Thermal Performance of an Integrated Earth-Air Tunnel System with Building's External Wall in UAE

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Abstract - **This paper addresses the evaluation of the thermal performance of integrating the Earth-Air Tunnel System (EATS) with the building's external composite walls. The potential heat gains reductions through the buildings' envelop as well as the consequence reduction of cooling demand were estimated. EnergyPlus simulation program was used to estimate the EATS outlet temperature. The EATS was sized to supply a flow rate of 0.52 m³/s of air which was used primarily to ventilate the air gap inside the external composite wall of the building. The obtained results revealed that the soil temperature at 6 meters depth is about 30 °C and remains relatively constant across the year. Also it was found that the air temperature inside the EATS dropped from 47.0 °C to 32.3 °C and the ventilated external wall's overall heat transfer coefficient reduced from 0.538 to 0.474 W/m²K, accordingly. The proposed design was implemented for the case study of an office building located in Dubai. It was found that the proposed EATS model contributed to 11 % reduction in the Annual Energy Consumption (AEC) and cut off CO_2 emissions by about 7 tons/year.**

Keywords: Earth-Air Tunnel System, dynamic composite wall, annual energy consumption.

1. INTRODUCTION

The United Arab Emirates (UAE) general climate characteristics are classified as arid and semi-arid zones, temperature during summer may reach up to 48.0 °C with a relative humidity reaching up to 90% [1]. In UAE, the residential sector is the major electricity consumer with 33% of total electricity consumption. Also the statistics revealed that the electricity consumed just for the purpose of space cooling in Dubai is about 50% of the total energy consumption which is equivalent to 13700 kWh/year [2]. Moreover, the global warming is expected to increase the energy demand for cooling in residential buildings existed in UAE which in return will contribute to higher level of CO_2 and Greenhouse Gases (GHG) emissions by 5.4 % in the next decades. In order of the construction of energy buildings to be efficient, it should be technically and economically feasible, and it should be aligned with local and international codes of health, safety and environment. Many studies have proposed efficient solutions for reducing cooling demand in buildings in UAE; such as reducing solar heat gains through glazing by introducing a multi-facade system or more efficient types of glazing, while other studies were focusing on reducing the cooling demand by increasing thermal resistance of external walls [3]. Ghaith et al. [4] studied the possibility of reducing the energy consumption required for space cooling by means of Hybrid Solar Heating and Cooling (SHC). The proposed system involved integrating of the absorption chiller with solar thermal collectors to provide a continuous cooling, while in the absence of sun, the bio-mass heater is used as an auxiliary heating source. In spite of the potential savings in energy consumption and the consequence reduction of CO_2 emissions, but such system showed to require high initial cost. Some investigators reported in the literature that the heat gains through building envelop counts for 56% of total cooling demand [5].

This paper aims to reduce the heat gain from the external composite walls by means of EATS. The EATS is a combination of tubes buried underground at certain depth, in which ambient air passes through the tubes and allow it to exchange heat with the underground soil. The soil in this situation acts as a heat sink [6]. Not many studies have been done in regions known with hot summer months; this is because of the assumption that the cooling opportunities of EATS are not feasible due to high temperature of soil during this period. Similarly, other papers studied the opportunities of improving the thermal performance of EATS in hot regions by reducing soil temperature using cooling techniques such as soil irrigation and shading [7]. Ghaith et al. [8] investigated the thermal performance of earth tubes for pre-cooling in the UAE during summer to assist in lowering the cooling load of a building. It was found that energy savings of 16% are attainable, based on the case study of an office building area of 100 m². External composite walls are formed from different layers of construction materials in addition to an air cavity in the middle of the wall, if air passes through the cavity either by mechanical means or naturally by buoyancy force, the wall is then called dynamic composite wall [9]. Some studies defined dynamic walls as ventilated walls if the airflow is entering the wall cavity from one end and leaves it from the other end, it was also concluded that the use of ventilated walls in high solar radian regions maintains the temperature of the outer skin close to the outside ambient temperature which results in reducing the solar radiation amount and the heat gain through building envelope [10].

Sung et al. [11] presented an estimation of the reduction in the cooling energy that closed-loop EAHE can provide if combined with air-sourced heat pump in the hot humid climates of Texas. This study was based on a simulation model, in which the room return air was mixed with the EAHE outlet air to reduce its temperature before the evaporator coil. The annual energy savings were estimated to be within 9.6% to 13.8% at different locations.

The primary objective of this paper is to investigate the thermal performance of integrated EATS with the building's external wall in UAE. This involved producing a reliable mathematical model and carrying wide range of numerical and comparative studies in order to predict the potential savings in energy consumption. In order to verify the systems' overall performance, the proposed model was implemented for a single floor office building located in Dubai.

Description of the integrated EATS with the dynamic composite wall

The schematic diagram of the proposed integration between EATS and building's external composite wall with air gap cavity is shown in Fig. 1. EATS is open loop system were ambient air enters the tubes from the inlet and leaves it at the outlet as shown in Fig.1. The tubes shall be buried at certain depth and the soil temperature is influenced by the yearly annual outdoor temperature, soil temperature, soil classification, and soil surface temperature amplitude. Soil temperature fluctuates in time but amplitude of fluctuations gets very limited based on how deep the tubes were buried. The proposed system was implemented for the case study of a single floor office building in the Emirate of Dubai. The weather is tropical desert climate which is very hot during summer with an average high temperature of 47 °C as recorded on a typical day in July [1]. The office building is 18 m long, 4m width and height of 4m as illustrated by Fig.2. The building has 8 double glazing windows (1.4m × 1.7m each) with U-value of 3.28 W/m² K and shading coefficient of 0.8. The total air conditioned area is 335 m². The outdoor design temperature is 47/29°C (db/wb) and indoor design temperature is 24/17°C (db/wb). The required fresh air amount for ventilation is based on the minimum recommended ventilation rates as specified in ASHRAE 62.1 Standard which requires 9 m³ per person in addition to 0.216 m³ of air per unit area/m² of the occupied area which result in total fresh air requirements of 232 m³/ hr. The internal heat gains have been estimated based on ASHRAE 90.1 standard [12].

The external walls are multi-layer composite walls with air cavity; each layer has certain thickness and certain thermal conductivity value that resulted in identifying the thermal resistance for each layer and the wall's overall heat transfer coefficient. Fig. 3 shows the cross section of the external wall construction. The thermal characteristics of the layers forming the external wall and the internal heat gains are tabulated in Table 1. The wall is constructed from 100 mm heavy weight concrete, 50 mm air gap spacing, 50 mm rock-wool insulation and 150 mm light weight concrete. Thermal properties of the stagnant air gap and the wall layers have been collected from Dubai municipality regulations [13]. Following these regulations, the U-value of external walls should be equal to or less than 0.57 W/m².K.

2. MATHEMATICAL MODEL

This section describes the basic energy balance equations that govern the thermal performance of the proposed integrated EATS. The current analysis includes the determination of the soil temperature and the air earth tubes outlet temperature in addition to the thermal model of the dynamic composite wall.

3.1. Soil Temperature

Soil temperature is the mostly determinant factor for evaluating the heat transfer effectiveness among the air passing through the tubes and surrounding soil. As the heat transfer mechanisms surrounding the earth tube are extremely complex, several assumptions were established to simplify the problem. The soil is assumed to be homogeneous and the thermal conductivity of the soil surrounding the earth tube is constant. Also it was assumed that convection inside the earth tube is thermally and hydrodynamically developed. By implementing these assumptions, the sub-soil temperature at a depth, *z*, and time, *t*, can be predicted by eq. (1), as proposed by K. Labs and J. Cook [14].

$$T_{(z,t)} = T_m - A_s \cdot \left(e^{-z \left(\frac{\pi}{8760\alpha'} \right)^{0.5}} \right) \times \cos \left(\frac{2\pi}{8760} \left(t - t_o - \frac{z}{2} \left(\frac{8760}{2\pi} \right)^{0.5} \right) \right) \qquad (1)$$

where T_m is the annual average soil surface temperature, A_s is the amplitude of soil surface temperature, t_o is the phase constant, α' is the thermal diffusivity of the soil.

The amplitude of soil surface is described as the difference between the whole years' maximum and minimum temperature of the soil surface divided by two. A simplifying assumption was made by most authors is that the soil surface temperature is equal to the ambient air temperature. The phase constant is defined as the time taken, in days, from the start of the year for the surface to reach its minimum most temperature. Upon closer inspection of the model described by eq. (1), it is clear that the sub-soil temperatures follow a sinusoidal pattern; this occurs simply due to the seasonal fluctuation in temperatures of the ambient air.

3.2. Heat Transfer across the Earth Tubes

The overall heat transfer coefficient, *U* is a vital parameter to study the heat transfer between the earth tube and the ambient air. It can be calculated by identifying the following thermal resistances:

$$R_c = \frac{1}{(2\pi \, r_1 \, L \, h_c)} \qquad (2)$$

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$$R_p = \frac{1}{(2\pi \, L \, k_p)} \, ln\left(\frac{r_1 + r_2}{r_1}\right) \tag{3}$$

$$R_s = \frac{1}{(2\pi \, L \, k_s)} \, ln\left(\frac{r_1 + r_2 + r_3}{r_1 + r_2}\right) \tag{4}$$

where R_c is the thermal resistance due to the convective heat transfer between the ambient air inside the tube and the inner surface of the earth tube, R_p is the thermal resistance due to the conductive heat transfer within the thickness of the pipe, R_s is the thermal resistance due to the conductive heat transfer between the pipe outer surface and undisturbed soil and r_2 is the pipe wall thickness. The distance between the earth tube's outer surface and undisturbed soil is r_3 and is assumed to be identical to the radius of the pipe (i.e. $r_1 = r_3$).

The convective heat transfer coefficient, h_c is a function of the Nusselt number, Nu and thermal conductivity of air k_{air} which can be expressed as

$$h_c = \frac{Nu \, k_{air}}{d} \tag{5}$$

The thermal conductivity, k_{air}, and kinematic viscosity of air, v for any given ambient air temperature, T_{amb}, can be calculated using equations (6) and (7) respectively.

$$k_{air} = 0.02442 + (0.6692 \times 10^{-4} \, T_{amb}) \tag{6}$$

$$v = (0.1335 + 0.000925 \, T_{amb}) \times 10^{-4} \tag{7}$$

The Nusselt number in Eq. (5) can be calculated using the expression proposed by Gnielinski [15]. This expression is valid only for fully developed laminar and turbulent flow inside a circular pipe within the range of $2300 < Re < 5 \times 10^6$ and $0.5 \le Pr \le 2000$.

$$Nu = \frac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)} \tag{8}$$

where f is the Darcy friction factor. Thus, the overall heat transfer coefficient can be expressed as

$$U_t = \frac{1}{R_t} \tag{9}$$

where $R_t = R_c + R_p + R_s$.

Now, the total heat transfer between airflow passing inside the covered tubes and surrounding soil can be calculated from the following equation [16]:

$$G \, dy \left[T_a(y) - T_{(z,t)}\right] = -\dot{m}_a C_a \, dT_a(y) \tag{10}$$

where y is the distance from tube inlet, G is the thermal conductance of the whole earth to air heat exchanger including air, pipe and soil. C_a is the specific heat of the outdoor air and $T_a(y)$ represents the air temperature inside the tube at distance y from tube inlet.

3.3. Heat Transfer across the double Composite wall

   Double skin composite walls are made of multiple layers of materials such as concrete, thermal insulation on both sides of the wall and separated by air cavity as illustrated by Fig.3. Ventilated walls allow external ambient air passing through the air cavity. Ventilated walls are proposed for this study provided that the air exiting the EATS will be supplied through the air cavity inside the wall rather than the ambient air. Fig. 4 shows the schematic of the proposed dynamic composite wall.

The heat flux throughout the wall can be expressed as

$$\dot{q} = \frac{\dot{Q}}{A} = U_w(T_o - T_i) \tag{11}$$

where $\dot{Q}$ is the heat transfer rate throughout the wall, U_w is the overall heat transfer coefficient of the wall, A is the wall surface area, T_o is the outdoor air temperature and T_i is the indoor air temperature.

The overall heat transfer coefficient of the wall, U_w can be calculated as

$$\frac{1}{U_w} = \frac{1}{\alpha_o} + \frac{t_1}{k_1} + \frac{1}{\alpha_a} + \frac{t_2}{k_2} + \frac{t_3}{k_3} + \frac{1}{\alpha_i} \tag{12}$$

where
α_o: The outdoor air convective heat transfer coefficient (W/m^2. K).
α_a: The convective heat transfer coefficient of the air passing through the air gap (W/m^2. K).
α_i: The convective heat transfer coefficient of the indoor air (W/m^2. K).
k_1: Thermal conductivity of the outer (i.e. heavy weight) concrete layer (W/m K).
k_2: Thermal conductivity of the insulation (i.e. Rockwool) layer (W/m K).
k_3: Thermal conductivity of the inner (i.e. light weight) concrete layer (W/m K).
t_1: Thickness of the outer concrete layer (m).
t_2: Thickness of the insulation layer (m).
t_3: Thickness of the inner concrete layer (m).

The value of the convective heat transfer coefficient of the air passing through the air gap, α_a can be calculated in terms of Nusselt Number, Nu , thermal conductivity of the air k_a and the hydraulic diameter of the air channel, d_h such that

$$\alpha_a = \frac{Nu\,k}{d_e} \qquad (13)$$

The temperature of the air passing through the gap at different heights, y is estimated by the aid of the following correlation [10]:

$$T_{air}(y) = T_s - (T_s - T_{in}).e^{-\left(\frac{\alpha_1 + \alpha_2}{\rho.U.C_P}\right)y} \qquad (14)$$

This correlation links the entering air temperature T$_{in}$ and the adjacent wall's surface temperature T_s with the air velocity U, the channel width S and the heat convective heat coefficients of the air channel inner and outer surfaces α_1 and α_2, respectively.

4. METHODOLOGY

In this work, the soil and EATS mathematical models described in section 3 were modeled and simulated using EnergyPlus Software [17]. The numerical outputs to be evaluated are the soil temperature at certain depth and the corresponding outlet air temperature from the buried tubes. To setup the model, it was required to identify many input parameters such as the soil classification. The majority of the soil in the UAE is of the silty sandy type consisting primarily of 85% sand that is low in organic substance [18]. This type of soil is known as 'light' rather than 'heavy'. The selected soil properties for Dubai are listed in Table 2. In order to maximize the benefit of using EATS, the outlet EATS air was used primarily to supply the air through the air gap cavity in the composite wall and secondary for the purpose of pre-cooling the air supplied for the conventional air conditioning system. The airflow was estimated based on the recommended velocity of air that should be supplied into the air gap cavity through the external wall of the proposed office building. Dronkelaar and Schijndel [19] found that the minimum heat gain was achieved at 0.15-0.45 m/s air velocity inside the air gap. Therefore; air velocity of 0.15 m/s was used in this study, and according to the office building's dimensions (i.e. perimeter of 60.0 m and air gap spacing of 0.05 m), then the required airflow for the purpose of supplying the air gap in the walls was estimated to be 0.45 m³/s. In order to meet the fresh air requirement for ventilation as described by section 2, additional supply air of 0.07 m³/s will be considered.

The base input parameters of the air flow rate and tube dimensions are provided by Table 3. Several numerical runs were carried out using EnergyPlus in order to select the optimum design of the EATS (i.e. tubes length, depth and diameter) and to determine the expected air outlet temperature. The obtained outlet EATS air temperature was used to carry out the heat transfer analysis of the proposed dynamic wall as outlined in subsection 3.3 and to determine the corresponding overall heat transfer coefficient, U_w. In order to compare the annual energy consumption of the conventional case (i.e. without implementation of the EATS) and the proposed integrated EATS, the overall energy model was developed for both cases using VisualDOE4.0 energy simulation program. This study took into account the estimation of the fan power consumption.

5. RESULTS AND DISCUSSION

5.1 Estimation of the soil temperature

The soil temperature at different depths has been estimated using Energyplus Software. This was achieved by running the simulation feature called CalcSoilSurfTemp. Fig. 5 shows the simulation results of soil temperature at different depths as well as the annual temperature profile for Dubai soil. Fig. 5(a) illustrates the temperature profile at 4 meters depth. It was shown that the soil temperature varies between 29.0 °C and 31.5 °C across the year. Similarly, Fig. 5(b) illustrates the temperature profile at 6 meters depth which showed less variation in the soil temperature (i.e. between 29.0 °C and 30.0 °C). As minor soil temperature variation was achieved at 6 meters depth, an average soil temperature of 30.0°C at depth of 6 meters was selected for this study.

5.2 Determination of the EATS outlet air temperature

In order to study the influence of the design parameters of the EATS on the outlet air temperature, the design parameters such as the length of the earth tube, number of air tubes and the earth tube diameter were varied. The optimum design was specified according to the minimum air outlet temperature and the relevant lower cost. Table 4 shows the EATS outlet temperature for

several simulation runs at different design parameters. The first two cases show clearly the high influence of the tube length on lowering the outlet air temperature. As the tube length increased from 100 to 500 m, the outlet air temperature have dropped from 42.0 °C to 33.0 °C, respectively. However, the increase in pipe length results also in increasing the system pressure drop and the power consumption of the fan. Also higher length requires a long area to be buried with additional investment cost. Contrarily, it was found that increasing the tube diameter from 200 mm to 600 mm at common tube length of 100 m (i.e. as illustrated by case 1 and case 3) led to slight increase in the air outlet temperature (i.e. from 33.0 °C to 33.4 °C). This agrees with the study performed by Richard and Kwang [20] as they found that increasing the tube diameter results in increasing the air outlet temperature. This is expected as larger tubes diameter results in lowering the convective heat transfer coefficient due to the boundary layer formed on the internal tube surface. Another simulation run was conducted to optimize the size of the tubes and the required buried area. At this run, the flow was split into 8 equal earth tubes, each deals with 0.066 m³/s. This is presented under case 4 in which the required tube size is 200 mm and length of 100 m. The resulted outlet temperature was found to be 32.3 °C. Although case 5 resulted in a lower air outlet temperature of 30.0 °C, but it was excluded since it was found to be less feasible as a result of using longer pipes (i.e. 300 m) in addition to the relevant high buried area. Accordingly, case 4 was selected and provided outlet air temperature of 32.3 °C.

5.3 Heat Transfer Analysis for the ventilated Composite Wall

This section aims to find the overall heat transfer coefficient of the proposed ventilated composite wall illustrated by Fig. 4 .The obtained value is compared with the corresponding value for the conventional composite wall (i.e. with air cavity having still air). In order to determine the convective heat transfer coefficient of the air passing through the air gap, α_a, the Nusselt Number was calculated. For the selected air flow inside the gap (i.e. 0.15 m/s), the flow was found laminar. Accordingly, the Nusselt Number has been evaluated [21] and α_a was calculated to be 2.4 W/m²K. By considering equation (13) and recalling the thermal properties and thicknesses of the composite wall layers (i.e. as listed in Table 1), the overall heat transfer coefficient of the ventilated wall U_w was found to be 0.474. Following the same procedure, the overall heat transfer coefficient of the conventional wall (i.e. unventilated one) was calculated to be 0.538(W/m² K). This yields that the heat flux dropped from 12.33 to 10.902 W/m². The reduction of 11.5 % in the heat flux amount indicates the potential energy savings of the proposed external dynamic wall over the conventional one. In order to predict the air temperature inside the gap at different highest of the wall from the ground level, equation (14) was solved and the obtained results were provided by Table 5. It was found that the temperature of the air exiting EATS have increased from 32.3 °C to 33.7 °C along the wall height of 4.0 meters. However, the obtained temperature is still much lower than the corresponding one in the case of unventilated gap (i.e. T=43.5 °C). The reduction of the temperature presents the potential reduction in heat gain to the building.

In order to verify the results obtained from solving the mathematical model described in section 3, a Computational Fluid Dynamics (CFD) model was developed using COMSOL Multiphysics Version 4.4 simulation program. In this model, the heat transfer by conduction and convection were considered. The input parameters such as thermal conductivity of the wall's layers, thickness, density and specific heat, were defined according to Table 1. The outside temperature was considered as 47.0 °C and the indoor temperature was 24.0 °C. As the developed model represents only the steady state conditions, the wall is modeled for 0.6 m only instead of 4.0 meters for the purpose of using higher mesh density. The CFD model mesh is presented in Figure 6. Fig.7 illustrated the temperatures contours at different construction layers within the composite wall. Also Fig.7 demonstrated that the surface temperatures for different layers resulted from CFD model were found highly matching the corresponding ones resulted from solving the mathematical model with maximum difference percentage of 1 %.

5.4 Energy simulation for the selected case study

This section aims to investigate the potential savings of implementing the proposed integrated EATS with the composite wall for a single floor office building located in Dubai. The properties of the office building were introduced earlier in section 2. In order to compare the Annual Energy Consumption (AEC) of the conventional case (i.e. unventilated walls) and the proposed ventilated wall, the thermal models were carried out using VisualDOE 4.0 energy simulation for the both cases. The proposed air conditioning system is a single zone, direct expansion split system having an indoor unit containing the supply air fan and cooling coil, in addition to the outdoor unit containing the compressor, condenser and the expansion valve. The schematic diagram of the proposed indoor unit and supply/return air ducts is illustrated by Fig. 8.

5.4.1 Energy simulation of the case study without EATS

In this model, the overall heat transfer coefficient of the wall was taken as 0.547 W/m²K such to represent the case where no air flow inside the air gap cavity. For the specified heat gains and ventilation rate, the resulted cooling size of the cooling equipment was found to be 35.0 kW (i.e. 10 refrigeration tons). Figure 9 presents the annual electric end use of the conventional model as generated from VisualDOE reports. It was found that the annual electrical consumption was about 54,000 kWh, from which 31,074.0 kWh was consumed by the cooling system (i.e. including the power required for AHU fans). This implies that the cooling consumption counts for about 58.0% of the total consumed electricity which is close to Radhi findings [3].

5.4.2 Energy simulation of the proposed integrated EATS system with Dynamic composite wall

This system took into the account using the EATS to supply the air within the office external wall in order to evaluate the energy savings. Another potential saving was represented by using the pre-cooled air (i.e. resulted from EATS) to supply fresh air for the air conditioning system rather than using the ambient fresh air. The total airflow inside the external wall air gap was

0.52 m³/s with a speed of 0.15 m/s and a temperature of 32.2°C as described earlier in section 5.2. Also the overall heat transfer coefficient of the ventilated wall, U_w was found to be 0.474 W/m²K according to the calculations presented in section 5.3. Additionally the proposed EATS used 8 supply fans that were interlocked with the split unit operation. For this case, the power consumption of the fans was added to the total cooling system power consumption. Evaluating the EATS fan's power consumption starts by identifying the total pressure drop inside the tubes plus the pressure drop inside the external wall's air gap. Tubes diameter size was simulated using EnergyPlus software based on a pressure drop of 0.18 Pa/m for straight pipe length, while fittings pressure drop was represented by means of the equivalent straight pipe length. An equivalent pipe length of 5.0 meters was considered for 90° elbow and 7.0 meters for straight tee for 100 mm PVC fittings [21]. Accordingly, the total external static pressure drop of PVC tubes was found to be 32.0 Pa. The pressure drop inside the external wall air gap was calculated using equation (15) and (16)

$$\Delta P_f = \frac{1}{2}\left(\frac{f.H}{d_e}\right)\rho\, v^2 \qquad (15)$$

$$f = 0.11\,(\varepsilon/d_e + 68/Re)^{\,0.25} \qquad (16)$$

where f is the friction factor and ε is the absolute roughness which equals 0.003 m for concrete ducts [22]. Solving equations (15-16) resulted with a pressure drop of 3 Pa. On the other hand, Lecompte [23] estimated the pressure drop between the outer layer of an external wall and the air gap to be around 5 Pa which was used in this study during the fan selection process. Based on the above pressure drops, the total expected external static pressure of the fan was found to be 35 Pa, additional 20% as a safety factor was considered, thus the total expected pressure drop of the fan is 42 Pa. Fan selection was carried out using the industrial selection software prepared by Dynair industrial ventilation. Each fan was selected based on 0.066 m³/s (240.0 m³/hr) flow rate and 42.0 Pa external pressure drop while the expected motor load was found to be 0.05 kW as listed in Table 6. The resulted fan power required for operating the EATS system was simulated as part of the total annual energy consumption using VisualDOE software. Fig.10 shows the annual electric end use of the proposed EATS system as generated from VisualDOE reports. The AEC resulted from this model was 48255 kWh out of it 25330 kWh is consumed by the cooling system (i.e. includes the power required for AHU fans). Fig.11 shows a comparison of the annual electricity consumptions required for cooling and fans operation between the conventional and the proposed EATS. It was found the total annual electricity consumption associated with the proposed system less by 27% compared to the conventional system. On the other hand, one should note that the EATS fans consumed additional 981 kWh compared to the conventional system. By this end, it was concluded that the proposed system would lead for an overall saving of 11 % in the annual electricity energy consumption compared to the conventional system without EATS. This may lead to reduction of the CO_2 emissions by 7181kg/year.

6. CONCLUSIONS

In this paper, the energy performance of the integrated EATS systems was evaluated and compared to the conventional cooling system. The proposed system was implemented for selected case study represented by office building (i.e. area of 400 m²) located in Dubai. In summary, the outcomes of this paper are outlined below:

- It was found that the optimum soil temperature of 30.0 °C can be achieved at 6.0 m depth with a minor soil temperature variation throughout the year.
- Parametric study was carried out to estimate the optimum length and diameter of earth tubes required to achieve the design requirements of the outlet air temperature for the specified design parameters using EnergyPlus software. The proposed EATS consists of 8 tubes of 100 m length and has a flow of 0.066m³/s. The EATS was sufficient to decrease the ambient air temperature from 47°C to 32.3 °C.
- The derived mathematical heat transfer model showed that the overall heat transfer coefficient of the ventilated composite wall equals to 0.474 W/m²K. On the other hand, the corresponding value for the conventional composite wall is 0.538 W/m²K. Hence, the proposed ventilated wall achieved an energy savings of 11 % compared to the conventional unventilated wall. The obtained results from the developed mathematical model were verified using CFD model which showed very good agreement with a maximum difference of 1%
- Based on the energy simulation of the proposed case study, it was found that the AEC required for cooling the office building decreased by 27 % compared to the conventional system without EATS. Once the fan power associated with the EATS was taken into account, the overall saving of 11 % of the overall AEC was achieved. This implies a possible reduction of CO_2 emissions by 7181 kg/year.
- Integrated EATS systems are more financially attractive during the building construction phase due to the expected high cost of burying the tubes at the required depths.

At this end, one should consider that further possible implementation of EATS applications in buildings can improve the potential savings. One possible application is using the pre-cooled air resulted from the EATS in cooling the condenser unit for the air conditioning system. This would possibly enhance the efficiency of the condenser and yield to increase in the corresponding COP value.

Nomenclature

A	Surface Area (m^2)
A_s	Annual amplitude of the soil surface temperature (°C)
AEC	Annual Energy Consumption (kWh)
AHU	Air Handling Unit
ά	Thermal diffusivity (m²/s)
α	Convective heat transfer coefficient (W/m².K)
C_P	Specific heat of the air in the external wall gap(J/kg.K|)
C_a	Specific heat of outdoor air (J/kg˚C)
CFD	Computational Fluid Mechanics
COP	Coefficient of Performance
d_h	Hydraulic Diameter (m)
db	Dry bulb temperature (°C)
EATS	Earth-Air Tunnel System.
f	Darcy friction factor
G	Thermal conductance of the pipe (W/m.K).
g	Gravitational acceleration (m/s²)
h_c	Convective heat transfer coefficient of the air inside the earth tube (W/m²K)
H	Height of the wall (m)
HVAC	Heating, Ventilation and Air Conditioning.
k	Thermal Conductivity (W/m.K)
$\dot{m}_a$	Mass flow rate of outdoor air (kg/s)
Nu	Nusselt Number
$\dot{Q}$	Heat transfer rate (W)
$\dot{q}$	Heat flux (W/ m²)
R	Thermal Resistance (m².K/W)
Re	Reynold Number
S	Channel width of the air gap (m)
t	Layer thickness (m)
t_o	Phase constatnt
$T_{(z,t)}$	Soil temperature at certain time t and depth, z (°C)
T_m	Mean yearly ambient temperature (°C)
T_s	Equivalent channel wall surface temperature (°C)
$T_{air}(y)$	The temperature of the air passing through the wall gap at certain elevation, y (°C)
$T_a(y)$	Air temperature inside the tube at distance y from tube inlet (°C)
T_∞	Free air temperature (°C)
U_t	Overall Heat Transfer Coefficient of EATS (W/m².K)
U_w	Overall Heat Transfer Coefficient of the external composite wall (W/m².K)
υ	kinematic viscosity (m²/s)
wb	Wet bulb temperature (°C)
z	Depth below ground (m)

REFERENCES

[1] Civil Aviation Department, Dubai Meteorological Services (2014) [online] available from {https://services.dubaiairports.ae.> [10 July 2016].

[2] Dubai Government, Dubai Electricity and Water Authority, DEWA [online] available from <http://www.dewa.gov.ae/aboutus/electStats2013.aspx>, [20 March 2015].

[3] H., Radhi. (2009). Evaluating the potential impact of global warming on the UAE residential buildings- A contribution to reduce CO_2 emissions. *Building and Environment* 44: 2451-2462.

[4] F., Ghaith, R., Abusitta. (2014). Energy analyses of an integrated solar powered heating and cooling systems in United Arab Emirates, *Energy and Buildings* 70: 117-126.

[5] J., Haung, J., Hanford, J., F., Yang. (1999). Residential Heating and Cooling Loads *Component Analysis*. California: University of California. [online] available from<http://www.descoenergy.com/pdf/Residential%20Load%20Analysis%20and%20Comparison.pdf> [10 July 2015].

[6] R., Misra, V., Bansal, G., Agrawal, J., Mathur, T., Aseri. (2013). Transient analysis based determination of derating factor for earth air tunnel heat exchanger in summer. *Energy and Buildings* 58: 103-110.

[7] B., Givoni. (2007). Cooled soil as a cooling source for buildings. Solar Energy 81: 316–328.

[8]   F., Ghaith, W., Qayyoum, M., Nour. (2012). Thermal performance of Earth Tubes for Pre-cooling during summer in the United Arab Emirates (U.A.E). *International Conference on Renewable Energy: Generations and Applications* (2012), Al-AIN, UAE.

[9]   T., Klintberg, F., Bjork. (2008). Air gap method: Measurements of airflow inside air gaps of walls. *Structural Survey* 26: 343-363.

[10] P., Seferis, P., Strachan, A., Dimoudi, A., Androutsopoulos. (2011). Investigation of the performance of a ventilated wall. *Energy and Buildings* 43: 2167-2178.

[11] Sung Lok Do, Juan-Carlos Baltazar, Jeff Haberl. (2015). Potential cooling savings from a ground-coupled return-air duct system for residential buildings in hot and humid climates. *Energy and Buildings* 103: 206–215.

[12] ASHRAE 90.1 Energy Standards for Buildings except Low-Rise Residential Buildings (2008) Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

[13] Dubai Municipality (2014) *Legislations* [online] available from <http://www.dm.gov.ae> [12 July 2014]

[14] K. Labs and J. Cook. (1989). .*Passive Cooling.* Massachusetts : MIT Press, Cambridge,

[15] V. Gnielinski. (1976). New equation for heat and mass transfer in turbulent pipe and channel flow. *Int. Chem. Eng*. 16: 359-368.

[16] C. Jacovides and G. Mihalakakou. (1995). An Underground Pipe System as an Energy Source for Cooling/Heating Purposes. *Renewable Energy* 6: 893-900.

[17] U.S. Deparment of Energy**.** EnergyPlus Energy Simulation Software. *U.S. Deparment of Energy.* [Online] [Cited: June 20, 2015.] http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_sources.cfm#IWEC.

[18] AlBarshmgy, Ahmed. (2012). UAE Environmental and Agricultural Information Center. *United Arab Emirates - Ministry of Environment and Water.* [Online] September 27, 2010. [Cited: June 15, 2015.] https://www.moccae.gov.ae/en/home.aspx

[19] C. Dronkelaar, J. Schijndel, Assessing the potential of ventilated facades on reducing buildings thermal load using decoupled COMSOL simulations Technical Papers and Presentations, 1-14. Available from <http://www.ch.comsol.com/paper> [3 July 2015]

[20] K. Richard, H. Kwang. (2006). Implementation of an Earth Tube System into Energyplus Program. Cambridge: Simulation Research Group.

[21] W. Brodhead, D. Saum. (1996). Airflow Pressure Drop in Typical Radon Piping. International Radon Conference, 1-12.

[22] McCartney, et al. (2011). ASHRAE Handbook - HVAC Applications. Atlanta: American Society of Heating, Refrigeration and Air Conditioning .

[23] J. Lecompte. (1987). Airtightness of masonry walls. *Ventilation technology research and application* 8: 21.1-21.10

List of Tables

Properties of the external wall construction materials and internal heat gains

Layer Name	Thickness (mm)	Thermal Conductivity (W/m.K)	Convective HeatTransfer Coefficient (W/ m².K)	Thermal Resistance (m².K/W)
Outdoor air film	---	---	22.7	0.044
Heavy Weight Concrete	100	1.85	N/A	0.054
Air Gap Spacing	50	----	----	0.180
Rock Wool Thermal Insulation	50	0.039	N/A	1.280
Light Weight Concrete	150	0.84	N/A	0.178
Indoor air film	---	---	8.30	0.120
Internal Heat Gains				
Number of People	18			
Lighting (W/m²)	16			
Electrical Equipment (W/m²)	10			

Table 2: Soil properties in Dubai, UAE.

Soil condition	Light and Dry
Ground surface condition	Covered and Dry
Yearly Mean Soil Temperature (°C)	30.2
Soil Surface Temperature Amplitude(°C)	7.5
Phase Constant of Soil Surface Temperature(°C)	13.0
Thermal conductivity (W/m°C)	0.346
Thermal diffusivity (m^2/s)	2.4 x 10^{-7}

Table 3: Earth tube input data for EnergyPlus software

Item	Value
Design airflow (m³/s)	0.52
Tube Radius (m)	0.100
Tube Thickness (m)	0.005
Tube Thermal Conductivity (W/m.K)	0.28
Depth of tubes underground surface (m)	6.0

Table 4. EATS outlet air temperatures for different design parameters.

Ref	Number of Pipes	Length of Pipes (m)	Pipe diameter (mm)	Air flow (m³/s)	EATS outlet temperature (°C)
Case 1	1	100	200	0.52	42.0
Case 2	1	500	200	0.52	33.0
Case 3	1	500	600	0.52	33.4
Case 4	**8**	**100**	**200**	**0.066**	**32.3**
Case 5	8	300	150	0.066	30.0

Table 5. Air temperature inside the air channel at various wall heights.

Height from Ground Level (m)	Air Temperature at various heights (°C)
0	32.3
1	32.7
2	33.0
3	33.4
4	33.7

Table 6. Proposed fan selection

Flow rate (m³/hr)	External pressure drop (Pa)	Fan Model	Motor Power (kW)	Motor Speed (rpm)
240.0	42	AXICEN 2702V	0.05	1400

Captions of the Figures

Fig. 1   Schematic drawing of the integrated EATS system
Fig. 2   Space layout of the office building.

Fig. 3   Cross section of the external wall construction
Fig. 4   Schematic of the ventilated composite wall
Fig. 5   Annual soil temperature profile for sandy soil in Dubai city (a) at 4 meters depth (b) at 6 meters depth

Fig.6   Mesh of the CFD model of the dynamic wall construction

Fig.7   The surface temperatures of the walls' layers resulted from the CFD simulation.
Fig.8   Schematic of the proposed cooling system

Fig.9   Annual electrical consumption (kWh) for the conventional air conditioning system.
Fig.10   Annual electrical consumption (kWh) for the proposed EATS integrated system.
Fig.11   Comparison of the annual electrical consumption (kWh) required for cooling and fans between the conventional and proposed EATS integrated system.
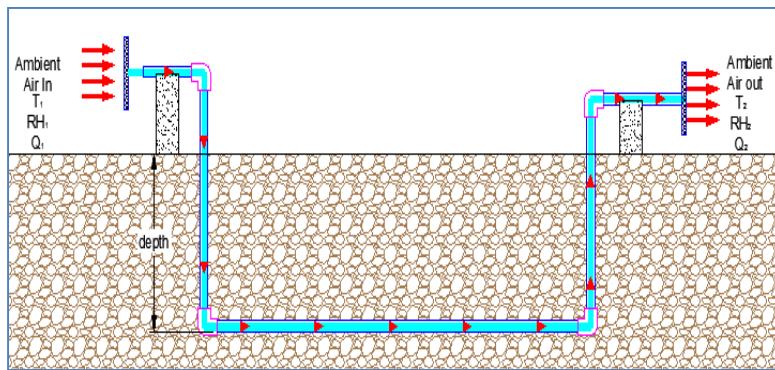
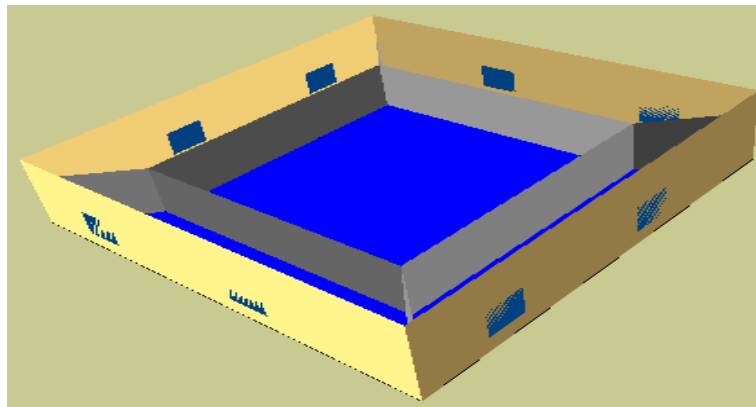Fig. 1: Schematic drawing of the integrated EATS system

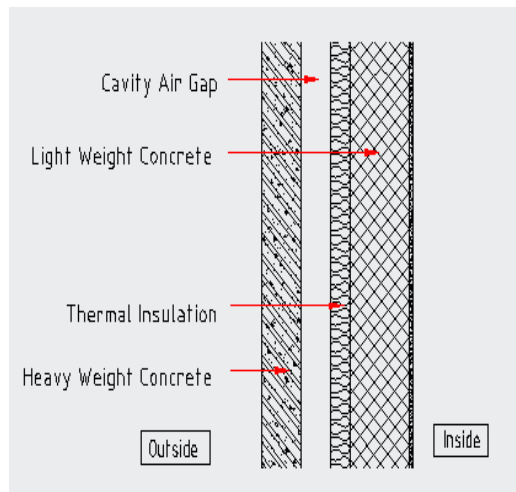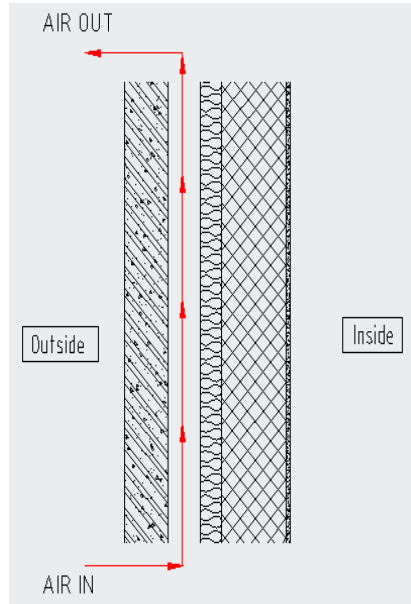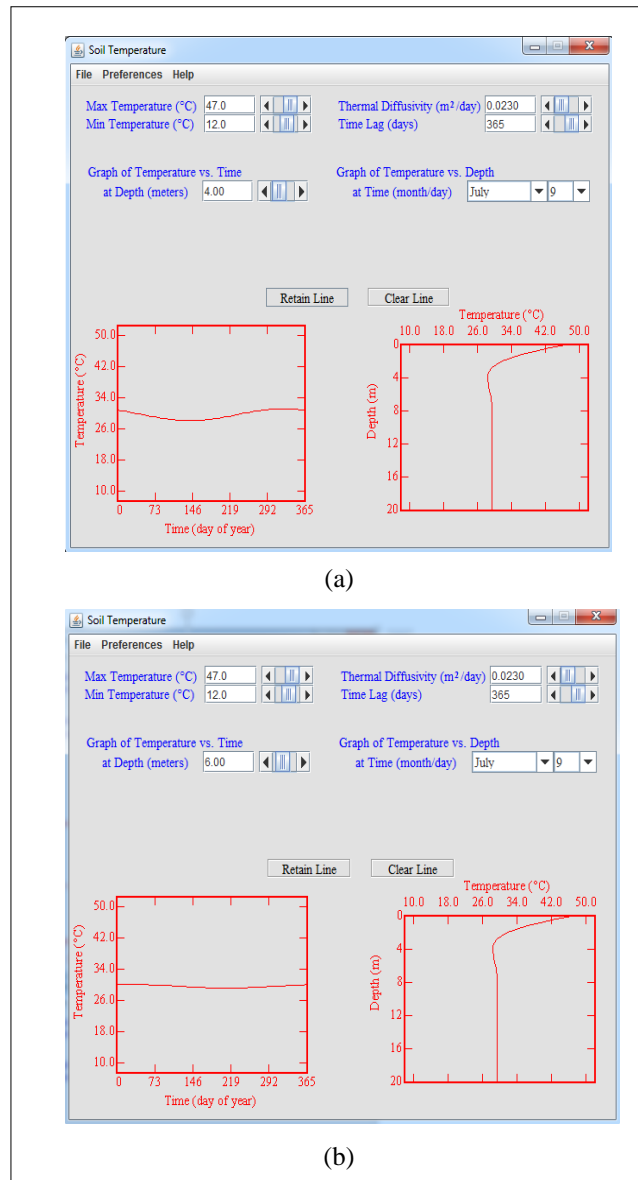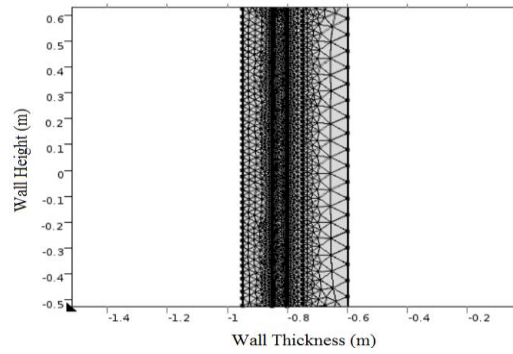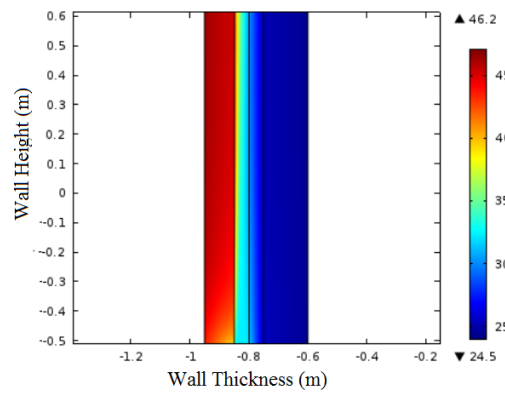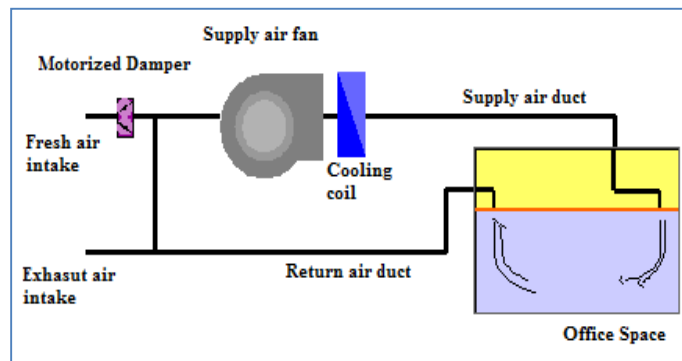Fig. 2: Space layout of the office building

Fig.3: Cross section of the external wall construction

Fig.4: Schematic of the ventilated composite wall

(a)

(b)

Fig. 5: Annual soil temperature profile for sandy soil in Dubai city (a) at 4 meters depth (b) at 6 meters depth

Fig. 6: Mesh of the CFD model of the dynamic wall construction

Fig. 7: The surface temperatures of the walls' layers resulted from the CFD simulation.

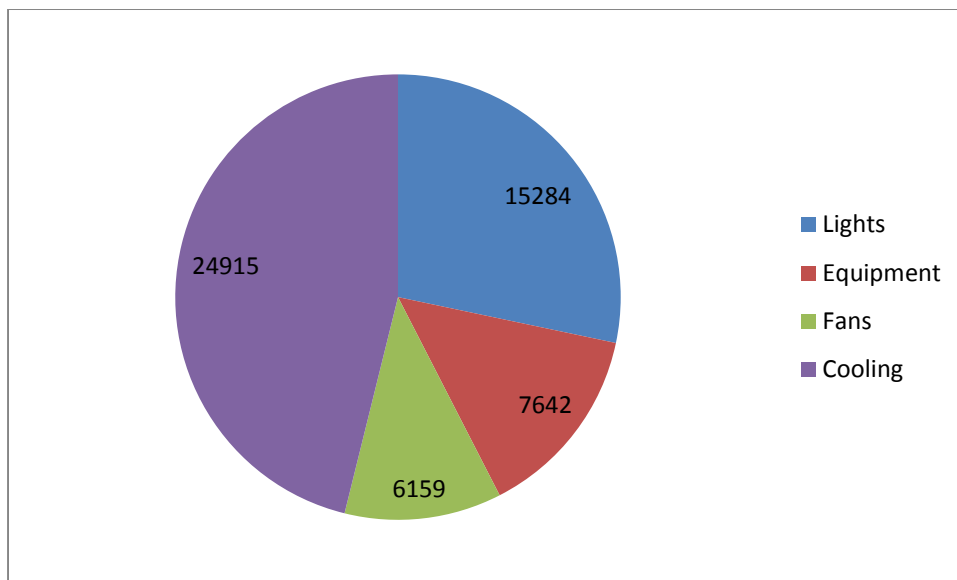Fig 8. Schematic of the proposed cooling system

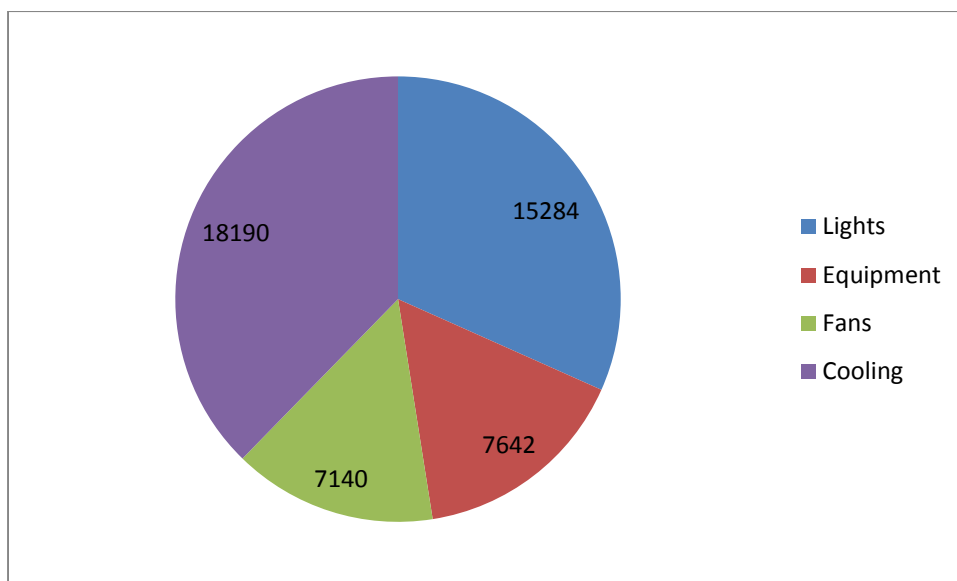Fig 9. Annual electrical consumption (kWh) for the conventional air conditioning system.

Fig. 10: Annual electrical consumption (kWh) for the proposed EATS integrated system.
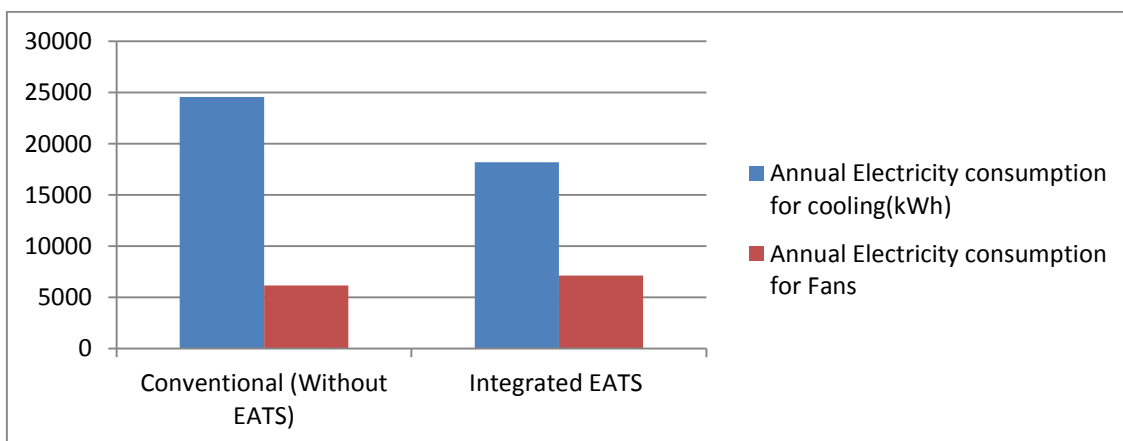

Fig. 11: Comparison of the annual electrical consumption (kWh) required for cooling and fans between the conventional and proposed EATS integrated system.