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Efficiency Validation of Hybrid Cooling Application in Hot and Humid Climate Houses of KSA

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Abstract**—**Reducing energy consumption and CO_2 emissions are probably the greatest challenge now facing mankind. From considerations surrounding global warming and CO_2 production, it has to be recognized that oil is a finite resource and the KSA like many other oil-rich countries will have to start to consider a horizon where hydro-carbons are not the dominant energy resource. The employment of hybrid ground-cooling pipes in combination with the black body solar collection and radiant night cooling systems may have the potential to displace a significant proportion of oil currently used to run conventional air conditioning plant. This paper presents an investigation into the viability of such hybrid systems with the specific aim of reducing cooling load and carbon emissions while providing all year-round thermal comfort in a typical Saudi Arabian urban housing block. Soil temperatures were measured in the city of Jeddah. A parametric study then was carried out by computational simulation software (DesignBuilder) that utilized the field measurements and predicted the cooling energy consumption of both a base case and an ideal scenario (typical block retro-fitted with insulation, solar shading, ground pipes integrated with hypocaust floor slabs/stack ventilation and radiant cooling pipes embed in floor). Initial simulation results suggest that careful 'ecological design' combined with hybrid radiant and ground pipe cooling techniques can displace air conditioning systems, producing significant cost and carbon savings (both capital and running) without appreciable deprivation of amenity.

Keywords**—**Cooling load, energy efficiency, ground pipe cooling, hybrid cooling strategy, hydronic radiant systems, low carbon emission, passive designs, thermal comfort.

I. INTRODUCTION

THE rationalization of energy use and CO_2 emissions to inhibit global warming and climate change is probably the greatest challenge now facing mankind. First world lifestyles are underpinned by unprecedented levels of energy use per capita, yet an investigation carried out by the US Energy Information Administration (EIA) estimates that global consumption of Energy will grow by over 70% by 2030 [1]. Saudi Arabia, the world's largest producer and exporter of petroleum, produces an average of 11.6 million barrels per day, exporting an estimated 8.6 million while consumes approximately 3 million barrels of oil per day [1]. Saudi energy efficiency indicates that the primary energy consumption per capita is almost 3.6 times over the global average, at 6.7 tons in 2012" [2]. Electricity generation represents 34% of Saudi Arabia's internal oil consumption. Electricity consumption has also increased significantly over the last two decades, as result of economic development, population growth and the absence of energy conservation measures [3]. In 2013, the total electricity consumption of Saudi Arabia was 123.16 million Watt. This compares with 39.58 million Watt for the UK which is almost double the population [3]. Built environment predominate the energy use by 77% while residential buildings form around 52% of the building total electricity consumption (Fig. 1). Air conditioning is the largest user representing 69% of domestic energy use. According to the Saudi Ministry of Electricity (SME) due to intensive use of AC in summer the electricity consumption in the country has increased by 35% over the last two decades largely [3].

According to JODI (The Joint Organizations Data Initiative), the peak rate ever recorded was in July 2014, when 0.9 million barrels of crude Saudi oil was burned to generate electricity.As a result, the monthly peak demand rising from 56.574 MW to 62.260 [3]. Studies attributed this to the fact that 70% of Saudi's buildings are poorly insulated which has led to excessive cooling energy load [4]. Consequently, in 2013, Saudi Arabia ranked the ninth among nations for CO_2 emissions (494,000 metric tons equating to 16.8 metric tons per capita), that represented 1.38% of the total global CO_2 emissions [5]. Therefore, it is crucial for Saudi Arabia to consider the residential cooling energy consumption trends through developing low energy cooling strategy alongside enhancing the thermal performance of building fabric towards healthy and energy efficient houses. However, optimizing the energy performance of the current use of mechanical HVAC applications was extensively studied throughout the years and have reached a level of maturity [6]-[9]. The result was limited potential in conserving cooling energy use and CO_2 emission.

Several research and studies addressed the potential application of Passive Cooling Strategies (PCS) in various climatic conditions towards saving cooling energy and provide thermal comfort without causing much pollution to the surroundings [10]-[13]. Nevertheless, in hot and humid regions, such PCS is difficult to accomplish due to the high temperature and relative humidity. Whilst, other authors such as [4], [15] have argued that some of these PCS can be efficiently optimized when integrated with key Passive Designs and Measures (PDMs) such as façade, glazing treatments, and thermal insulation to reduce heat gains and enhance the cooling efficiency. However, few studies have considered the combination of passive and active cooling technique [14], [15]; this integration has revealed a significant result in saving cooling energy and maintaining the desired indoor condition. Therefore, it is crucial to bridge the gap between building designers and building physicists, by

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developing low energy cooling system prototypes considering the mechanical and architectural factors to propose sustainable houses which is thermo-physically climatic adaptive with high energy efficiency. This study essentially aims to investigate the potential application of low energy Hybrid Cooling system (HCS) into existing hot and humid Saudi houses towards reducing cooling energy use, carbon footprints and maintain the desired indoor thermal comfort condition.

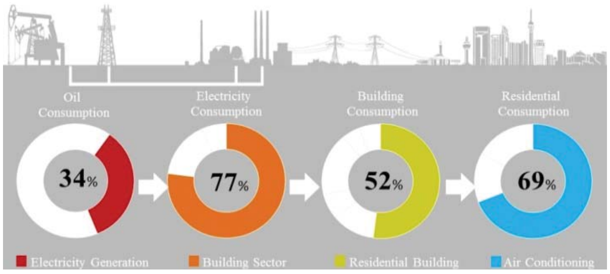

Fig. 1 The percentages of Saudi energy use per sector [3]

II. Methods

To meet the proposed aim, this study is divided into four main phases. Each phase uses a specific methodological approach. The first phase is to examine the actual thermo-physical and energy performance of an existing typical residential building in Saudi Arabia (Jeddah) as a baseline case to investigate the rationale behind the excessive cooling energy consumption. Based on the energy use analysis of the case study, the second phase involves in developing a viable low energy HCS considering parametric study and field experiments. The proposed hybrid system is an integration between Ground Pipe Cooling System (GPCS) and Hydronic Radiant Cooling System (HRCS) taking into consideration key PDMs such as façade treatment and fabric insulation. The third phase involves in numerical modelling and simulation of the developed passive design and hybrid systems while the fourth phase involves in conducting an analytical comparative assessment of the simulation result with the baseline results to ensure energy saving potential as well as cooling and cost efficiency of the applied systems.

A. Current Energy Use and Thermal Analysis of Typical Existing Residential Building in Jeddah: Case Study

The selected typical case study is a residential building located in the city of Jeddah, the main Saudi seaport on the Red Sea in the western province of Saudi Arabia. A typical residential block was selected which represents the most common residence type in Saudi Arabia. The six stories building consists of 20 flats with a total built floor area of 1532 m² and total land area of 650 m². Each of the 20 (four bedrooms) flats are occupied by 5-6 dwellings and is assigned a car parking space on the ground floor of the building. The flats are elongated and symmetrical around a staircase with a mid-axis perpendicular to the street (Table I).

Building's roof and floors are structured from reinforced concrete slabs filled by concrete blocks while walls are constructed from three layers include exterior cement plaster, hollow concrete block and coated by interior cement plaster. However, there is a lack of thermal insulation implemented in current case study building which leads to an excessive use of mechanical AC systems to maintain the desired indoor condition. A detailed description of building fabric thermo-physical property is shown in Table I.

The energy use of the case study building was numerically calculated by DesignBuilder simulation software on daily, weekly, and monthly bases. Generally, the outcome figures seem exceptionally high especially in comparison with other countries around the world with similar climatic conditions. According to the simulation results, the total annual electricity consumption was 607.458.20 kWh/year which is approximately 276 kWh/m²/year with an average monthly consumption of 50621 kW/month.

The annual electricity consumption per flat was then obtained by dividing the total annual consumption for the building by the number of flats (20); hence, the average annual consumption for each flat was estimated at around 30.372 kWh/year, with the per capita figure being 6074 kWh/year. The result shows parity in DesignBuilder figures with electricity bill which clearly demonstrated the validity and reliability of simulation software outcomes. By breaking down the energy use, it was evidently shown that the major cause of this high electricity consumption was energy use for air cooling purpose. As illustrated in Fig. 2, residential air cooling system applications form around 76% of the total residential energy consumption.

AC systems were dominated the total cooling energy use by 64% while fans and other cooling applications shape approximately 12% of the total cooling electricity consumption. Lighting systems were the second largest residential electricity consumer by 18% of the total electricity consumption whilst the other domestic cooking and freezing appliances consume around 6% of the total domestic electricity consumption (Fig. 2). As cooling energy consumption forms around 76% of the total residential energy consumption, Fig. 3 shows in detail the average monthly cooling energy consumption and the correlation between the cooling load and the total energy load. The electricity consumption rate increased according to the increasing of cooling energy use, especially in summer months from April to October. For instance, the electricity consumption reached its peak in July at approximately 70.000 kWh at the same time the cooling load reached its peak at around 51.000 kWh.

The total annual cooling energy consumption 466967 kWh differs between flats, according to direct heat and solar radiation and flats locations. The cooling load of the residential units are in the range between an average of 26.000 kWh to 35.000 kWh according to its location in floor plan (Fig. 4). Fig. 5 illustrates the monthly sensible cooling load breakdown of the simulated case study building. The sensible cooling load which refers to the dry bulb temperature is a measurement of the amount of heat that must be removed from the internal in order to maintain the desired indoor temperature. However, the specified set point temperature of the simulated case was at 26 °C and the simulation results of calculating building cooling load were based on this temperature. Since the case study building is poorly insulated, external and internal walls were in charge of the greatest amount of the total building cooling load. Walls were responsible for 15154.17 kW of the cooling load which form around 40% of the total monthly average building cooling load. In addition, buildings' floors, roofs and windows were responsible for almost 34% of the cooling load while occupants, equipment, lighting fixtures and infiltration form around 16% of the total building cooling load. However, these figures are changeable from month to month according to the climatic condition and occupancy (Fig. 5).

TABLE I
ARCHITECTURAL ANALYSIS AND FLOOR DESIGN

Vertical Section Perspective South Elevation

Ground Floor Plan

Typical Floor Plan

5th and 6th Floor Plan

Type	Description
Number of floors	6 floors - 1st-4th Floors: 16 flats (four flats/floor) - 5th-6th Floors: 4 flats
Number of Units	Flats:20
Unit Area	Flats: 76.6 m2 × 20 = 1532 m^2
Orientation	Front Elevation facing North
Plan Shape	Rectangular
Occupants	Average 5/flat- total occupants 100

TABLE II
THE TYPICAL THERMO-PHYSICAL SPECIFICATIONS OF BUILDING FABRIC

Building	Material	Thickness m	Density Kg/m³	K -value W/m K	R-value m²K/W
External walls	Plaster (dense)	0.025	1800	0.870	0.028
	Concrete blocks	0.225	1602	0.79	0.289
	Plaster (dense)	0.025	1800	0.870	0.028
			U-Value= 2.92 W/m²K		
Intermediate floors	Ceramic tiles	0.015	2000	1.00	0.015
	Mortar	0.08	1800	0.87	0.092
	Concrete blocks	0.225	1600	1.00	0.22
	Plaster (dense)	0.025	1800	0.87	0.028
			U-Value= 2.77 W/m²K		
Roof	Sandstone	0.10	2600	2.30	0.043
	Mortar	0.08	1800	0.87	0.092
	Concrete blocks	0.225	1600	1.00	0.22
	Plaster (dense)	0.025	1800	0.50	0.028
			U-Value= 2.460 W/m2K		

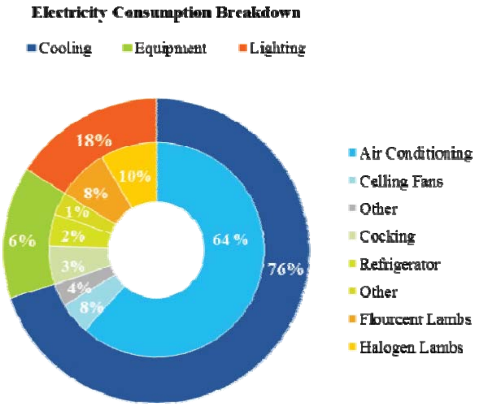

Fig. 2 The apportionment of residential electricity consumption modality

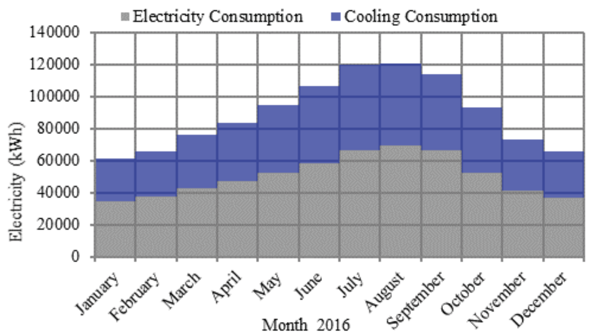

Fig. 3 The correlation between electricity and cooling consumptions

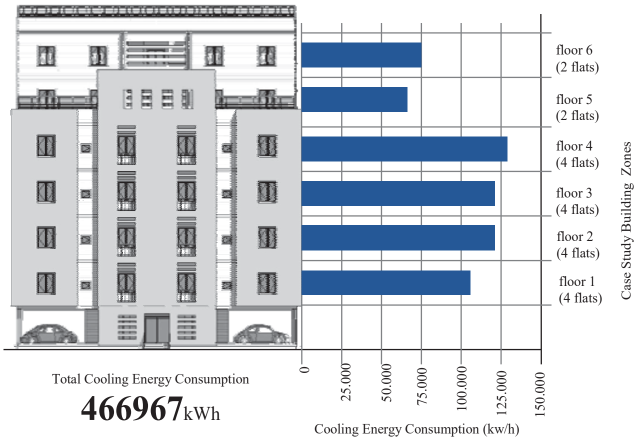

Fig. 4 Residential cooling energy consumption per flat

B. Developing HCS and PDMs Applications

Based on the thermo-physical properties of building fabric and the actual building energy performance of the simulated building which distinctly emphasized the high residential electricity consumption in form of air conditioning. Indeed, the low thermal capacity of building fabric was the main cause of this exaggerated use of cooling electricity consumption and CO2 emission which leads to lower standard of indoor condition and air quality. Since cooling energy dominated the total energy use, a significant amount of energy can be saved if cooling needs can be efficiently reduced.

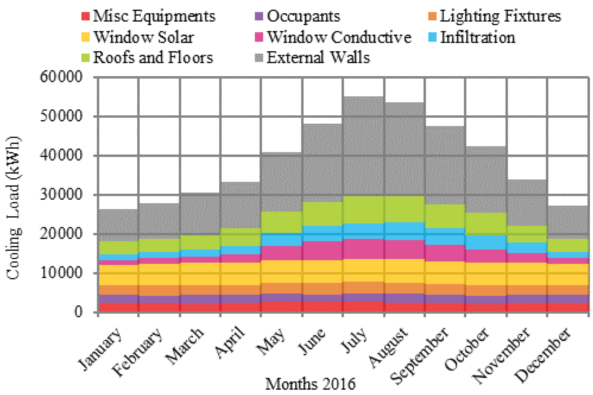

Fig. 5 The division of monthly residential cooling energy consumption sources

Towards achieving this aim, key strategies include PDMs to control the heat gain and cool loss and proposing viable HCS. The developed hybrid system is substantially and functionally combined two low energy PCS GPCS and HRCS. In addition, specific parameters and criteria were considered in designing and developing both integrated system. Although the selected case study building exists, some PDMs were considered to optimise the thermos-physical performance of building fabric. For instance, Floors and roofs were constructed from a 0.20m Hollow core concrete slap (TermoDeck) insulated by 0.05m of Extruded Polystyrene Insulation Boards (XPS) followed by 0.08m of mortar and 0.02 ceramic tiles/porcelain with calculated U-value of 0.315 W/m2K and R-value of 3.180 m2K/External walls were constructed from 0.2m hollow block covered by 0.05m of Polyurethane Foam Board (PUR) and 0.025 m of cement plaster coated by heat-reflective white cool paint with total U-value 0.41 W/m2K and R-value of 2.77m2K/W).In order to avoid direct, indirect and low-angled sun radiation and heat from different directions, an adjustable horizontal louvers shading device (0.10 SC) was used to automatically control sunlight level and providing privacy and security for the interior followed by double clear 0.006m thick (U-value 2.0) glazing panel was used to protect the interior from the direct solar heat. Green roof, and together with the substrate layer work as thermal mass to protect the roof structure from the direct solar gain small trees in ground floor filter the air and reduce air temperature and green grass reduce the soil temperature and protect it from solar heat gain. All floodlight bulbs Halogen and Flourcent were replaced to the highly energy efficient LED bulb with operation time schedule utilizing the daylight benefits (Fig. 6).

The proposed HCS is essentially relying on two heat sinks to absorb the heat. In HRCS mode, the night clear sky absorbs the radiant heat during the night and cool the building by longwave radiative cooling effect while in GPCS mode the ground soil absorbs the heat and disperse to the surrounding ground earth layers. In this hybrid system, two mediums were used to deliver the cooling energy which is water in HRCS and air in GPCS. Two times frameworks were considered to effectively perform the cooling process of the hybrid system. Since the effective longwave radiation occurred at night; the HRCS perform effectively at this time while the GPCS perform during the daytime.

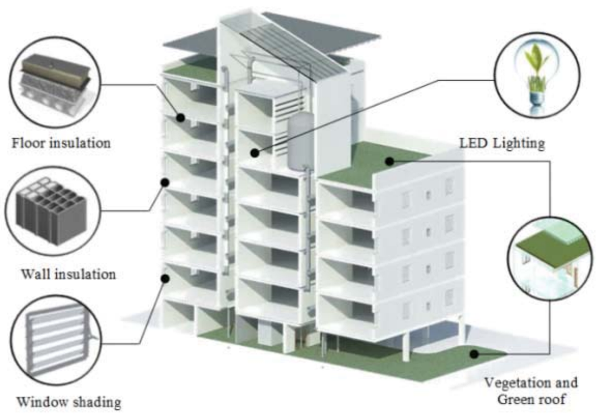

Fig. 6 The proposed Passive Design and Measure (PDMs)

Parametric studies were performed to determine the influence of four significant variables that affect the ground pipe outlet air temperature which includes pipe's length, depth, and diameter and air flow rate. A computational simulation was carried out on five different values of each selected parameter whilst the other parameters were kept at the same values. The standard values of each parameter were set at 30m for pipe length, 2.5m for pipe depth, 0.150m for pipe diameter, and 5m/s for air velocity, thus, at every simulation process; only one variable was changed while the other variables were maintained at mentioned standard values (Table III).The Parametric study was conducted in summer day at an average maximum ambient temperature in a shaded area at 34.8°C and 70% relative humidity while the average ground temperature and amplitude of the variation of soil temperature were numerically calculated by EnergypPlus simulation software depending on weather data profile of selected case study location in Jeddah.

TABLE III
VARIABLES OF THE GPCS PARAMETRIC ANALYSIS

Parameter	Standard	Variables
Length	30m	10m, 30m, 50m,70m, 90m
Depth	2m	1m.2m.4m.6m.8m,10m
Diameter	0.1m	0.025m. 0.05m,0.075m, 0.10m 0.20m,0.40m
Air velocity	5m/s	2m/s.5m/s.8m/s.11m/s.14m/s

The primary findings of simulation process to determine the impact of pipe length on outlet air temperature showed that longer buried pipe produces lower outlet air temperature. The rationale behind this is that, longer pipe allows the air to circulate for a longer time underground and thereby, transfer more heat into the surrounding underground soil, However, the pipe outlet air temperature decreased as the underground depth increased Duo to that, soil temperature is decreased by increasing the depth. Another parameter that has an influence on the cooling performance of ground pipe is the buried pipe diameter. Increasing pipe diameter result in higher outlet air temperature. The rationale behind this is that bigger pipe diameter minimizes the convective heat transfer coefficient and consequently, the outlet air temperature of the buried pipe is higher. Similar to the other parameters, air flow rate affects the ground pipe cooling performance. Increasing air velocity results in increasing pipe outlet air temperature. This leads to reduce the temperature difference between pipe inlet and outlet, which consequently reduced the coefficient of performance (COP). Parametric studies were performed to determine the efficient system design of HRCS for the optimum cooling scenario. Therefore, a proposed testing model of the retrofitted case study building was numerically developed considering the implemented PDMs.Computational simulations were carried out on four different values of each selected parameter whilst the other parameters were kept at the same values. The standard values of each parameter were set at 0.2m for pipe spacing, 0.10m for pipe diameter, 18ºC for inlet water temperature and 1.5 l/s for water flow, thus, at every simulation process; only one variable was changed while the other variables were maintained at mentioned standard values

TABLE IV
VARIABLES OF THE HRCS PARAMETRIC ANALYSIS

Parameter	Standard	Variables
Spacing	0.2m	0.01m.0.02m.0.04m.0.06m.0.08m,0.1m
Inner diameter	0.01m	0.0025m. 0.005m, 0.10m,0.15m,0.35m
Inlet water temp	16ºC	10 ºC, 12ºC, 16ºC, 20ºC, 25ºC,30ºC
Water flow rate	1.5	1 l/s.1.5 l/s.2 l/s.4 l/s.8 l/s

The proposed HCS components and cooling mechanism as illustrated in Fig. 7 starts from the night radiative cooling effect result from the high emissivity (0.9) of a blackbody radiator. the circulated water blew the radiator was cooled by conduction to a certain temperature close to the radiator surface temperature (range between 14ºC to 23ºC) according to the clarity of the night sky, ambient temperature, humidity level and the thermal conductivity of radiator surface and PVC pipe. This amount of cold water (450 litters) is stored in the thermal storage at a certain temperature (usually 18ºC which is 4ºC to 6ºC below the indoor average thermal comfort temperature) which is the ideal standard of water temperature to carry out the HRCS depending on the desired indoor set-point temperature and thermal properties of the floor.Utilizing the passively cooled water by the effect of night radiative cooling leads to a significant reduction in total cooling load of the HRCS. In case of peak demand that commonly happened in hot summer season especially when water temperature exceeds the 18ºC and the indoor temperature exceed the setpoint temperature at 28 ºC, an auxiliary low energy DC chiller combined with cold water thermal storage can be automatically operated. This cold water is pumped to the embedded pipe in the floor through a complete controlling and sensors system to adjust the water flow and temperature. However, the hot water circulated in the black body radiator during the daytime is stored in hot water tank for domestic use.

C. Numerical Modelling and Simulation of Passive and HCS Applications

The cooling process of GPCS usually occurred during the day by pulling the moderate air temperature that cooled by the adiabatic cooling effect in the shaded zone in the ground floor. In this created "microclimate" zone, the air temperature is (4 ºC to 9 ºC) lower than the actual ambient temperature in the exposed area. The adiabatic cooling impact leads to minimize the cooling load of the GPCS. The air is drawn into the ground PVC pipe through an insulated air inlet and circulated through the deep ground pipe following the serpentine shape which significantly maximizes the loop length and thus the contact surface with the ground soil for utmost thermal conductivity and heat exchange. Consequently, the air is cooled to a certain temperature close to the average daily ground soil temperature (usually between 23 ºC and 28 ºC) based on factors including the ambient temperature humidity and the thermal properties of ground soil and pipe. Due to the high humidity level and temperature amplitude between the ambient outdoor and ground soil temperatures, the condensation inside the ground pipe is occurred and specifically concentrate at the lowest point at the U shape pipe loops where a sloped pipes are designed to collect the condensed water to water tank as a source of clean and relatively cold water that can be used domestically or sprinkle it on the shading zone to enhance the adiabatic cooling and irrigate the soil surface for cooling purpose .The air is drawn into air tank chilled by water coil system as air to water heat exchanger taking the advantage of the cold water produced by night radiative cooling to cool the air by conviction to the desired setpoint temperature at 22 ºC. The cooled air then is distributed and blown to indoor space through supply fan attached to each unit supply duct. As shown in Fig. 7, the Building section (height) was designed to boost the stack effect to naturally exhaust the hot air from the upper levels of each unit through central exhaust inline duct fans to the exterior at the upper point of the building. The cooling load and operating time schedule of the proposed HCS is entirely depending on the required indoor setpoint temperature and supply water temperature. Therefore, the numerical simulation of the proposed HCS considered this criterion when computationally set up the HCS to calculate the cooling load of this system and examine the impact of the HCS application on indoor condition and thermal comfort.

D. Efficiency Validation of HCS Application

Since the selected case study building is relatively huge and complicated to be simulated as a whole, it was appropriate and more accurate to examine the influence of the proposed passive designs and cooling strategies on the thermal and energy performance of each flat as an individual case study and multiplied the results by the number of flats in the building. The results in Fig. 8 shows a significant reduction in cooling load occurs as a result of various cooling applications. This reduction is disparate according to the adopted applied cooling systems. The total reduction level of baseline cooling consumption in effect of applying floors, walls, windows PDMs and upgrading lighting system is approximately 170946 kWh/year (36.60%) with monthly average reduction of 14245.5 kWh/month. The reduction level in cooling load is multiple according to the cooling system application. In the GPCS Scenario, the monthly cooling load was minimized by 86.18 % compared with baseline. Likewise, the monthly cooling load as a result of applying HRCS was minimized by 88.47%. In HCS mode which combined GPCS and HRCS applications, the monthly cooling load was remarkably reduced by approximately 74.65% compared with baseline. the monthly average cooling energy consumption decreased to 9867.5 kWh/month in comparison with around 38913.91 kWh/month in the baseline (Fig. 8).

Maintaining the indoor condition is a significant factor to determine the efficiency of the applied cooling system. Fig. 9 shows the monthly mean ambient temperature and the monthly average indoor temperature of various applied simulated cooling systems. The baseline (AC) annual Indoor condition remains constant throughout the year with an average temperature of 24.74 °C which is exactly within the comfort zone between 23 °C and 29 °C. However, indoor temperature fluctuated throughout the year as a result of applying GPCS, HRCS and HCS. In GPCS and HRCS mode, the indoor temperature reaches its peak at an average temperature of 27.25 °C and 26.3 °C respectively in July. However, the HCS is considered as an optimum low energy cooling scenario in terms of energy saving and maintaining the average indoor temperature invariably within the comfort level from 24.2 °C to 25.7 °C despite the monthly temperature fluctuations over the year (Fig. 9).

Besides the consideration of thermal comfort, carbon dioxide concentration in air is an important factor to indicate air quality. According to ASHRAE standard, the recommended minimum amount of fresh air per person for acceptable indoor air quality of residential spaces is 25 CFM/person [16]. This standard was considered to calculate the actually required air ventilation rate and CO_2 concentration in indoor air. Fig. 10 clearly shows the distinction between the carbon dioxide levels in baseline compare to HCS mode. The key factor for the CO_2 concentration inside the building was the air exchange rate. In the baseline scenario, the average monthly concentration of CO_2 in the internal air is 823 ppm which classified according to ASHRAE 62 as a medium to low air quality. In addition, the CO_2 concentration in the air increased by the increasing of AC system usage. For instance, the highest average CO_2 concentration in air was recorded in hot July and August at 952 and 926 respectively as a result of the excessive use of AC system while in winter season the indoor CO_2 concentration decreased to an average of 770 ppm due to utilizing the outdoor relatively cold air. Moreover, applying alternative air condoning system such as HCS is remarkably reduced the indoor air CO2 concentration to an average of 718.8 ppm, however, the reduction level is varied from month to month according to the ambient temperature and system usage .the minimum average CO2 concentration was recorded in January as a result of the low cooling load. In comparison with baseline, the high temperature of hot summer has increased the outdoor air flow of HCS and consequently decreased the CO2 level of internal air and enhanced the air quality (Fig. 10). In addition, applying HCS sustained the internal RH to be within the comfort zone with an average between 44% to 65% depending on the average outdoor RH (Fig. 10).

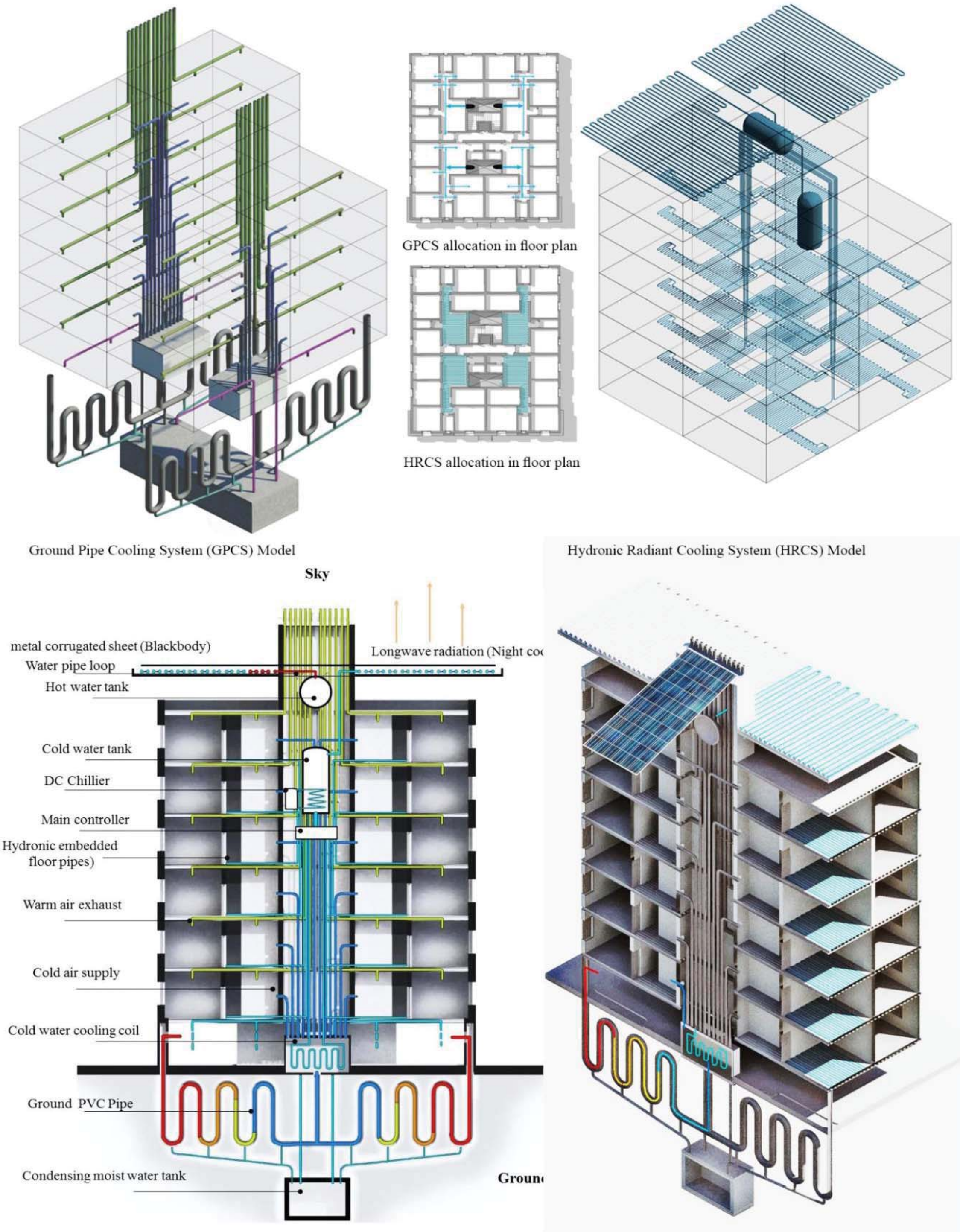

Fig. 7 HCS component and cooling mechanism

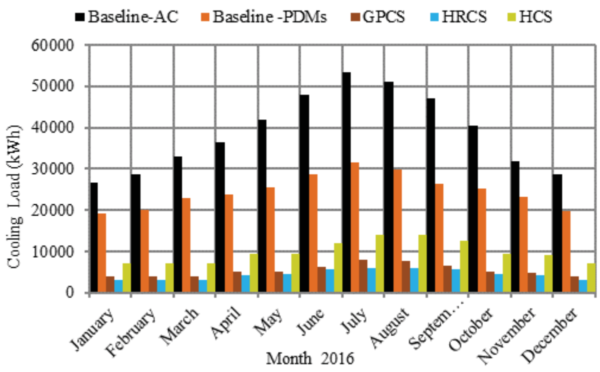

Fig. 8 Average monthly cooling load of various passive and hybrid cooling systems

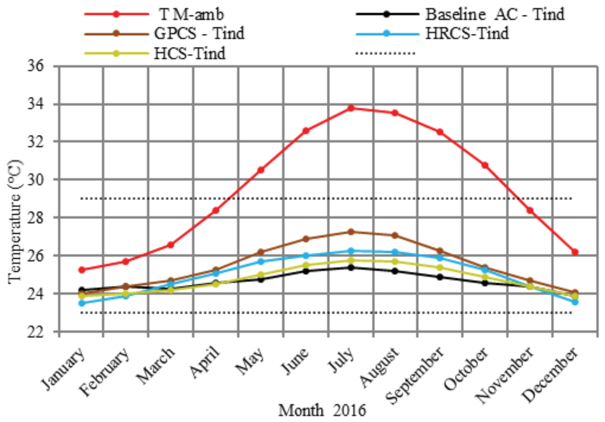

Fig. 8 Average monthly indoor temperatures of various passive and hybrid cooling systems

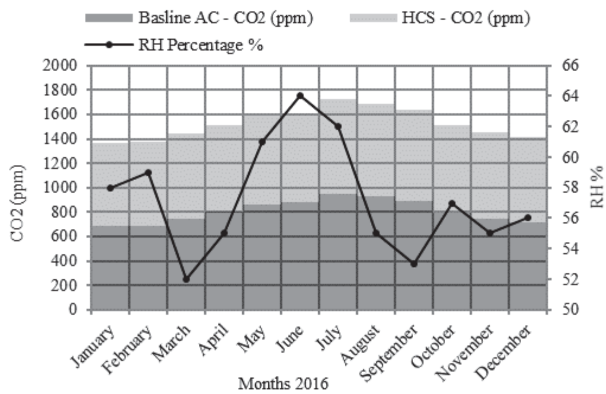

Fig. 9 Comparative assessment of HCS indoor air quality

E. Feasibility Study and Life Cycle Cost

This study presents detailed estimated energy and capital cost of various cooling system applications and the payback period as a result of energy saving. Two factors were considered towards determining the cost-effectiveness of the proposed cooling system applications. The first factor is the capital cost of assembling and setting up the cooling system and the second factor is the energy cost of operating the system. The energy consumption tariff that applied in this study is considered according to Saudi Electricity Company average tariff for the residential building in Saudi Arabia. The average residential tariff is approximately 0.17 SR/kW which is approximately £0.034 (GBP) /kW of electricity. As known from the baseline case energy simulation results, the average annual cooling energy consumption is an approximately of 466967 kWh hence, the average annual energy cost of baseline case using Ac system based on the defined tariff of £0.034 (GBP) /kWh is approximately £15876.878 GBP/year. As a result of above calculation, Fig. 11 shows the average monthly estimated cooling energy cost of various cooling systems. The graph demonstrates the huge contrast between the baseline AC energy cost and the other low energy cooling systems applications also the fluctuation of cost and usage from month to month according to the hot and cold season.

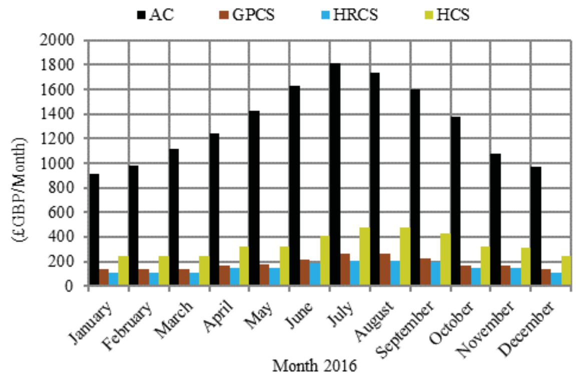

Fig. 10 The average monthly energy cost of the applied cooling systems

Additionally, the detailed cost of various cooling systems including capital and operation cost was calculated. The cost study of the cooling systems is classified in five categories including the cost of the main components, instalment, operation and maintenance. The application of HCS is a long-term cost-effective, this system which cost approximately £19508 GBP can significantly reduce the cooling energy consumption and cut down electricity bill up to 75%. The cost analysis was presented to obtain the life cycle saving and estimated payback period which is the number of years after which the initial GPCS, HRCS and HCS applications cost will be retrieved due to energy savings and taking into consideration the capital cost of each application in comparison with baseline cost of energy. The graphs in Fig. 12 estimates the payback period of implementing GPCS after approximately 8 months of the initial operation similar to HRCS application which can retrieve the total cost after almost 6 months of running the system. However, the estimated payback period of applying HCS is approximately after 1.7 years from the initial application (Fig. 12).

III. Conclusion

The study primary aim is to propose energy efficient and climatic adaptive hybrid cooling system to existing Saudi houses toward minimizing its current excessive cooling energy consumption, CO2 emissions and maintain the desired thermal comfort temperature taking into account the local hot climate conditions and the architectural context.

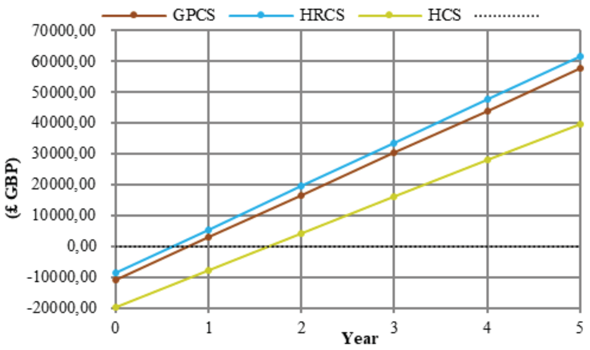

Fig. 11 The life cycle cost and an estimated payback period of HCS

The study proved the cooling efficiency and cost-effectiveness of the proposed HCS application and its basic components PDMs, GPCS and HRCS. The applied PDMs have controlled and sustained the internal temperature and reserved any cooling loss or infiltration which reflect on minimizing the daily operating hours of AC, GPCS, HRCS and HCS and consequently reduced the cooling system energy consumption.

In addition, the analyzed results of the simulated baseline case-study of AC system in comparison with the simulation results of various cooling systems applications demonstrated the potential energy saving up to 75 % of the total cooling load and energy usage cost. Moreover, applying HCS has proved as an optimum cooling scenario when significantly maintained the indoor temperature within the comfort zone and enhanced the air quality. The Initial simulation results propose that efficient 'ecological design' combined with hybrid radiant and ground pipe cooling techniques can supersede AC systems, offering significant cost and carbon savings.

References

[1] EIA, U.S. Energy Information Administration, Office of Energy Statistics-Washington, DC 20585. - The Annual Energy Review "Country Analysis Brief: Saudi Arabia "Last Updated: September 10, 2014-pp.4-14.
[2] Saudi Arabia Energy Efficiency Report; 2013و Last Updated: April 26, 2014 pp. 16-38.
[3] Saudi Electricity Company" Annual Report 2014" 12-31, retrieved 2015-08-30.
[4] Al-Ajlan SA, Al-Ibrahim AM, Abdulkhaleq M, Alghamdi F. Developing sustainable energy policies for electrical energy conservation in Saudi Arabia. Energy Policy 2006; 34(13):1556–65.
[5] World Bank Data - CO2 emissions (metric tons per capita), currently includes 2013 data World Per Capita Carbon Dioxide Emissions - exhaustive and up to date list of statistic by country from 2013.
[6] Homod R. Z., Energy saving by integrated control of natural ventilation and HVAC systems using model guide for comparison. Renew Energy 2014; 71:639–50.
[7] Chua KJ, Yan J. Achieving better energy-efficient air conditioning – a review of technologies and strategies. Appl Energy 2013; 104:87–104.
[8] Wan J. W., An energy efficient air-conditioning system with an exhaust fan integrated with a supply fan. Energy Build 2009; 41 (12):1299–305.
[9] Nosrat A. H., Improved performance of hybrid photovoltaic-trigeneration systems over photovoltaic-cogen systems including effects of battery storage. Energy 2013; vol. 49:366–74.
[10] Parameswaran R, Kalaiselvam S. Energy efficient hybrid nano-composite-based cool thermal storage air conditioning system for sustainable buildings. Energy 2013; 59:194–214.
[11] Stavrakakis GM, Zervas PL, Sarimveis H, Markatos NC. Development of a computational tool to quantify architectural-design effects on thermal comfort in naturally ventilated rural houses. Build Environ 2010; 45(1):65– 80.
[12] Givoni B. Indoor temperature reduction by passive cooling systems. Sol Energy 2011; 85(8):1692–726.
[13] Kamal MA. An overview of passive cooling techniques in buildings: design concepts and architectural interventions. Acta Tech Napoc Civ Eng Arch 2012; 55(1):84–97.
[14] Maleki BA. Shading: passive cooling and energy conservation in buildings. Int J Tech Phys Probl Eng 2011; 3(4):72–9.
[15] Al-Shaalan AM, Ahmed W, Alohaly A. Design guidelines for buildings in Saudi Arabia considering energy conservation requirements. Appl Mech Mater 2014; 548 549:1601–6.
[16] ASHRAE Standard 62, 2007, ASHRAE Standard 62–2007, Ventilation for acceptable indoor air quality. Atlanta: American Society of Heating and Refrigerating and Air-Conditioning Engineers Inc.