BUILDING SERVICES ENGINEERING
RESEARCH & TECHNOLOGY

2016, Vol. 37 (1) 66–84

DOI: 10.1177/0143624415596924
bse.sagepub.com
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Displacing air conditioning in KSA: An evaluation of 'fabric first' design integrated with hybrid night radiant and ground pipe cooling systems

Building Serv. Eng. Res. Technol.

Jamil Hijazi[1]. **Stirling Howieson**[1]

Abstract

This paper presents an investigation into the viability of 'fabric first' intelligent architectural design measures, in combination with a hybrid cooling system (HCS). The specific aim is to displace AC and reduce CO_2, while maintaining thermal comfort, in a typical housing block in KSA. The results of thermal modelling and prototype field trials suggest that passive design measures (PDMs) combined with night radiant cooling and supply ventilation via ground pipes, can negate the requirement for a standard AC system. Such a strategy may also have a remarkably short payback period when energy savings, in use, are set against the additional capital costs associated with improved building fabric performance.

Practical application

This study suggests that a significant proportion of AC cooling energy can be displaced by improving building fabric performance in combination with supply ventilation via ground pipes. As radiometer readings fell as low as 2.8°C when the night sky is clear, roof mounted high emissivity hydronic radiant panels can also provide a significant opportunity for additional heat flushing. In hybrid combination, these strategies have the potential to lower the carbon footprint of a typical housing block in KSA by over 80% and these measures and strategies will be equally applicable and cost-effective in all geographic regions of the world where cooling loads represent the predominant domestic energy use.

Keywords

cooling load, energy efficiency, ground pipe supply ventilation, hybrid cooling strategy, hydronic night radiant cooling, low carbon design, thermal comfort.

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[1]Department of Architecture, University of Strathclyde, Glasgow, UK

[1]Department of Architecture, University of Strathclyde, Glasgow, UK

Corresponding author:
Jamil Hijazi, Department of Architecture,
University of Strathclyde, Glasgow, UK
Email: jamil.hijazi@strath.ac.uk

Introduction

First world lifestyles are underpinned by unprecedented levels of energy use per capita, yet an investigation carried out by the US Energy Information Administration estimates that global consumption will continue to grow by 70% over the next decade.[1] According to the latest Saudi energy efficiency report, the primary energy consumption per capita is 3.6 times higher than the world average.[2] Electricity use has increased significantly over the last two decades as a result of economic development, population growth and the absence of any energy conservation measures, and now represents 34% of the nation's oil consumption. 77% of this output is used by the built environment with the residential sector responsible for 52%. Air conditioning represents 69% of domestic consumption.[3] In the summer of 2014, the use of AC resulted in a 35% increase in electricity usage, with annual peak demand rising from 56 to 62MW.[3] A significant proportion of this has been attributed to poor building insulation standards.[4]In 2013, KSA ranked ninth among nations for CO_2 emissions (494,000 tons of carbon equating to 17.9 tons of CO_2 per capita). This represents 1.38% of total global CO_2 emissions.[5] Given that oil is a finite resource and climate change agreements may limit future exploitation, it is important for KSA to consider the adoption of energy efficiency measures and low carbon cooling strategies. Several studies have attempted to address this challenge by optimising the performance of HVAC systems, however, the predicted savings were modest.[6-8] Fabric first thermal retrofitting strategies have been reported to have the potential to reduce cooling loads by between 20 to 35%.[9-11] Cooling techniques such as ground pipe supply ventilation, evaporative and night radiative cooling, have been evaluated by two studies in climatic zones where temperatures are moderate.[12,13] The climate of KSA - where peak summer temperatures can reach 50°C with high RH, particularly on the east coast of the Red sea - presents a formidable challenge. A project evaluating the performance of hybrid water cooled PV systems in this region of KSA demonstrated an increase in output of 9%.[14] The potential of a hybrid wind/solar installation on the west coast of KSA, demonstrated a saving of almost 34% of AC energy demand.[15] These results suggest that a combination of passive and active measures may offer the greatest potential for displacing AC demand. A hypothesis was developed that centred on evaluating the potential of ground pipe supply ventilation and overnight radiant black body emissivity in symbiotic combination with 'fabric first' insulation and solar shading.

Methodology

The interrogation of the hypothesis was addressed in three stages. The initial task was to generate a baseline analysis for the thermo-physical and energy performance of a typical residential block in Jeddah. The second stage involved developing an alternative low energy cooling approach that could handle such high ambient temperatures. The task involved designing supply ventilation via deep ground pipes in combination with hydronic radiant black body infra-red panels with a high emissivity selective surface, to displace residential AC systems. The design of the this 'hybrid' system required a parametric analysis combined with testing prototypes in field trials, to establish actual ground temperatures at various depths and black body emissivity ranges for night cooling under varying sky conditions. This hybrid approach (HCS) became the subject of numerical modelling and simulation using 'DesignBuilder' software in conjunction with the 'EnergyPlus' simulation engine. The third task was then to assess the results and validate the cooling efficiency and cost-effectiveness of the measures compared to the baseline case (Figure1).

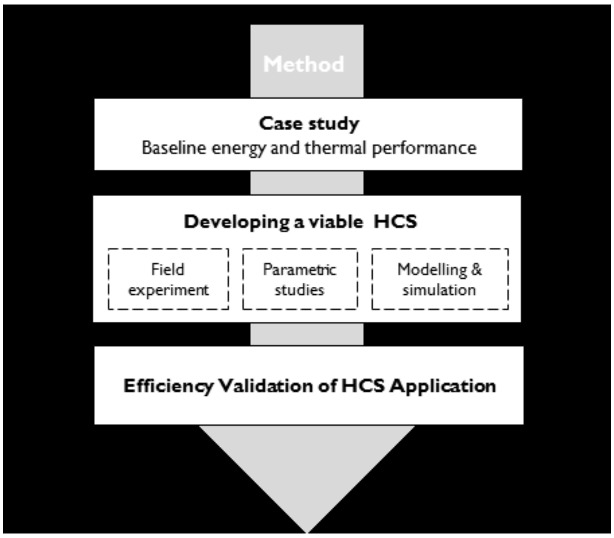

Figure 1. Method for Assessing the HCS strategy

A. Energy use and thermal analysis

The six-storey building consists of twenty flats with a total floor area of 1532 m^2. Each of the four-bedroom flats is occupied by an average of five persons (Table1). The floors are constructed using reinforced concrete slabs with external walls formed using single skin concrete blocks, rendered externally and plastered on hard internally, with a resultant U value calculated to be $2.92W/m^2K$. Windows typically use 4 mm single glazing with a U value of circa $5.3W/m^2K$ (Table2).[4]

Figure 2. Baseline model d

Type	
Number of units	20 flats (1st-4th floors: 16 flats and 5th-6th floors: 4 flats)
Unit area	Flats: 76.6 m2 × 20 = 1532 m2
Orientation	Front Elevation facing North
Plan shape	Rectangular
Occupants	Average 5 /flat- total occupants 100

Table 1. Building description and architectural specification.

	Material	Thickness m	Density Kg/m³	K-value W/m K	R-value m²K/W
Wall	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= 2.92W/m²K		
Floor	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= 2.7W/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= 2.460W/m2K		

Table 2. The typical thermo-physical specifications of building fabric. [4]

A series of computer simulations were run to predict daily, weekly and monthly energy consumption. As shown in Figure 3, the electricity consumption of the simulated block was compared to actual consumption profiles from electricity bill and meter readings. The annual electricity usage for a block is 607458kWh/year equating to 30372kWh per flat (6074kWh per person). Space cooling accounts for 74% of the total electricity usage. Electricity consumption reached its peak in July (70000kWh) with a concurrent cooling energy use of 51000kWh. The lowest electricity use and cooling demand were monitored in January at 38000kWh and 26000kWh respectively, however, the average annual cooling energy usage, differed between flats according to floor area, orientation and storey height.

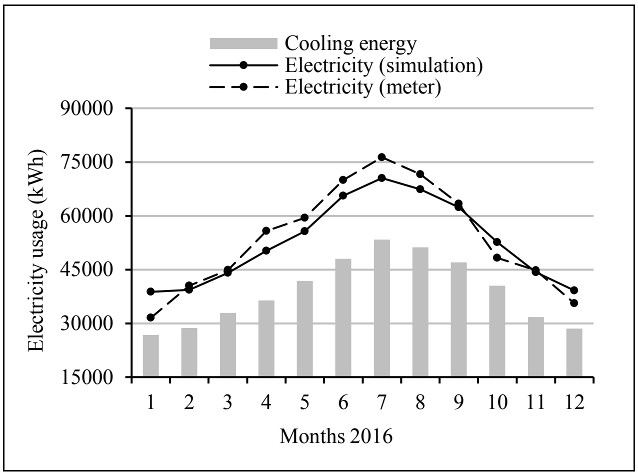

Figure 3. Simulated and calculated average monthly electricity usage and cooling energy use.

Figure 4 shows domestic air conditioning makes up 74% of the total energy consumption. AC systems dominate the total cooling energy use (70%), while fans and other cooling technologies share around 4% of the total. Lighting systems are the second largest consumer at 18%, whilst other domestic appliances consume around 12%.

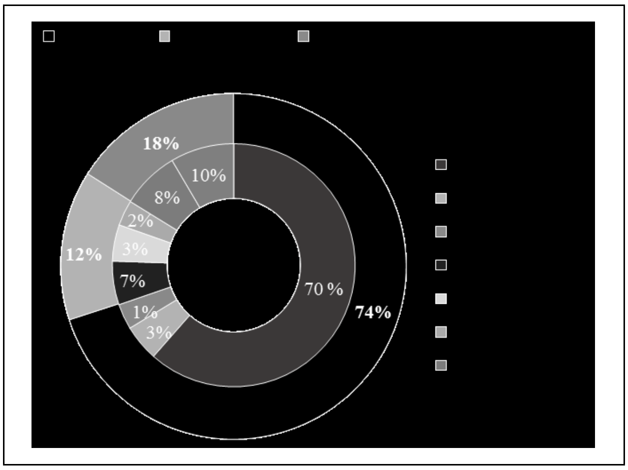

Figure 4: Domestic electricity consumption division.

The sensible and latent cooling loads are a measurement of the amount of heat that must be removed from the interior in order to maintain indoor temperatures below the upper threshold comfort temperature of 28°C.[16] In order to measure the cooling load of a central air-conditioning system with fan coil units, the set-point and set-back indoor temperatures were set at 28 and 23°C respectively. Weather data for the region is pre-programmed into the EnergyPlus software. The simulation was carried out on a typical 1540m² block with an average occupancy load factor of 0.065persons/m². The zones are illuminated using standard Halogen spotlights and all other appliances have a fixed operational schedule.

Figure 5 quantifies the sensible and latent cooling loads of the baseline case. The simulation results show that external walls dominate cooling loads at 40% of the total. This equated to an annual load of 186662kWh/year and an average monthly cooling load of 15555kW. The peak load was recorded in July at 23574kW. Floors and roofs form around 19 % of the total annual cooling load with summer peak load of 9780kW recorded in August. Solar heat transfer through windows was responsible for almost 12% of the total annual cooling with an average cooling load of 4645kW/month. Building occupants, equipment, lighting fixtures and air ventilation and infiltration formed around 29% of the cooling load.

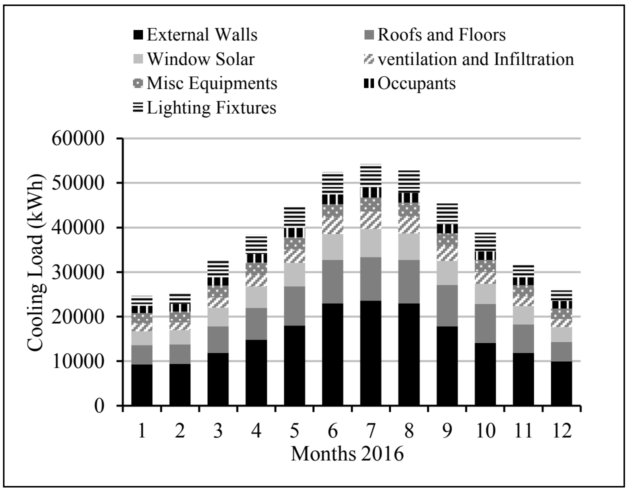

Figure 5. The average monthly cooling load by element.

B. Assessing 'fabric first' measures

Before developing and applying the proposed cooling strategies, an assessment was made of passive 'fabric first' design measures to reduce external and internal heat gains and optimise the thermo-physical performance of the building fabric.

External insulation and clay blocks

The wall specification was changed to 50mm closed cell insulation on 200mm hollow clay blocks 'Ziegel' with a 25mm lightweight polymer render and heat reflective white mineral paint to increase the 'Albedo' effect. This reduced the U value from 2.92 to 0.41W/m^{2}K. Floors and roof construction used 200 mm hollow core pre-cast concrete slabs (Termodeck) topped with an 80mm screed, 50mm closed cell insulation and 20mm white ceramic tiles, that produced a U value of 0.31W/m^{2}K, representing an improvement in thermal resistivity of 87%. 50 mm closed cell insulation was also added to the roof deck and the soffit of the ground floor ceiling.

Solar Shading

In order to avoid both direct and indirect solar radiation, externally mounted adjustable horizontal louvres with a solar shading coefficient of 0.25 were added, providing additional privacy and security. Standard 6mm double glazing window units were also incorporated with a U value of circa 2.5W/m^{2}K, reducing heat gain by circa 50%.

Green roof and integrated PV array

A specification for a 'green' roof to protect the slab from solar gain was added to areas not required for access, as was vegetation to the immediate surround on the ground floor to inhibit the heat island effect from paving and roads. The intention is to use the condensate from the ground pipe supply ventilation to irrigate these elements. Such greenery can also improve air quality in the immediate surrounds by absorbing modest quantities of particulate matter and other products of combustion. This can create a 'microclimate' with the air temperatures predicted to be 4ºC to 9ºC lower than ambient due to the adiabatic and albedo cooling effects.[17] It is from this zone that the supply air for the ground pipe supply ventilation system is drawn. 30m^2 of roof-mounted PV array will provide almost all the electricity required to drive the supply fans during daylight hours.

LED lighting

LED lamps on automatic controls were introduced throughout the development to further lower casual heat gains from the standard Halogen fittings.

Thermal effect of the applied PDMs

The preliminary analysis suggested that passive 'fabric first' design measures such as external insulation, solar shading, additional vegetation, increasing the 'Albedo' effect and a high level of thermal inertia using hypocaust flooring could produce a reduction in heat gain of circa 60%. Simulations predicted a total annual reduction in AC cooling energy use of 37% with a peak monthly saving during July of around 40%. This displaced over 150000kWh of AC cooling energy, however, PDMs on their own are unable to maintain internal temperatures below the upper threshold (28°C) for around 180 days of the year (April to October) (Figure 6).

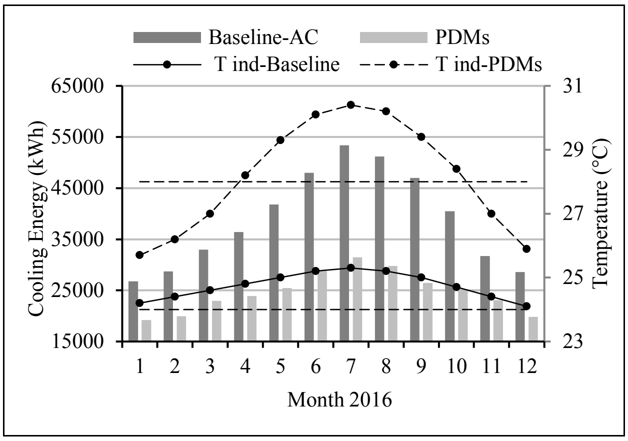

Figure 6. The effect of PDMs on average monthly indoor temperature and AC cooling energy demand.

D. Ground pipe cooling system (GPCS)

Ground pipe cooling relies on the soil/sand temperature being significantly lower than ambient air and good conductivity between the soil/sand/pipe interfaces, to disperse heat gain at 4m in depth. The large diameter pipes are buried in trenches in a serpentine loop configuration, with the gaps between vertical risers back filled before the capping bends are attached. In order to determine the optimum cooling scenario for these ground pipes, field measurements were combined with parametric analysis.

GPCS field experiment

Investigations were performed to measure the soil temperature in Jeddah. The initial aim was to go 4m in depth where ground temperatures remain relatively stable however, it proved challenging to dig to this depth without hiring heavy plant. The measurement was thus taken at 0.5, 1 and 2m depths. A TGU-4500 'Tinytag' data logger was placed inside the buried pipes to measure the ground temperature over time. The holes were back-filled with insulation

Figure 7 suggests that an average reduction of circa 9°C below ambient air (44°C) can be achieved. During a typical summer day at 12:00 noon, the difference between soil temperatures at 0.5m, 1m and 2m was 2°C and 5°C respectively, while at 12:00 mid-night, the temperature difference was less than 2°C. Over the long term, soil temperatures at 2m depth were more constant with slight fluctuations between 29.2 to 35.2°C which is between 5 to 9°C lower than ambient air temperature. At 4m depth, the performance is expected to be significantly better in providing pre-cooled air supply, particularly if an efficient thermal interface can be engineered.

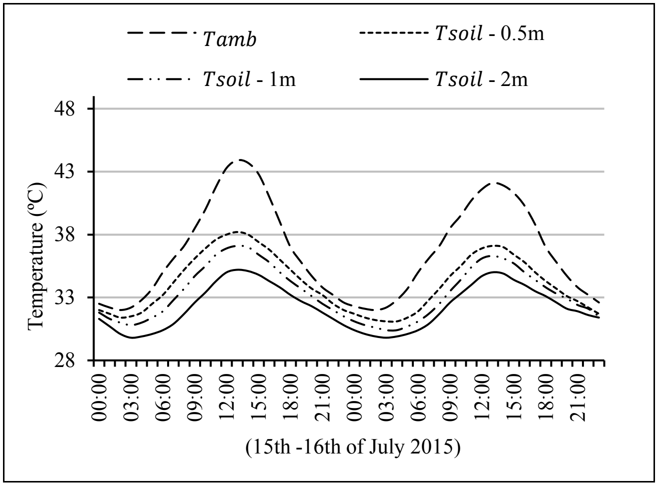

Figure 7. The hourly soil temperature at various depths.

GPCS parametric analysis

The effect of varying four key parameters (pipe length, diameter, depth and air flow rate) was then subject to multiple simulations to determine their influence and optimal configuration. 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 (Table 3).

Perhaps unsurprisingly pipe length was the dominant variable in reducing the temperature of the supply air. Increasing pipe length from 10m to 50m resulted in a reduction in outlet air temperature of almost 2.3°C (from 32°C to 29.8°C) due to both the heat exchange time frame and increased contact area.

Likewise, the greater the pipe depth, the lower the outlet temperature. By increasing pipe depth from 1 m to 4 m, the outlet air temperature decreased by 2.2°C. Pipe diameter was also influential as most of the energy transfer occurs at the bends where air turbulence is greatest, allowing more heat to be transferred into the ground. Increasing air velocity from 2 to 20m/s increased the outlet temperature by 2.8°C.

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

Table 3. Variables of GPCS parametric analysis.

E. Hydronic Radiant Cooling System (HRCS)

The basic concept of the HRCS is to install roof-mounted water-filled metal panels (with a high emissivity coating) that will lose heat by black body long wave infra-red radiation to a clear night sky (90% clarity based on Jeddah weather data profile).[18] This cool water will then be pumped round pipework embedded in the floor screeds of the living zone.

HRCS field experiment

To test the concept in-situ, a prototype trial panel (profiled black metal cladding 1.8 x 1.0 x 0.35m incorporating 50mm insulation) was assembled and fitted with thermocouples. The profiles had 12.5mm PVC pipes attached to the underside (4.5m in length) linked to a 25 litre storage tank. The sheet was exposed to the sky over several 24 hours cycles, with four temperature measurements being recorded at regular intervals.

Figure 8 shows a maximum surface temperature of 58.1°C which was around 16°C higher than the ambient temperature. The maximum average air temperature in the 150mm gap, located between the radiator and insulation layer was 44.1°C which is only 4°C higher than the ambient temperature. Night temperatures dropped to 21.4°C, 11°C lower than ambient. The air gap temperature recorded a minimum temperature of 22.8°C. The water outlet temperature at this point was 23.8°C, 10°C lower than ambient air (Figure 8).

This relatively crude prototype - with a less than optimal thermal interface - confirmed that hydronic night radiant cooling, operating in clear sky conditions, will have the capacity to supply a significant level of 'coolth' by radiant heat flushing. Additional efficiency gains would be possible by increasing the effectiveness of these thermal interfaces with flow rates being modulated to maximise heat flushing when sky temperatures are falling towards their diurnal minimum. Radiometer readings during the summer months dropped to 2.8°C confirming that there is considerable scope to increase heat loss to a clear night sky if the thermal interfaces between the water pipes and panel emitter plate can be improved.

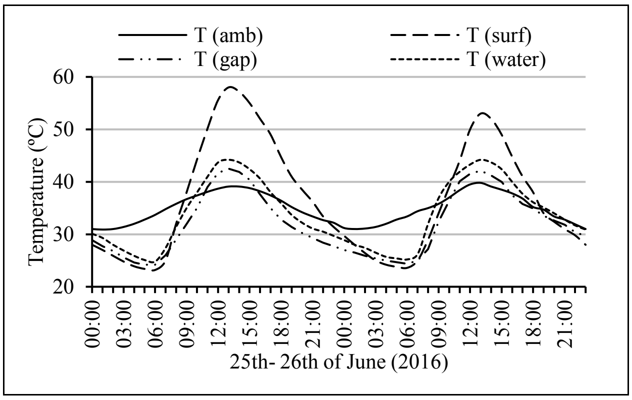

Figure 8. The average hourly air, surface and water temperature on a typical summer day 25th-26th July 2016.

HRCS parametric analysis

Parametric studies were performed on the system to determine the optimum values for pipe spacing, diameter and flow rates across a range of water temperatures. (Table 4).

Parameter	Standard	Variables
Spacing	0.02m	0.01, 0.04m,0.08m,0.1m
Inner diameter	0.015m	0.01m, 0.015m, 0.020m
Water temp	16°C	10°C,12°C,16°C,20°C
Water flow	1.5	1 l/s,1.5 l/s,2 l/s,4 l/s,8 l/s

Table 4. Variables of HRCS parametric analysis.

F. Hybrid Cooling Systems (HCS)

Based on the field experiment and parametric studies of the GPCS and HRCS, the subsequent task was to model the proposed systems design and configurations. The GPCS comprises four high-density polyethylene pipes with a diameter of 0.4m, 32m in length and buried to an average depth of 4m. Four air intake fans (with dust filters) can deliver up to 2000l/s; over twice the recommended air intake rate of 800l/s for 100+ occupants. Figure 9 shows the ground pipe layout with deep and narrow trenches being cut to accommodate several ‘serpentine’ loops.

Cooling in the pipework will produce condensate formation, lowering the absolute humidity of the supply air and providing – particularly when RH is high – useful amounts of water for irrigation. The pipework incorporates a drainage sump that can collect an average of 250 litres per day. As shown in Figure 9, the building section was designed to enhance the stack effect with exhaust air being extracted through the hypocaust floor, to produce an effective ‘heat flush’.

The proposed HRCS consists of 420m^2 of roof-mounted, water filled corrugated metal panels, coated with a high emissivity selective surface. Computer simulations predicted water temperatures ranging between 14ºC to 23ºC with an average of 16ºC. It may also be possible to switch the panels to provide a pre-heat facility for domestic hot water during daylight hours.

The task was then to combine the GPCS with the HRCS over stepped time frames to determine whether the ground pipe supply ventilation and radiant cooling system operating in symbiotic concert with the thermal inertia of the ‘fabric first’ passive measures, could deliver sufficient ‘coolth’ to ‘heat flush’ and maintain internal temperatures below the target threshold. The results are presented in Figure 10.

It should be understood that combining both systems produces a highly dynamic set of parameters, interfaces and boundary conditions that simulation programmes may ‘shortcut’. It is likely for instance that the additional surface area and turbulence provided by the hypocaust bends will allow greater heat flushing and subsequent 'coolth' storage, particularly when nights have cloud-free conditions. Increasing the rate of flow at these opportunities could see an increase in heat flushing, effectively chilling a large thermal mass (floors) that is centrally located in the floor plan. The simulations may therefore, underestimate the thermal capacitance of the ‘Termodeck’ system to store 'coolth'.

Installing CO_2 sensors will also allow the ground pipe supply ventilation rate, to be reduced when any flat is unoccupied. Although requiring control systems to modulate fan and pump rates, the software is unable to model such intelligent feedback loops and may, therefore, be underestimating the hybrid systems potential to suppress peak summer temperatures.

A significant proportion of the electricity demand for the ground pipe in-line fans could also be met by the installed 30m^2 PV array (Figure 9). This can deliver circa 12500kWh/year, representing 100% of the total daylight hours fan load.

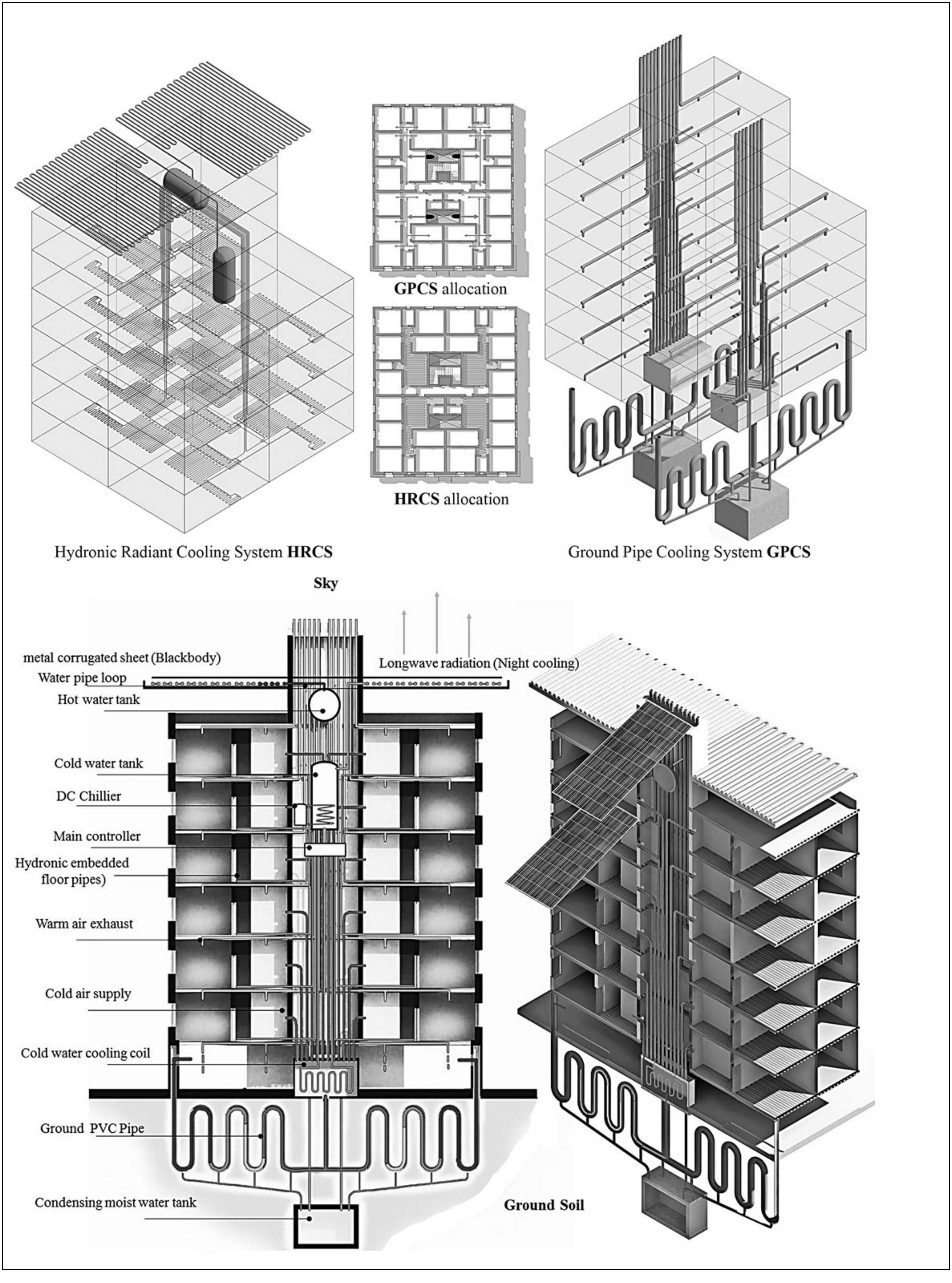

Figure 9. HCS configuration and cooling mechanism.

G. Efficiency validation of HCS application

Cooling Energy Saving

The results of the modelling (Fig 10) demonstrated a significant reduction in cooling energy over the baseline case. The application of passive ‘fabric first’ design measures reduced the AC cooling energy use by 37%. In the HRCS scenario, the monthly cooling loads were reduced by 88% compared to baseline, however this figure did not factor in ventilation gains in peak summer required to maintain ‘healthy’ indoor air quality. Although the GPCS was predicted to displace 86% of the AC energy use (402405kWh p.a.) compared to 80% reduction in HCS scenario, the thermal capacity of the HCS was able to sustain the indoor temperature at a lower and more constant temperature.

Indoor Thermal Comfort

The thermal comfort temperature was determined according to a revised version of ASHRAE standard 55, known as the Adaptive Comfort Standard (ACS) that is applicable for naturally ventilated buildings. Although ASHRAE Standard 55 suggests a temperature range in the air-conditioned building between 23°C and 26°C, recent revisions include a new adaptive comfort standard that allows warmer indoor temperatures for naturally ventilated buildings during the summer.[19] The comfort temperature T_{comf} is calculated based on the mean outdoor dry bulb temperature, T_{out} :

$$T_{comf} = 0.31\,T_{out} + 17.8 \quad \text{(Equation 1)}$$

The adaptive comfort range in naturally ventilated buildings is therefore between 23°C - 28°C.

Figure 10 shows the monthly average indoor temperature of GPCS and HRCS and when both systems are operating in tandem (HCS) compared to baseline. The baseline (AC) annual indoor condition remained constant throughout the year with an average temperature of 24.7°C which is within the adaptive comfort target range. In GPCS and HRCS mode, the indoor temperature reaches its peak in July with predicted temperatures of 27.2°C and 26.3°C respectively. While in HCS scenario, the indoor temperature is relatively constant throughout the year with an average monthly temperature of 25.4°C and monthly temperature amplitudes between 24.4 and 26.2°C. Any shortfall in comfort can, of course, be offset by the installation of a small chiller unit in the water storage tank to cope with peak summer conditions.

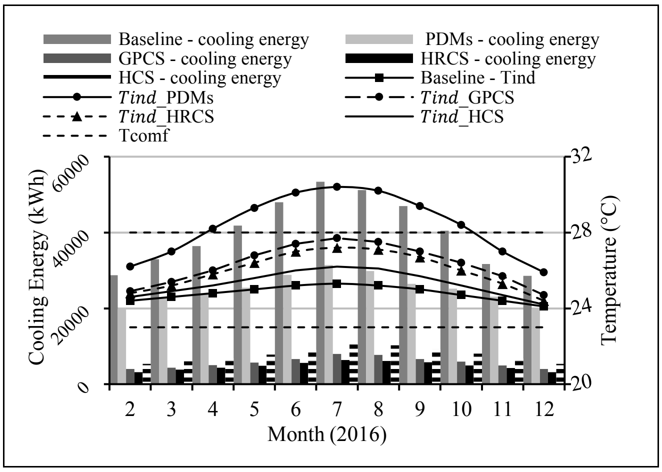

Figure 10. Average monthly cooling energy and indoor temperature of various passive and hybrid cooling systems.

Indoor Air Quality (IAQ)

Carbon dioxide concentration can be used as a proxy for indoor air quality (IAQ). The air supply rate recommended by CIBSE is 8l/s per person to maintain CO_2 below 1000ppm.[20] Figure 11 clearly shows the distinction between the carbon dioxide levels in the baseline case compared to HCS mode. In the baseline scenario, the average monthly concentration of CO_2 in the internal air is 823ppm, a concentration classified by ASHRAE as representing medium to low air quality.[19] This figure, however, relies on fresh air being introduced into the system with little recirculation occurring. To boost the coefficient of performance (COP) of the AC system the temptation is always to increase recirculation rates and minimise fresh air input, particularly when the temperature of that external air may be as high as 50°C. This figure may, therefore, underestimate the actual CO_2 level in many dwellings where windows are habitually closed for over five months (May – September). In contrast to the AC system, ground pipe cooling relies on delivering relatively high levels of ‘fresh air’ that in turn will reduce CO_2 and improve IAQ. CO_2 concentrations were predicted to average 718 ppm; however, the reduction level varied from month to month according to the ambient temperature and system usage. In direct contrast to AC use, the maximum average CO_2 concentration was predicted in January as a result of the lower cooling load. In comparison with baseline, high temperatures in peak summer have increased the airflow rate of the HCS. The HCS also lowered the internal RH falling within the accepted comfort parameters of 44% - 65%. This is due to the mixing ratio of the supply air falling as water condenses in the ground pipes (Figure 11).

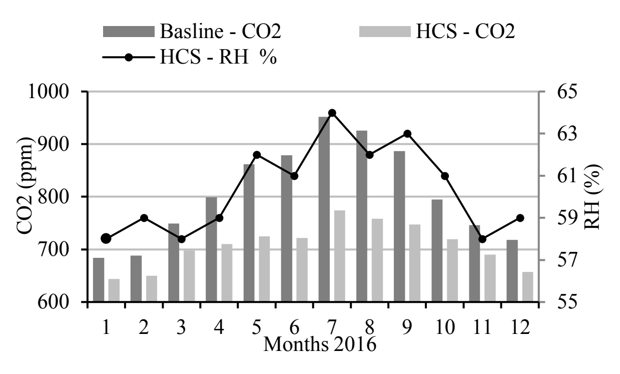

Figure 11. Comparative assessment of HCS indoor air quality.

Payback Analysis

Two factors were considered when determining the cost-effectiveness of the proposed hybrid cooling strategies. The capital cost of the passive and active interventions measured against energy cost savings in use. Electricity in KSA is currently heavily subsidised at approximately £0.034p/kWh. Figure 12 shows the average annual cooling energy consumption for the baseline case at 466967kWh with an annual energy cost for AC cooling at £15876/year for the block. Figure 12 also shows the average monthly estimated cooling energy cost of both the radiant and ground pipe cooling systems. Building costs in KSA compared with the UK are relatively low due to low labour costs. A cost study of the three cooling systems was estimated under 4 categories: the cost of the components, installation, operation and maintenance. Although marginally more expensive in capital outlay, the hybrid system has a short pay-back period estimated to be under 25 months (Figure 13).

Discussion: This research has attempted to evaluate the potential impact of ground pipe supply ventilation in combination with diurnal heat flushing using black body emitters in hot and humid climates. It assumes that the standard ‘cost-effective, fabric first’ measures will be applied.

Limitations

Most of the available energy simulation software packages cannot accommodate the novel passive and hybrid cooling strategies and systems under consideration. The only viable method of progress was to use a combination of modelling and simulation with physical scale models in an attempt to provide further validation or at least, quantify the margin of error. The outcomes of any simulation software have to be treated with care and a degree of scepticism, however, the data generated by prototype testing and field measurements go someway to underpinning the hypothesis and support the view that these techniques in additive hybrid combination, are at least worthy of further investigation. The next stage will be to construct full-scale prototypes of the ground pipe and hydronic panel with enhanced thermal interfaces and test these for their cooling potential, particularly in ‘high’ summer. If these tests provide data of the same order as the simulation results, the building industry in KSA should have the confidence to produce a prototype housing block for full-scale trials.

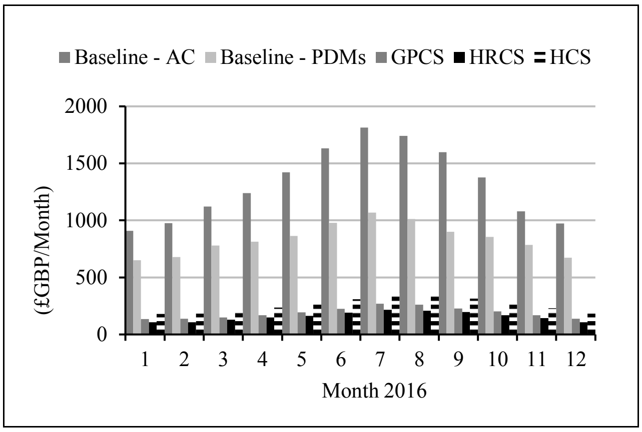

Figure 12. Average monthly energy costs of cooling systems.

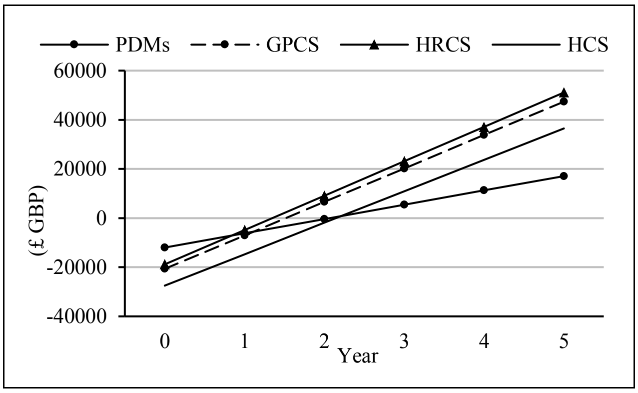

Figure 13. Life cycle cost and an estimated payback period of the proposed passive and hybrid cooling applications.

Conclusion

The study suggests that a combination of ‘fabric first’ design measures, combined with two active cooling systems (hydronic radiant cooling in tandem with ground pipe supply ventilation) can displace around 80% of AC demand in KSA. Passive ‘fabric first’ measures can reduce the demand by 37% against the baseline housing block. The hybrid system is predicted to contribute an additional 43% reduction, with the shortfall being met by the addition of a small chiller unit to the water reservoir.

A national impact over time

Since the cooling load dominates domestic energy costs, applying such a strategy to all new developments could reduce the overall electricity use in the domestic sector by 64%. As the KSA housing program plans to build 950000 housing units by 2020, applying such low carbon measures may save around 1900GWh/year. This represents 5% of the total new housing budget, allowing an additional 47500 units to be built from the savings. It could also reduce the carbon footprint of the citizens living in these new blocks from 17.9 to 8.9 metric tonnes of CO_2 per annum.

Declaration of conflicting interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author received no financial support for the research, authorship, and/or publication of this article.

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Appendix

Nomenclature

°C	Temperature degree Celsius
COP	Coefficient of Performance [-]
K	Thermal conductivity [W/m·K]
ppm	Parts Per Million
R	Thermal resistance [m2K/W]
RH	Relative humidity [%]
T	Temperature [°C]
U	Overall heat transfer coefficient [W/m2.K]

Subscripts

amb	Ambient air
comf	Comfort temperature
ind	Indoor
inlt	Pipe inlet air temperature
optv	Operative temperature
out	Outlet air of pipe
rad	Radiant temperature
soil	Soil temperature
surf	Surface temperature