resistance and therefore ($T_i$) will be decreased into (45.29, 43.42, 42.57 °C). This decreasing was for thermal painting surface wall with a closed air gap, opened air gap and opened air gap with a fan (wall 8, wall 9 and wall 10) respectively and caused ($\Delta T_{i-o}$) by (18.7, 16.92, 16.07 °C) according to the previous arrangement.

5.4. Utilization thermal insulation:
Addition thermal insulation on the external surface of the cement layer in a modified wall will be augmented thermal resistance and lessening heat transfer rate into room space. Also, ($T_i$) is decreased to (46.56, 45.40, 44.3 °C) and ($\Delta T_{i-o}$) becomes (9.1, 10.26, 11.36 °C) for reflective surface wall with closed air gap, opened air gap and opened air gap (forced circulation) (wall 5, wall 6 and wall 7) respectively. As previously mentioned, the width of the gap (50 mm) and the thickness of insulation layer (25 mm) so that the free passage to flow air will be (25 mm). This leads to increase air velocity and convection current through the gap. ($\Delta T_{i-r}$) be equal to (20.06, 18.9, 17.8 °C) according to the sequence of previous gaps which reduced the cooling load to (152.7, 141.1, 130.3 kW/m²).

5.5. The combined effect of thermal insulation and thermal painting:
From Table (2), it can be seen that ($T_i$) equal to (42.15, 40.74,39.97 °C), ($\Delta T_{i-o}$) (13.51, 14.92, 15.69 °C) and ($\Delta T_{i-r}$) (15.65, 14.24 ,13.4 °C) for thermal painting surface wall and thermal insulation with closed air gap, opened air gap and opened air gap (forced circulation) (walls 11, 12 & 13) respectively. The cooling load can be decreased by (109.8, 96.8, 90 kW/m²).

5.6. Energy savings:
Employment the modified walls are conducted to decrease electrical energy demand when compared with the conventional wall (wall 1) and the differences between them are (56, 121, 153 kW/hr). The energy savings ratios are (9.2, 19.9, 25.2 %) for the reflective surface wall with a closed air gap, opened air gap and opened air gap (forced circulation) (walls 2, 3 & 4) respectively. The savings have risen when using thermal painting as (167, 195, 223 kW/hr) and energy savings ratio became (27.4, 32, 36.6 %) (walls 8, 9 & 10) while the savings are (90, 131, 166 kW/hr) and savings ratio equal (14.8, 21.5, 27.3 %) at modified wall with thermal insulation (wall 5, 6&7). The highest rate in energy savings obtained when utilization thermal painting and thermal insulation with the reflective wall (wall 11, 12 &13) were (236, 280, 303 kW.hr) and savings ratios were (38.8, 46.0, 49.8 %).
Table 2. The experimental readings and results

| Wall kinds                      | Thermal insulation | Air gap   | Wall No. | $T_i$ (°C) | $\Delta T_{i-o}$ (°C) | $\Delta T_{i-r}$ (°C) | $Q$ kW/m$^2$. season | $E$ kW.hr/m$^2$. season | $\Delta t$ E | Energy saving % |
|---------------------------------|--------------------|-----------|----------|------------|----------------------|----------------------|---------------------|---------------------|--------------|----------------|
| Conventional                  | /                  | /         | 1        | 49.1       | 6.56                 | 22.6                 | 179                 | 609                 | /            | /              |
| Modified wall with reflective  | closed             | /         | 2        | 47.55      | 8.11                 | 21.05                | 162.8               | 553                 | 56           | 9.2            |
| plate                          | opened             | /         | 3        | 45.65      | 10.01                | 19.45                | 143.6               | 488                 | 121          | 19.9           |
| Modified wall with reflective  | closed             | with fan  | 4        | 44.90      | 10.76                | 18.4                 | 134.2               | 456                 | 153          | 25.2           |
| plate                          | opened             | /         | 5        | 46.56      | 9.1                  | 20.06                | 152.7               | 519                 | 90           | 14.8           |
| Modified wall with thermal     | With               | opened    | 6        | 45.40      | 10.26                | 18.9                 | 141.1               | 478                 | 131          | 21.5           |
| painting                       | insulation         | with fan  | 7        | 44.3       | 11.36                | 17.8                 | 130.3               | 443                 | 166          | 27.3           |
| Modified wall with thermal     | closed             | /         | 8        | 45.29      | 10.37                | 18.79                | 130.2               | 442                 | 167          | 27.4           |
| painting                       | opened             | /         | 9        | 43.42      | 12.24                | 16.92                | 121.3               | 414                 | 195          | 32.0           |
| Modified wall with thermal     | closed             | with fan  | 10       | 42.57      | 13.01                | 16.07                | 113.8               | 386                 | 223          | 36.6           |
| painting                       | opened             | /         | 11       | 42.15      | 13.51                | 15.65                | 109.8               | 373                 | 236          | 38.8           |
| Modified wall with thermal     | closed             | opened    | 12       | 40.74      | 14.92                | 14.24                | 96.8                | 329                 | 280          | 46.0           |
| painting                       | opened             | with fan  | 13       | 39.97      | 15.69                | 17.47                | 90.0                | 306                 | 303          | 49.8           |

In the numerical analysis, the studied parameters are included outlet wall temperature ($T_o$), fan velocity and the presence of the insulation for the closed and open air gap. In the experiments, the maximum ($T_o$) obtained was 61 °C so that the temperatures have been selected in numerical analysis are (30, 40, 61 °C) with fan velocities of (0.1, 0.2, 0.4, 0.6, 0.8 m/Sec). The numerical results are presented as temperatures, velocity distribution and with the Nusselt number for all cases and conditions employed in this study. The effect of the air gap, air gap, air flow through the gap (forced or natural flow) and thermal insulation on temperature and velocity distribution are plotted in figures (8-11). The results show that the temperature distribution decreased from the external wall surface toward the room inner wall. In wall 5, the closed gap, the variation in temperature is gradual but in wall 7, the opened gap the variation is sharp. From the velocity distribution, wall 5 with a closed gap, it observed that the convection current between the hot external surface and the cold internal surface will occur around stagnant air in the central area of the gap in the opened gap, the velocity enhanced adjust hot external wall and thermal boundary layer will form at the cold internal surface with increasing layer thickness toward the air exit.

![Figure 8. Temperature distribution in the case of closed gap without fan with insulation (wall 5).](image-url)
Figure 9. Velocity distribution in the case of closed gap without fan with insulation (wall 5).

Figure 10. Temperature distribution in the case of open gap with fan at inlet velocity of (u=0.1 m/Sec) and with insulation (wall 7).

Figure 11. Velocity distribution in the case of open gap with fan at inlet velocity of (u=0.1 m/Sec) and with insulation (wall 7)

By plotting the velocity profile inside the air gap with the time of solar radioed in the day from 6 A.M to 6 P.M in Figure 12. The results showed that the minimum air velocity found at 6 P.M and the maximum air velocity at 10 A.M. Also, the profile increased near the heated outer wall at x=0.28 m.
Figure 12. Air velocity profile with gap distance in the case of open gap with fan at inlet velocity of \(u=0.4\) m/Sec and without insulation.

Figure 13 illustrates the effect of air gap velocity in the case of the open gap with different fan inlet velocity at outlet temperatures \(T_0=30°C\) and without insulation. The results showed that the increasing the fan air velocity, the air velocity profile will increase dramatically. But when using the insulation along the outer wall the velocity profile will deflect near the inner wall.

Figure 13. Air velocity profiles with gap distance in the case of open gap with different fan inlet velocity at outlet temperatures \(T_0=30°C\)

The profile of the air temperature inside the air gap for an open case with different fan inlet velocity at outlet temperatures \(T_0=30°C\) and without insulation plotted in Figure 14. The profile is for two velocities of 0 and 0.8 m/Sec. The results showed that the using insulation will be decreased the temperature from 28.5 °C to 26.2 °C at \(X=0.2\) m.
Finally, a comparison between numerical and experimental results for the energy presented in Figure 15. The results showed that there's a little deviation by about 3% between the results presented by the simulation study of the energy of a modified wall with the reflective plate for the case of with and without insulation.

**Figure 15.** The numerical and experimental energy of modified wall with reflective plate

6. **Conclusion:**
In this work, experimental and numerical analysis was done to show the effect of using new techniques to eliminate cooling load and electrical energy demand in a residential building. These techniques are utilized waste washing water to wet air passing through the modification suggested wall to enhance the ability of air to absorb heat from the tested room. Aluminum reflective sheets were employed as a façade of natural and forced ventilated air gap. It is found that the opened air gap is best thermal performance than closed gap which can be considered as thermal insulation due to limited effect of convection heat transfer. Opened air gap with the fan was improved energy saving at approximately (1.84 & 1.26 times) than closed air gap and opened air gap. When using thermal painting aluminum sheets, energy saving is (2 times) better than polished aluminum sheets. The modified wall consist of gypsum, brick, cement, insulation, opened air gap with fan and thermal painting reflective aluminum. This wall have high energy
saving ratio of (49.8\%) when compared with conventional wall and the highest ratio of deviation between experimental and numerical analysis is (3\%).

**Nomenclatures:**

- **A** Area [m²]
- **C_p** specific heat of the fluid, [kJ/kg.K].
- **E** Electrical energy demand [kW.hr/m²]
- **g** gravitational acceleration [ms⁻²]
- **h** convective heat transfer coefficient, W/m².K.
- **k** thermal conductivity of fluid [Wm⁻¹K⁻¹]
- **L** length of the air gap, [m]
- **Nu** average Nusselt number, \( Nu = \frac{hL}{k} \).
- **P** dimensionless pressure
- **Pr** Prandtl number, \( Pr = \frac{\nu}{\alpha} \).
- **Q** Heat transfer rate [kW/m²]
- **q''_s** solar surface heat flux, W/m².
- **Ra** Rayleigh number, \( Ra = \frac{g\beta \Delta T L^3}{\alpha \nu} \).
- **Re** Reynolds number, \( Re = \frac{u_i L}{\nu} \).
- **T** dimensional temperature [K]
- **u, v** dimensional velocity components, [ms⁻¹]
- **U, V** dimensionless velocity components
- **W** width of the air gap, [m]
- **x, y** Cartesian coordinates [m]
- **X, Y** dimensionless Cartesian coordinates

**Greek Letters**

- **α** air thermal diffusivity, [m²/sec].
- **β** air compressibility, [K⁻¹].
- **μ** air dynamic viscosity, [Pa.sec].
- **ν** air kinematic viscosity, [m²/sec].
- **θ** dimensionless temperature.
- **ρ** air density [kg/m³].

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