Effect of Radiant Surface Combined with Displacement Ventilation in Office Building in Egypt

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ABSTRACT

In hot and humid climates, this paper describes a study to estimate the energy savings potential of a radiant system using simulation analysis. The medium size office buildings in Egypt used as a case study. To evaluate the thermal performance and energy consumption, the simulations were carried out using the IDA ICE software.

This paper addresses the compatibility between radiant cooling systems and the climates in the buildings mainly through the issue of condensation risk. The risk of condensation can be reduced, by dehumidifying the supply air in different cases. Five heating, ventilation, and air-conditioning (HVAC) systems namely: direct expansion Split Units (DX-SU), Displacement Ventilation (DV), Chilled Ceiling with Displacement Ventilation (CC-DV), Radiant Floor with Displacement Ventilation (FR-DV) and Radiant Wall with Displacement Ventilation (WR-DV) are simulated.

All simulations were performed for the whole year. However, two separate weeks in winter and summer are selected to investigate the thermal performance in addition of the energy consumption. The results showed that (RW-DV) system achieves 14.36% and 24.03% total energy saving from the base system (DX-SU) for the winter and summer seasons, respectively. While the DV system achieves 1.6% and 12% total energy saving from the base system (DX-SU) for the winter and summer seasons, respectively.

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1 INTRODUCTION

Contemporary recognition of climate change and global warming has brought building energy consumption into focus. The non-residential building or commercial sector consumes approximately for between 20-40% of total energy consumption of the energy of the countries [1][2]. Consequently, the modelling of HVAC applications is crucial to avoid adverse effects on the earth's ecosystem [3]. Energy savings and occupant thermal comfort are considered the main issues in building technology; thus, the development of energy efficient HVAC systems is continuously evolving in HVAC industry [2,4].

As a result, interest in energy efficiency has caused the revival of interest in integrated passive cooling strategies such as thermal mass, natural ventilation, evaporative cooling, radiant cooling, and earth cooling. Some of these systems were developed to promote the use of low-temperature heating (25–40℃) and high-temperature cooling systems (13–20℃) [5]. Although these passive strategies are environmentally friendly and provide wider range of occupant satisfaction [6], designers are reluctant to adopt them in arid climates [7].

In recent decades, Displacement Ventilation (DV) systems have become more popular than Mixing Ventilation (MV), in view of its ability to improve thermal environment around the occupants and potential to reduce energy consumption [8]. In this system, the conditioned air discharges at low velocity near the floor level to contacting the heat sources such as occupants, and equipment, a convective thermal plume will be generated and move up towards the upper part of the room, which causes stratified temperature layers [9,10]. Thermal stratification is one of the main features of DV system which have a central role to improve the indoor air quality (IAQ) and energy saving through pushing the warm air towards ceiling. Due to the thermal stratification and high-level return most of the lighting load and roof heat gain directly heats the return and did not affect in the lower occupied zone. Also, the increase of supply air temperature, caused increase of the COP of the air conditioning and increased energy savings [11].

The radiant heating and cooling (RHC) system has been approved to be more efficient and energy-saving than the traditional air-conditioning system because of its characteristics of low energy consumption (no energy consumption of fans), high thermal comfort level (low sound levels and low velocity of the supplied air), [12–14]. Radiant systems are optimal for small temperature differences because large surface areas are usually activated. Limitations to the cooling capacity could include the temperature of the cooled surfaces, vertical air temperature, radiant asymmetry, or a dew-point temperature [15]. Radiant cooling systems can handle the sensible heat gains, and the ventilation system need only be designed to provide the necessary air flow rates for air quality based on relevant standards [16]. Such air flow rates are usually used to remove latent heat loads generated from occupants [17].

Beside radiant cooling several advantages, condensation is a disadvantage of the radiant system applications that makes its practical use difficult. Moisture condenses on cold surfaces where it can cause deterioration of the building materials and mold growth related to allergic symptoms [18,19]. Where, the RHC system cannot circulate air to remove the latent heat and reduce contaminants to achieve standard indoor air quality [20]. Several methods can be used either to reduce or eliminate the risk of condensation on the radiant surface. One of the primary precautions to avoid condensation is to keep the temperature of the radiant surfaces above the dew point temperature, however this reducing the cooling capacity of the radiant system. [18,19].

Other possible solutions used ventilation system to dehumidifying the air. The ventilated air can be supplied either from the bottom area/floor or from the ceiling. Displacement ventilation (DV) and underfloor air distribution (UFAD) are commonly used, in which the air is supplied from the floor and returned via the ceiling [21,22]. In recent studies, it is seen that, a combined system of radiant system, DV are used together [21,23,24]. Haoa et al. compared the conventional all-air system with a combined chilled ceiling system; the combined system saves 8.2% of total energy consumption in the climatic conditions of Beijing. Moreover, the combined system reduces 62% of electricity consumption used by a conventional system operating under the same conditions and provides better thermal comfort (decreasing vertical temperature gradient) and IAQ (decreasing indoor humidity level, and contaminants) with respecting the condensation risks on radiant surfaces. [25].

Fabrizio studied numerically the performance of radiant heating/cooling systems and all-air and fan coil systems for different European countries with the same thermal comfort level among the various systems (values of operative temperatures during occupied hours fall within the acceptability range). The use of radiant technologies showed a good potential for warm climates (e.g., 10%–15% primary energy savings in Rome) [26].

Krusaa and Hviid [27] combined a radiant ceiling panel with diffuse ventilation and investigated the system’s thermal performance and thermal comfort in a building with two offices numerically. Causone et al. [28] studied experimentally the interaction between a radiant floor and the ventilation system. A large vertical air temperature difference between the head and ankles was observed when the cooled floor was combined with DV. Similar observations were concluded by Tomasi for air distribution with different mixing ventilation. Additionally, a short-circuit was noticed when both supply and extract air terminals were located at a high level [29].

There is consensus that the electricity demand of air conditioning would decrease if building conditioning systems were combined with radiant cooling/heating. Due to high loads at hot humid locations might indicate that radiant cooling systems do not have enough cooling power to condition certain buildings and might indicate a relatively high risk of condensation in certain buildings.

This study focuses on commercial buildings because of the amount of total energy consumption where these buildings are commonly air-conditioned by DX systems in Egypt [30]. In addition to the available information regarding the performance of cooling systems. Finally, the indoor moisture sources in commercial buildings are limited (occupants), so it is logical to use an alternative air conditioning system with respect to fear the condensation risk.

The objectives of this study are presented in two-fold. Firstly, showing the potential of using a different radiant cooling system in arid climatic weather with respecting the condensation risk. Secondly, calculating the energy-saving potential of the different radiant air conditioning systems in the office building. Then comparing the energy consumption of different radiant air conditioning systems with a conventional DX-SU system at accepted indoor conditions in an office building space during occupancy time. Then evaluate the opportunity of radiant cooling systems being adopted and promoted in Egypt.

2 METHODOLOGY

In arid climates, designers are used DX-SU systems for medium size office building because of the lower initial cost regardless of running cost, so that this paper developed different cases to reduce the energy consumption. Different suggested air conditioning systems are developed with different simulation cases and investigated by building simulation tool. The building simulation model is analysed for the whole year.

In this paper, the IDA ICE tool (Version 4.8) is used as a building simulation tool. The studied zones are analysed to extracts the room-air temperature, air humidity at the occupancy hours, with respect the condensation risk on the radiant surfaces. The energy consumption for all investigated cases are compared with the base case of a DX-SU system, under accepted temperature and humidity setpoints during occupancy hours as per ASHRAE Standard 55-2020 [6].

2.1 Case Study

The study is a medium-size office building with single and multi-occupancy offices. The building is cuboid with dimensions of 10.64m width, 22.67m length and 15.5m height. The longer facade is oriented 90° east of north. Figure 1 shows the building layout.

The office building consists of ground, basement and 4 typical storeys. The footprint area is 195 m^2. The basement floor is a parking area while the ground floor contains a lecture hall, manger room, and bathrooms. The typical floor contains four office spaces, small meeting room, kitchen, and three bathrooms as depicted in Figure 2 and Figure 3.

The study focuses on a building with thermal performance and envelope composition in compliance with the Egyptian codes building standard [31]. Table 1 lists all opaque building envelope elements, which are roofs, walls, and floors. The external glazing has a solar heat gain coefficient of 0.35, emissivity of 0.84, solar transmittance of 0.3, visible transmittance of 0.74, and U-value of 3.2 W/m^2 K. No drapes or mechanical shading are simulated for the windows. The whole window to wall ratio (WWR) of the building is 15.64% distributed as 12.16%, 22.45%, 7.26%, and 6.14% of North, East, South, and West faced walls, respectively.

Table 1, Specifications of the building's envelope constructions.

	Thick.	**Layer Material**	**Density**	**Thermal Cond.**	**Thermal Transmittance U value**
	m		**kg/m^3**	**W/m K**	**W/m^2 K**
External Wall	0.25	Brick (outside)	1700	1.31	0.562
	0.05	Rigid insulation	160	0.036	
	0.03	Plaster (Cement / Sand)	500	0.15	
Internal Wall	0.10	Brick	1700	1.31	3.618
	0.03	Plaster (Cement / Sand)	500	0.15	
Internal Floors	0.25	Concrete	2300	1.7	1.871
	0.05	Plaster (Cement / Sand)	500	0.15	
	0.02	Ceramic Tiles	1000	0.37	
Roof	0.35	Concrete	2300	1.7	0.138
	0.15	Insulation	30	0.023	
	0.075	Plaster (Cement / Sand)	500	0.15	
	0.025	Tiles	1900	1.05	

Figure 1, Building layout.

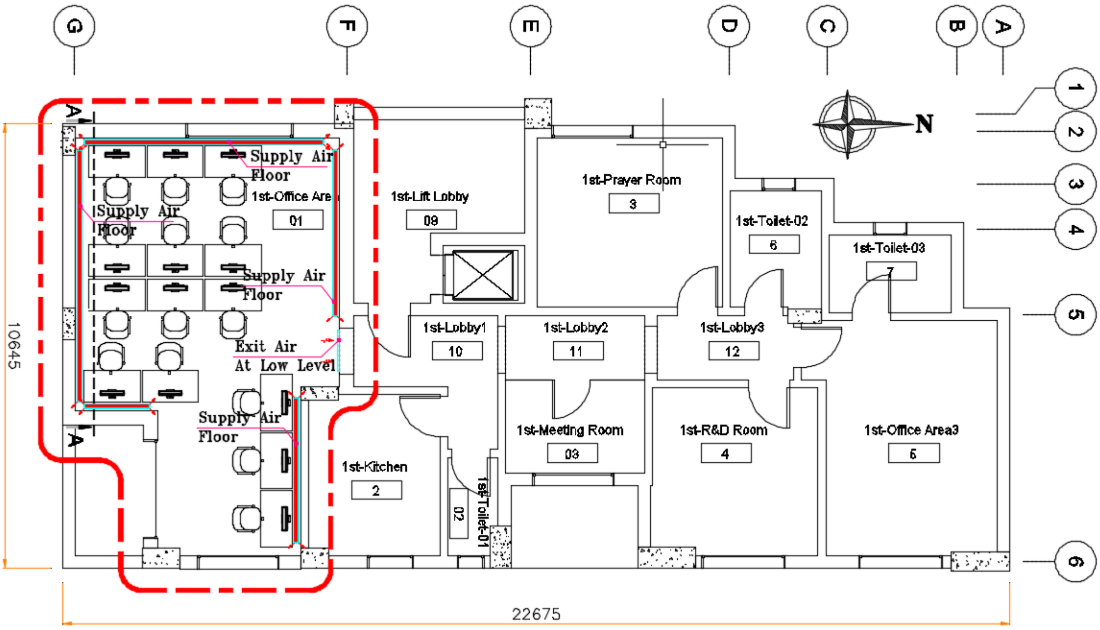

Figure 2, Base-case building typical floor.

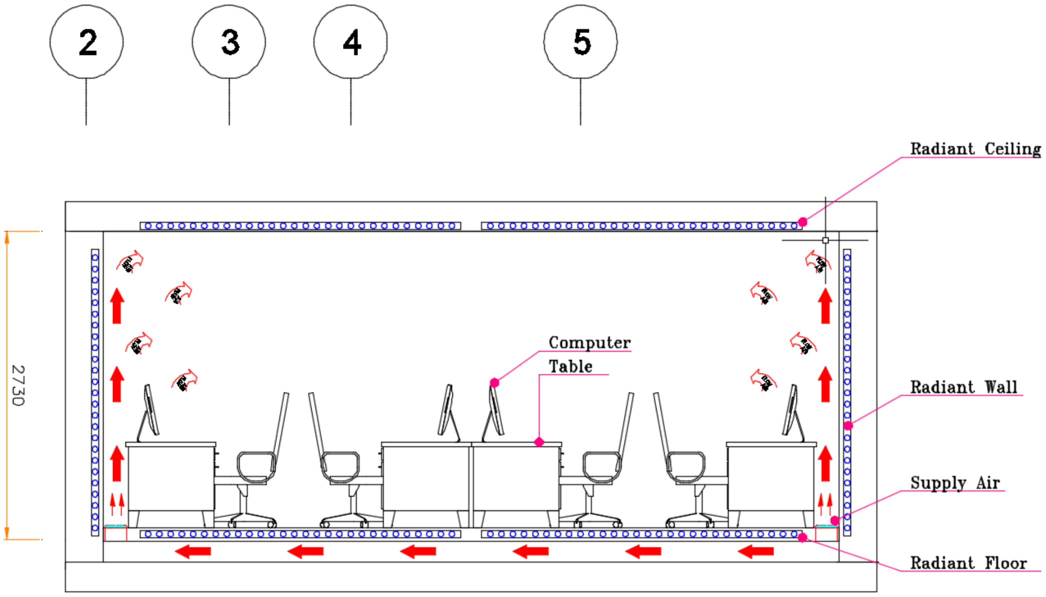

Figure 3, Section A for the 1st-Office Area zone.

2.2 Simulation study with building simulation model IDA ICE

The IDA ICE building simulation tool [32] was used by several published research [33,34]. The model includes all necessary data such as climate conditions, building geometry, zone classification, HVAC systems, control cases, etc.

2.2.1 Model setup

The simulations were carried out for Cairo according to World Meteorological Organization (WMO 623660, latitude 30.122°N, longitude 31.406°E, and elevation 116m). The simulation was conducted for office building, so the interior loads of the spaces do not change during the year. The time of the peak power demand is driven based on the weather-induced loads, which the heat gained by conduction through the building structure, and solar heat gain through the windows. The simulations were conducted over a year. However, a specified one-week-long period for summer and winter is used to illustrate the thermal performance and the condensation risks. The annual outdoor dry bulb temperature, relative humidity, and global horizontal radiation are shown in Figure 4.

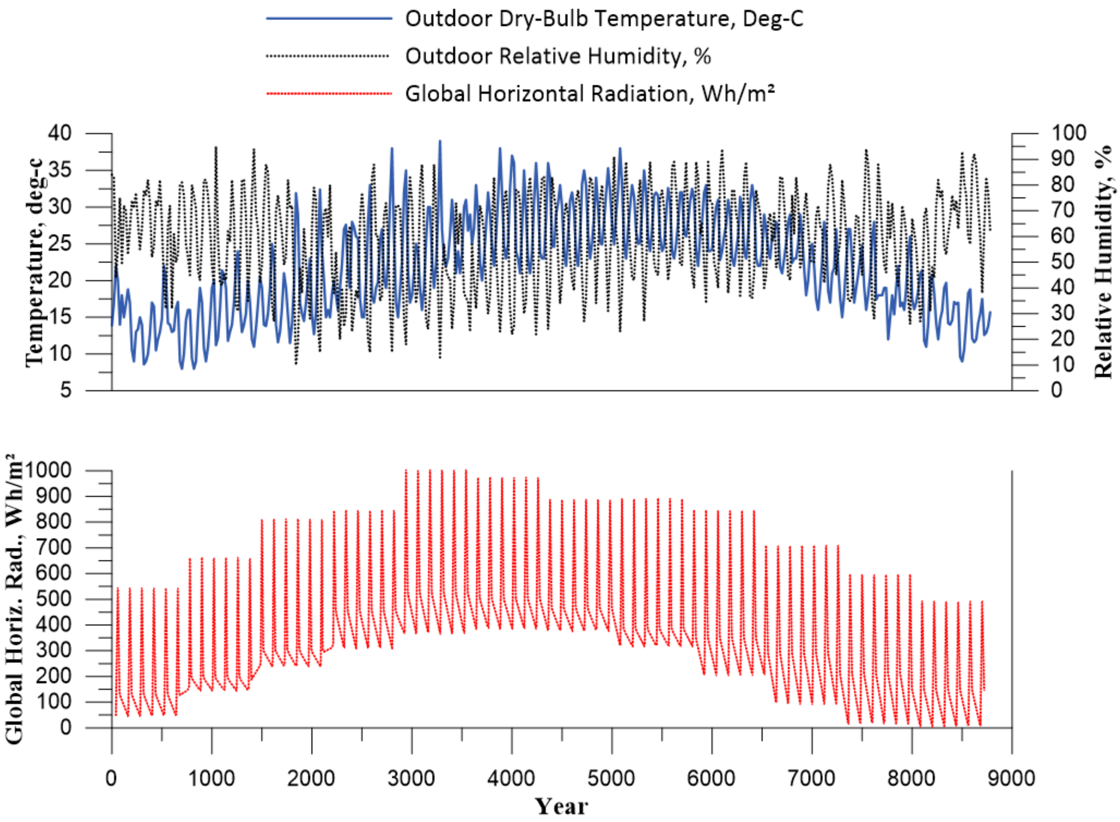

Figure 4, Annual dry bulb temperature, relative humidity, and global horizontal radiation.

The working hours in the office building between 8:00 AM to 5 PM. The studied office is open five days from Sunday to Thursday a week all year long, except holidays in Egypt. The occupancy profile during the opening hours increases gradually from zero to the maximum from 7 AM to 9 AM, then keeps maximum for 7 hours, then decreases gradually to zero until 7 PM. The occupancy activity level is 1.7 MET with clothing level 0.85±0.25 CLO. It is worth noting that all internal gains, lighting, equipment, human heat dissipation, and moisture load are depending on the occupancy profile. Table 2 listed all internal heat loads in the simulation models.

Table 2, Simulation parameters for internal heat loads

Name	**Parameter**			
	Floor area m^2	**Occupants No.**	**Lights W/m^2**	**Equipment, W/m2**
Ba-Garage	184	5	3.522	-
Gr-Reception	113.4	16	20.32	33.16
Gr-Office-01	39.12	10	4.908	60.07
Typ.-Meeting Room	7.231	4	11.06	32.5
Typ.-Office-01	**52.41**	**14**	**17.86**	**62.77**
Typ.-Office-02	23.86	6	13.41	59.09
Typ.-Office-03	16.02	3	17.98	44.01
Typ.-Prayer Room	18.25	15	15.78	-
Typ.-Kitchen	12.37	1	6.467	80.84
Typ.-Toilet-01	2.729	1	8.794	-
Typ.-Toilet-02	6.276	1	3.824	-
Typ.-Toilet-03	5.611	1	4.277	-

The base space in the building model is located on a middle floor because of the typical floors represent about of 60% of the building areas. Typ.-Office-01 was chosen as a base space due to that it has large solar loads and internal load of 14 persons with its equipment. To compare the thermal performance and condensation risks among studied systems. In particular, the total load of the space exceeds 140 W/m^2 and has the largest latent thermal load. The Typ.-Office-01 has an area of 52.41 m^2 (see Figure 2).

2.2.2 The air-conditioning systems

This section presents the main design parameters and the specifications of HVAC systems. The following HVAC system are compared in this study:

- Direct expansion split unit system (DX-SU)–used as a reference case
- Displacement ventilation (DV)
- Radiant ceiling (RC).
- Radiant floor (RF).
- Radiant wall (RW).

2.2.2.1 Direct Expansion Split Unit System (DX-SU)

Split unit system is a unitary system model with on-off control unit for heating, cooling, and dehumidification for each space separately. The specification and characteristics of the system is listed as follows:

Rated heating COP	5
Rated cooling COP	3

2.2.2.2 Displacement Ventilation.

The air handling units (AHU) used in this study comprise a mixing box, supply fan, exhaust fan, heating coil, and cooling coil. The temperature of the supply water in the cooling coil of the AHU is set to 7°C, and 40°C for cooling and heating, respectively with flow varies depend on the load. In the AHU, the setpoint of the supply air in summer is set to be constant with 18 °C, and 30% RH. The setpoint of the supply air in winter is set to be constant with 27 °C, and 50% RH.

Fan speed	Variable
Fan efficiency	70%
Fan pressure rises	1000 Pa
Fan motor efficiency	90%
Heating/Cooling coil air side effectiveness	90%
Waterside temperature drop	20°C
Waterside temperature rise	5°C
Outlet air max. relative humidity	70%
Rated heating COP	5
Rated cooling COP	3

2.2.2.3 Radiant Floor, Ceiling, and Wall

The supply water temperature of the radiant system is set to 15℃ for cooling and 40℃ for heating modes. The supply water flow varies depending on the zone temperature. Additionally, the radiant systems turn off when the difference between the surface temperature and the dew point temperature of the zone air falls below 1 ^{O}C. This control does not allow condensation on the radiant system as possible. The radiant system characteristics are listed as the following.

Waterside temperature drop (Heating)	15 ˚C
Waterside temperature rise (Cooling)	15 ˚C
Cooling design power	200 W/m^2
Heating design power	60 W/m^2
Controller type	PI Controller with air temperature sensor
Rated heating COP with integrated system	5
Rated cooling COP with integrated system	3

2.2.3 Simulation cases

Air conditioning unit is designed to maintain a desired RH and temperature values. These air conditioning systems used for all zones in the building. Although this paper focuses on the Typ.-Office-01 as a base case space. Various simulated cases are listed in Table 3.

Its worthy to note the radiant systems were merged with displacement ventilation system in building simulation tool. The displacement ventilation system provides the required fresh air and used as auxiliary air conditioner to overcome the gape of the sensible loads for the space and the cooling capacity of radiant system without condensation to achieve a desired temperature and relative humidity of the space.

Table 3, Various simulation cases for the ventilation and air conditioning systems.

Cases	**HVAC System**	**Temp. Control Sys.** (^{O}C)	**Humid. Control Sys.** (%)	**Airflow (**m^3/h)
01	**Direct Expansion Split Unit System** (DX-SU)	21-24	50	External Ventilation of 182.5
02	**Displacement Ventilation** (DV)	21-24	50	Variable (0-3500)
03	**Radiant Floor with Displacement System** (RF- DV)	21-24	50	Variable (0-1485)
04	**Radiant Ceiling with Displacement System** (RC-DV)	21-24	50	Variable (0-1485)
05	**Radiant Wall with Displacement System** (RW- DV)	21-24	50	Variable (0-1485)

The setpoint temperature for air-conditioned space in summer and winter seasons are 24℃, and 21℃, respectively. The humidity ratio range are set to 30-70 % according to ASHRAE Standard 55-2020 [6]. It is also important to note that in the infiltration rate can be used as a fixed flow with ACH equal to 0.5 (75.6 m^3/h in the office space). The ventilation rate is in compliance with ASHRAE Standard 62-2022 [35] (182.5 m^3/h for 14 persons in the office space). The ventilation air is supplied one hour earlier than the working hour and it keeps ON for one hour after working hours.

The effectiveness of the air conditioning systems and calculate energy consumption are investigated for each case. The room average temperature and RH are obtained for each case.

Case 1 is used as the reference case for the simulation and modelled according to experimental. The air conditioning units are DX-SU with direct fresh air from windows. In Cases 2, the displacement ventilation DV by recirculating AHU is used to remove all loads, and the ventilated air is supplied by using the same air handling units. In Cases 3, 4, and 5, the air conditioning system is achieved by mixing the radiant system (floor, ceiling, and wall) with displacement ventilated, RF-DV, RC-DV, and RW-DV respectively, where the radiant systems are used to overcome part of sensible load and the displacement ventilation are using recirculating AHU for remove the remaining sensible loads and the latent load from ventilated air is supplied by the AHU. The radiant system used the maximum available surface areas in each zone, where the radiant effective area for floor, ceiling, and wall in the base case space are 51.5, 51, and 59.4 m^2 respectively.

3 RESULTS AND DISCUSSION

In this section, the validation of the building simulation model is presented, followed by the results of the thermal performance of the investigated cases. The results of the winter and summer simulation periods are presented separately. The individual results for each case are presented in terms of temperature, relative humidity, and the energy consumption of the whole the building located in Cairo. Based on this comparison, the savings potential of the selected system is calculated.

3.1 Model Validation

The present model is validated by comparing the predicted results of the delivered electricity of the building with that measured from April to December. Figure 5, compares the obtained results from the building simulation tool against the experimental results. As shown in Figure 5, a good agreement exists between the simulated model, and experimental results of the delivered electricity. The maximum difference observed in delivered energy consumption is 0.8 kWh/m^{2}with percentage of 3.8%. This difference is lower than the acceptable value of 5% recommended in ASHRAE Guideline 14 [36]. Therefore, the proposed model is acceptable to predict and analyse the thermal behaviour of building.

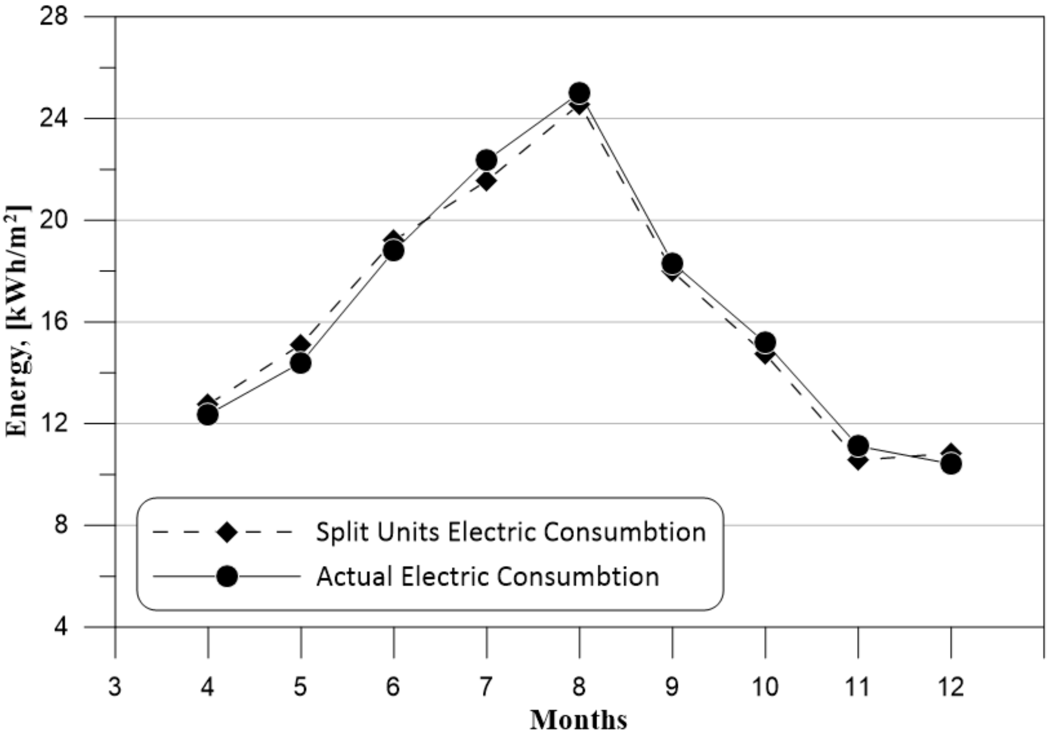

Figure 5, Comparison of the total energy consumption for the office building with current computational result.

3.2 Building Simulation Results in Winter Season

The simulation was conducted for the whole building, during a one-week period for each season. The selected period of the 3rd week of the calendar year (January 15th -21st) is representing the winter season. The mean dry bulb temperature and relative humidity distributions of various cases in the base case space during the simulated period are shown in Figure 6.

According to ASHRAE Standard 55-2020 [6] the comfort range for the temperature and the relative humidity in an office space setting (light sedentary activity, and occupants wearing clothing adequate to the season) are 21-26°C, and 30-70%. The simulation results show that the indoor air temperature presents a higher variation during off-occupancy hours and the two weekend days. This occurs because the main source of heating for the space is switched off during this time.

The indoor air temperature, and the indoor relative humidity during occupancy hours (8 a.m. to 5 p.m. on workdays) are presents fluctuates between 16.9°C and 22.7°C as shown in Figure 6, and the indoor relative humidity presents fluctuates between 34% and 76% as shown in Figure 6. The indoor air temperature and relative humidity in the space conditioned by the DX-SU, DV, and radiant heating system are not the same because each systems employ different mechanisms to condition space.

The mechanisms used by the two systems to heat the space explain this result. The heat-supplying mechanism employed by the DX-SU system provides heating to the indoor air directly, and to the occupants indirectly, through convective exchange with the hot air. The radiative heat exchange mechanism provides heating to the occupants directly through radiation, and to the indoor air indirectly through convective heat exchange with the heated surfaces.

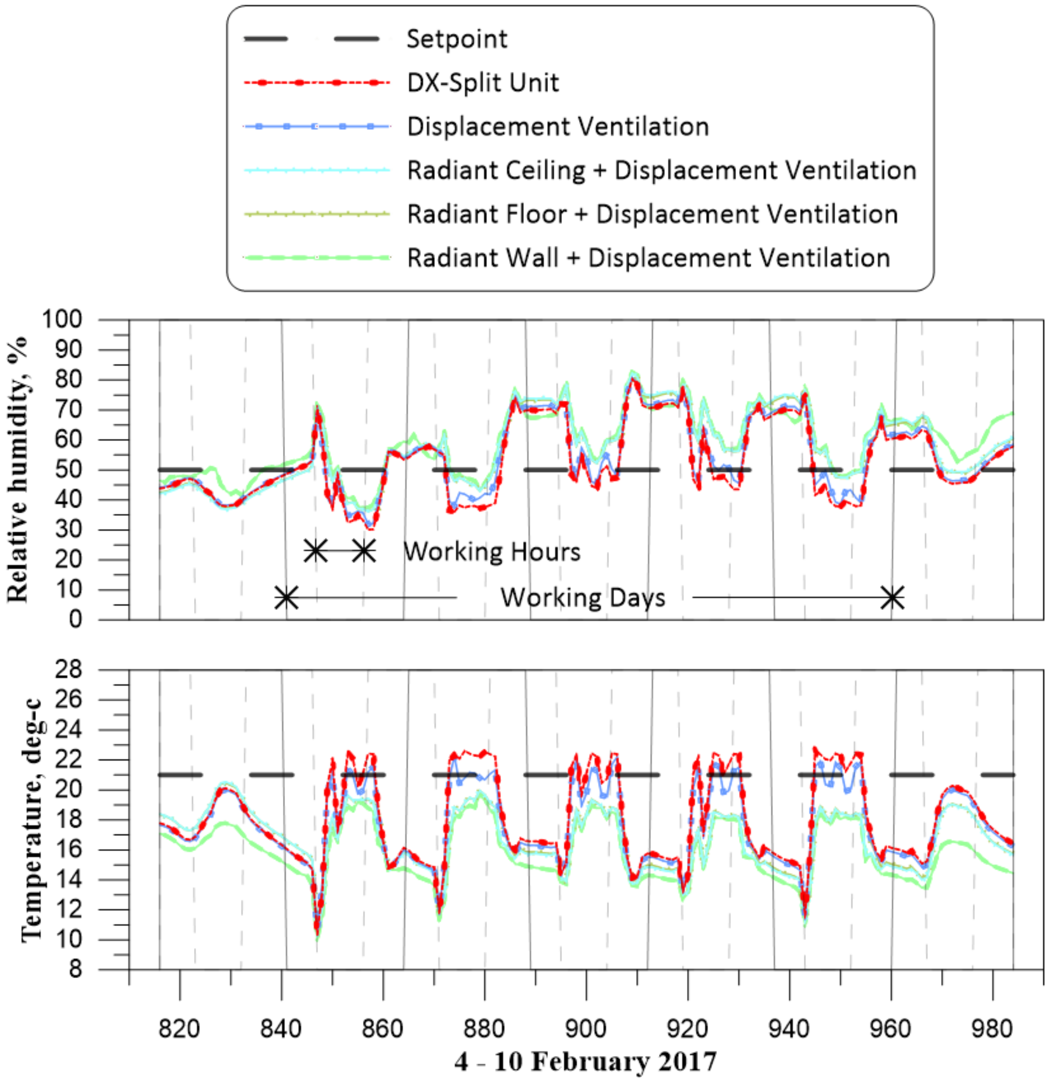

Figure 6, Indoor air temperature and relative humidity at the office space for various cases during the week in February

The results show that, for case 1 (DX-SU), the temperature fluctuates between 18°C and 22.8°C, with an average value of 20.4°C in the working hours. The relative humidity varies between 34% and 63% with an average value of 48.5%. For case 2, (DV), The temperature fluctuates between 17.8°C and 22.3°C with an average value of 20.05°C. The relative humidity varies between 35% and 64% with an average value of 49.5%. In case 3, and 4 (Radiant systems), the temperature fluctuates between 15°C and 20°C, with an average value of 17.5°C for the base space case. The relative humidity varies between 38% and 75% with an average value of 56.5%. In case 5 (RW-DV), the temperature fluctuates between 14.8°C and 20°C, with an average value of 17.4°C. The relative humidity varies between 38% and 79% with an average value of 58.5%.

3.3 Building Simulation Results Summer Season

The simulation period is the 30th week of the calendar year (August 26th – September 1st), representing the summer season. The mean dry bulb temperature and relative humidity distributions of various cases in the base case space during the simulated period are shown in Figure 7.

Figure 7, demonstrate that, the indoor air temperature, and relative humility of the space conditioned by the radiant cooling system is different than that in the space conditioned by the DX, and DV systems. The mechanisms used by the two systems to cool the space explain this result. The cool supplying mechanism employed by the DX-SU, and DV systems provides cooling to the indoor air directly, and to the occupants indirectly, through convective exchange with the cold air.

The radiant cooling system provides cooling to the occupants directly through radiation, and to the indoor air indirectly through convective heat exchange with the cooled surfaces. Because the other surfaces also exchange heat with the cooled radiant surfaces, they are actively cooled during the day, therefore they can store less heat than their counterparts in the space conditioned by the DX, and DV systems.

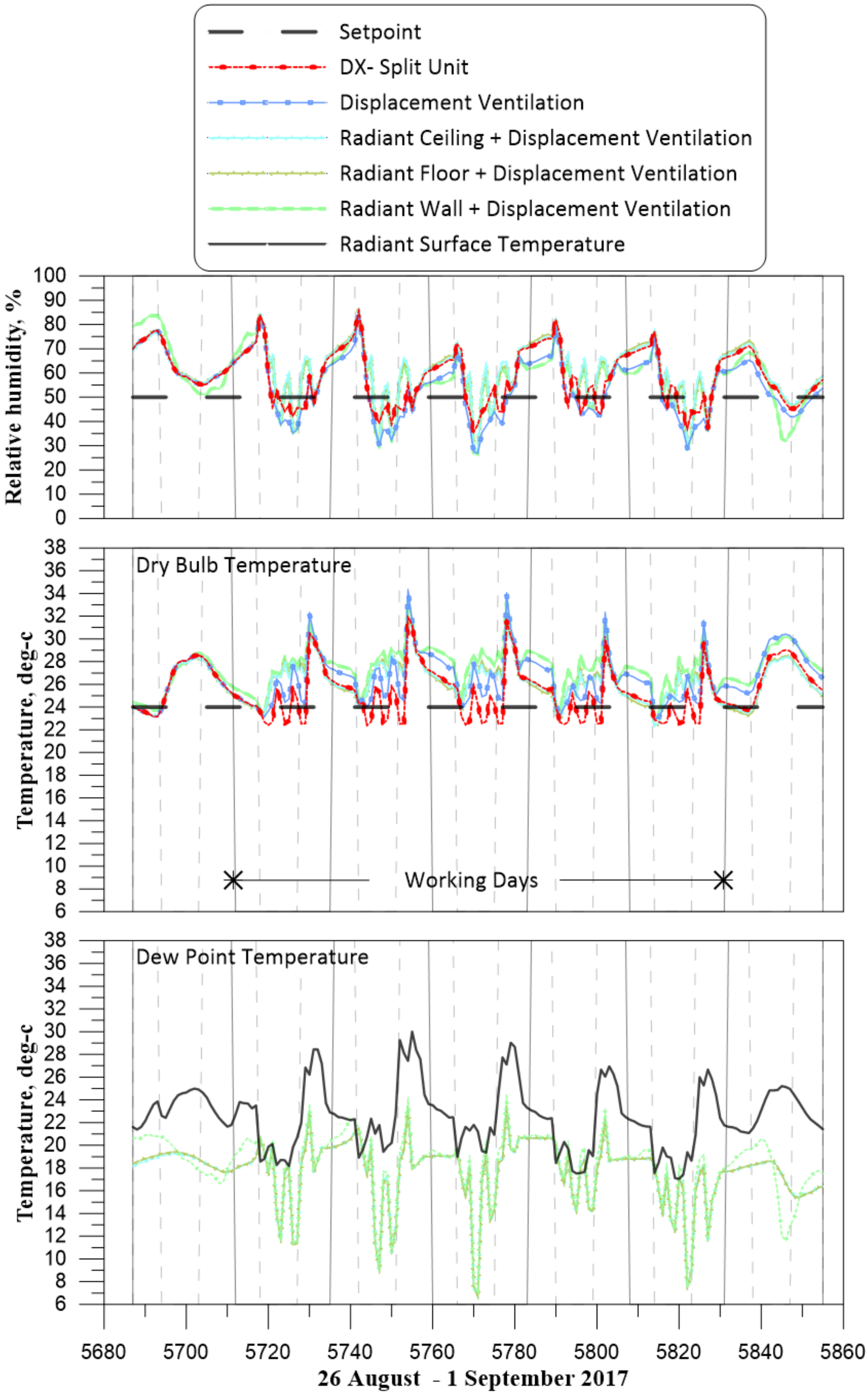

Figure 7, Indoor air temperature and relative humidity at the office space for various cases during the week in August.

The results show that, for case 1 (DX), the temperature fluctuates between 22.6℃ and 25.7℃, with an average value of 24.15℃ in the working hours. The relative humidity varies between 36% and 76% with an average value of 56%. For case 2, (DV), The temperature fluctuates between 27.5℃ and 23.2℃ with an average value of 25.35℃. The relative humidity varies between 32% and 66% with an average value of 49%. In case 3, and 4 (Radiant systems), the temperature fluctuates between 23.1℃ and 27.9℃, with an average value of 25.5℃. The relative humidity varies between 29% and 61% with an average value of 45%. In case 5 (Radiant wall systems), the temperature fluctuates between 23.5℃ and 28.1℃, with an average value of 25.8℃. The relative humidity varies between 28% and 62% with an average value of 45.

The average surface temperature for the radiant system, and dew point temperature for the indoor air for different radiant cases are presented in Figure 7. The dew point temperature is almost lower than the surface temperature for different cases, which this indication for the importance of mixing the displacement ventilation with radiant systems to avoid the risk of condensation. The radiant surface temperature is fluctuating between 16.9℃ and 22.2℃, with an average value of 19.55℃, while. the dew point temperature for the indoor air is fluctuates between 6.8℃ and 20℃, with an average value of 13.4℃.

3.4 Energy use in winter and summer seasons

The total energy consumption for the office building for the week in the winter, and summer simulation is shown in Figure 8. As the figure shows, the air conditioners require the most energy for all cases. In the case 1, as the reference case, it has consumed electricity for heating and cooling (including the dehumidification) of 2.19 kWh/m^2 and 6.16 kWh/m^2, respectively. It has negligible amount of electrical demand for HVAC auxiliary. In case 2, the Displacement ventilation consumed electricity for heating, and cooling of 0.98 kWh/m^2 and 3.71 kWh/m^2, respectively, while consumed electricity for HVAC auxiliary of 0.8 kWh/m^2, and 1.49 kWh/m^2 in winter and summer seasons.

In cases 3, 4, and 5, the Displacement ventilation combined with three deferent radiant system. These systems consumed electricity for heating of 0.15 kWh/m^2, 0.52 kWh/m^2, and 0.34 kWh/m^2, with radiant ceiling, floor, and wall respectively. These systems consumed electricity for HVAC auxiliary of 0.225 kWh/m^2, 0.224 kWh/m^2, and 0.284 kWh/m^2 in winter seasons mainly by DV system and negligible amount for radiant system. While these systems consumed electricity for cooling and dehumidification of 0.55 kWh/m^2, 0.554 kWh/m^2, and 0.63 kWh/m^2, with radiant ceiling, floor, and wall respectively by radiant systems and 2.76 kWh/m^2, 2.68 kWh/m^2, and 2.56 kWh/m^2 by DV system. These systems are consumed electricity for HVAC auxiliary of 0.523 kWh/m^2, 0.522 kWh/m^2, and 0.503 kWh/m^2 in summer seasons mainly by DV systems with negligible amount for radiant systems.

The displacement ventilation has the low delivered electricity by a reduction of 21.38% and 6.98% in winter and summer seasons, respectively, compared with case 1. The maximum electrical energy saving can achieve by using radiant wall combined with displacement ventilation are 44.71%, and 33.56% compared with case 1, as depicted in Figure 8.

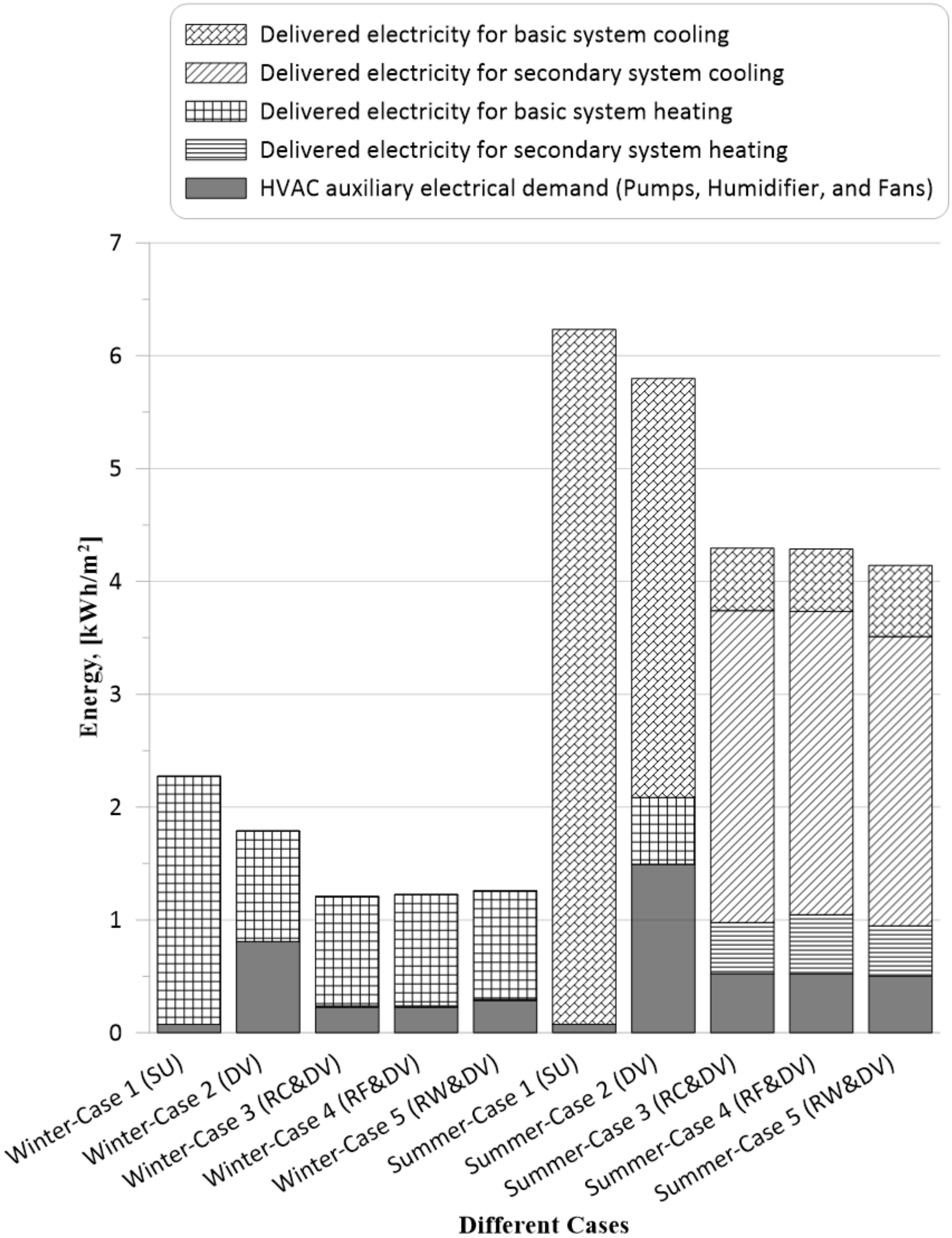

Figure 8, The total electrical energy consumption for the office building for one week in winter and one week in summer season.

3.5 Total energy consumption of building during a year

The total energy consumption for the office building for a year, simulation is shown in Figure 9. As the figure shows, the total energy consumption including the energy for light and facilities, equipment, and air conditioning for each case, where the energy consumption for lighting and equipment’s are almost the same for all cases.

The maximum energy consumption during August and lowest energy consumption during November, December, and March where the maximum energy consumption for DX system in August is 24.57 kWh/m^2 while the radiant wall consumes about 16.7 kWh/m^2 for the same month. The lowest energy consumption for the radiant wall through month of December is 9.11 kWh/m^2 while the DV, and DX system consume about 11.14, 10.83 kWh/m^2, respectively for the same month.

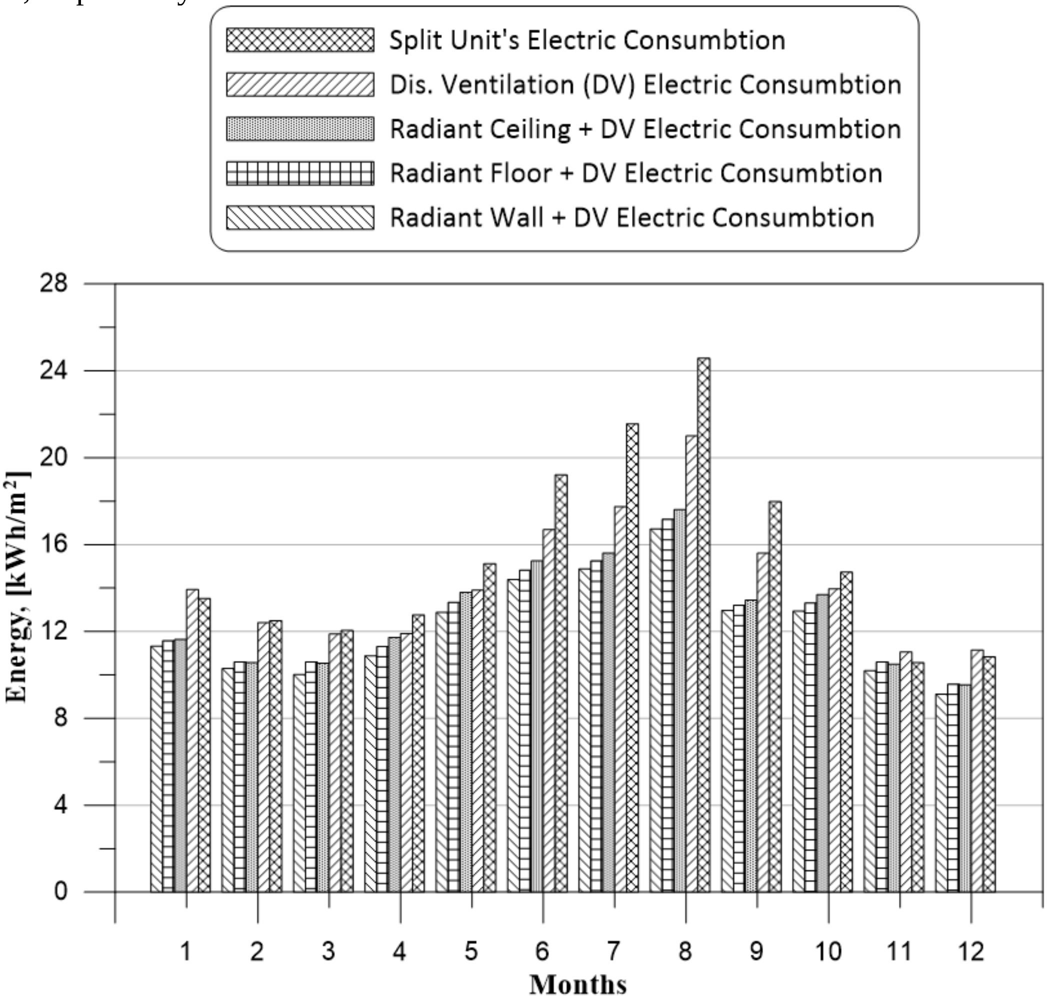

Figure 9, The total electrical energy consumption for the office building during a year.

4 CONCLUSIONS

This study aimed at implementing the radiant systems in a hot humid climate to estimate the energy savings potential with respect to the condensation risk. These techniques depend on the mixing between the radiant cooling system and displacement ventilation to avoid condensation in addition to the high cooling loads in these climates. Medium size of office building at Cairo, Egypt is simulated using the IDA ICE building simulation tool.

This paper provided five different air-conditioning systems analysed during whole the year but with focusing on two separate weeks representing the winter and summer seasons. Case 1, using the most common system in this size of building, DX system served all room. In case 2 used the displacement ventilation system to serve all room in the building. In cases 3, 4, and 5, using radiant ceiling, floor, and wall system, respectively, mixing with displacement ventilation to serve these room. The following conclusions can be drawn:

- The data collected from the results indicate that the radiant system strives to provide indoor conditions like those provided by compressor-driven systems. The radiant cooling technologies have the advantage of being able to function together with the familiar all-air systems to achieve the desired indoor temperature and relative humidity in hot and humid climates. In addition to the benefits of a cleaner environment, the dust-free and low-noise systems. The indoor air temperature during occupancy hours in winter fluctuates between 16.9℃ and 22.7℃, and the indoor relative humidity fluctuates between 34% and 76%. While the indoor air temperature during occupancy hours in summer fluctuates between 22.6℃ and 28.1℃, and the indoor relative humidity fluctuates between 28% and 76%.
- The results present condensation as a function of radiant surface temperatures and the dew point temperature of the air. The radiant surface temperature is fluctuating between 16.9℃ and 22.2℃. While the dew point temperature for the indoor air fluctuates between 6.8℃ and 20℃. Condensation is avoided without influencing desired setpoints or affecting the thermal comfort of the occupant.
- The performance of radiant cooling systems and that of traditional cooling technologies are compared based on energy consumption. Radiant cooling systems theoretically require less energy to operate. Where the maximum energy savings are achieved in August, the energy saving for radiant wall, floor, ceiling, and DV are 32%, 30%, 27.55%, and 14.52%, respectively when compared with DX system.
- ln such extreme conditions, the decision to install a radiant cooling system must be based on simulations performed for air-conditioning systems in the building separately. The building practitioner must then decide based on the energy building simulation to study the effectiveness of these systems and avoid the condensation risks.

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7 DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

8 ACRONYMS

ACH	Air Changes per Hour
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CLO	Clothing Levels
COP	Coefficient of Performance
DO	Discrete Ordinates Radiant Model
DX	Direct Expansion Air Conditioning
DV	Displacement Ventilation
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
MET	Metabolic Equivalent of Task (Activity Levels)
MV	Mixing Ventilation
PI	Proportional Integral Controller

RC	Radiant Cooling System
RH	Relative Humidity (%)
RHC	Radiant Heating/Cooling
SU	Split Unit
UFAD	Under Floor Air Distributions
WMO	World Meteorological Organization
WWR	Window to Wall Ratio