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A novel integrated building energy system for high performance façade

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Abstract

Qatar National Development Strategy (QNDS 2011-2016) stated that residential cooling loads count for two-thirds of the energy consumption. The extreme high air-conditioning loads raise the urgent need for novel and multifunctional technologies that reduce the thermal energy demand. The Global Sustainability Assessment System (GSAS) mandated thermal energy benchmarks to reduce the building's need for cooling. The most predominant impact on cooling loads is the solar radiation. Reflecting or reuse of solar radiation has attracted the attention of several researchers. This paper focuses on void space thermal insulation (VSTI) that functions to deliver high performance active and / or passive thermal insulation performance in buildings in tandem with managed fresh air ventilation supply for clean, healthy indoor environments. VSTI can combine the heat losses with the HVAC systems for better building performance. Different embodiments of the VSTI will include brick-block and steel frame constrictions, sandwich panels for pre-cast concrete constructions, internal wall insulation and external wall insulation. Initial modelling results showed that a VSTI panel can potentially deliver the desired level of fabric performance, using only 50% of the insulation thickness irrespective of what insulation material is used. In this paper, a dynamic simulation model was used to estimate the energy and carbon reduction due to the use of VSTI for a residential room. The results showed around 12% reduction in the cooling load and 4% in the overall energy consumption and carbon emissions.

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Keywords: Thermal Insulation, Ventilation, Air Conditioning, Carbon Emissions

1. Introduction

Passive design costs are relatively low to incorporate into a new building. The benefits are greatest when the design principles are incorporated into the entire design and build process, from site selection onwards. The Global Sustainability Assessment System (GSAS), developed by Gulf Organisation for Research and Development (GORD), is mainly a performance-based sustainability rating system. It was developed to create a sustainable urban

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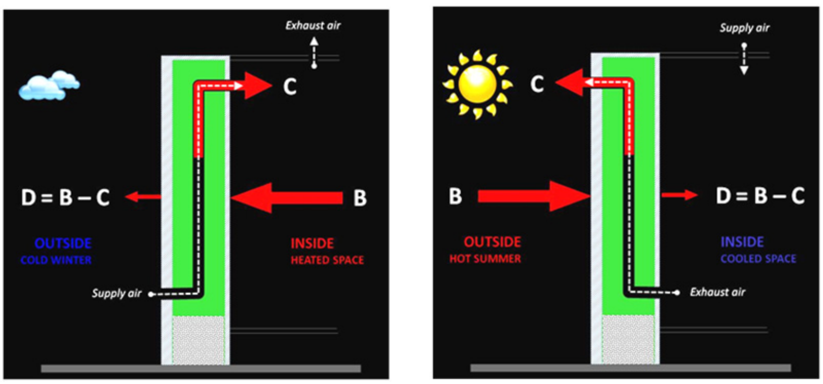
environment that reduces environmental impacts while satisfying local community needs in addition to addressing all relevant aspects of sustainability, ecological impact and green building design criteria. With respect to energy, GSAS main objective is to minimise the need for cooling by encouraging the deployment of passive design measures. The amount of energy used for cooling can be estimated by either a complex or simplified modelling. The first method requires professional experts and probably consumes a lot of time. The simplified model method requires a short amount of time, but less accurate, and is used for preliminary estimation purposes by energy assessors. Novel thermal insulation-ventilation technologies attracted worldwide attention [1-5]. Void space thermal insulation (VSTI) provides an energy efficient method of delivering ventilation air to (or from) the interior of a building, or air-handling unit, through an air-permeable, dynamically insulated envelope or façade. In hot humid climate, the outdoor air has to be conditioned to the desired comfort humidity and temperature before it can be supplied to indoor spaces. The cooling process also very often requires some post-heating of the tempered air before it is supplied to indoor spaces. Neither building energy modelling methodology can handle the complicated processes associated with dynamic insulation, which relies on reduction of fresh ventilation air to reduce cooling energy at the expense of compromised IAQ. A building that uses an air permeable, insulated external envelope can reduce the fabric overall heat transfer coefficient and hence energy use for both cooling and heating while at the same time allowing ventilation air to be introduced into the building at all times [9-12], see Fig. 1. The earliest work on dynamic insulation (DI) is attributed to Bartussek on porous roofs [6], Dalehaug on walls [8] and Wallenten on the OPTIMAT house [25]. Fundamental research on the use of diffusive and dynamic insulation for combined heat recovery and ventilation in buildings [20-24] has established our basic understanding of heat and mass transfer in dynamic breathing wall systems. Taylor et al [22], Imbabi and Peacock [14] and Imbabi [15, 16] have further extended our understanding to include the particulate filtration performance and service life of Type-I (permeodynamic) fibre-based DI. Research into DI by Wong et al [26] looked at the development of new breathable concrete materials for use in monolithic dynamic breathing wall construction. The diffusive insulation of Straube and Acahrya [19] should not be confused with DI. Elsarrag et al [9] reported the results from the first field trial of DI in Abu Dhabi. Elsarrag and Imbabi [10] investigated the use of DI in a building facade for zone local insulation and ventilation. The savings in energy and CO_2 reduction were quantified against existing standards in the Gulf Region. They showed that DI can provide tempered fresh air, raise energy efficiency and reduce air conditioning energy demand without compromising indoor air quality or thermal comfort level. Recent published work in the area of DI includes Imbabi and Elsarrag [17] on tuneable dynamic U-value, Elsarrag et al [11] on the UAE eco-villa demonstration project and Elsarrag et al [12] on building fabric energy efficiency in hot-humid climates. Publications relating to the most recent developments are in preparation. An important property of VSTI is that it enables ventilation air to be drawn into or exhausted from the building via appropriate inlet and outlet vents in the external fabric. On the other hand, the VSTI wall can be reversed to exhaust chilled indoor air provides an effective means of rejecting wall heat gain in a hot climate, to deliver precisely the same reduction in wall U-value as a function of airflow rate [4], see Fig.1 b.



(a) Supply mode (cold climates) *(b) Extract mode (hot climates)*

Fig. 1. Schematic of a VSTI wall section [4].

2. Modelling

The height-averaged dynamic R-value of a VSTI wall or building façade can be estimated using the following steady-state expression [18]:

$$\overline{R}_d = \frac{1}{U_d} = \frac{(T_i - T_o) \times NR_o}{(M - T_o)((e^{-N} + N - 1)} \quad (1)$$

where $M = (R_oT_i + R_iT_o)/(R_o + R_i)$, $N = (R_o + R_i)/(\rho_a C_a v_u R_o R_i)$, T_i and T_o are indoor and outdoor temperature, R_o and R_i are the aggregated thermal resistances (R-values) between the void space and the cladding to ambient and indoor interfaces respectively, ρ_a the air density, C_a the specific heat capacity of air and v_u the volume flow rate of air per unit width of wall. Equation (1) ignores radiation, convection, thermal inertia and secondary void space effects. The corresponding dynamic U-value U_d is plotted in Fig 2 for illustrative purposes for typical values of R_o and R_i.

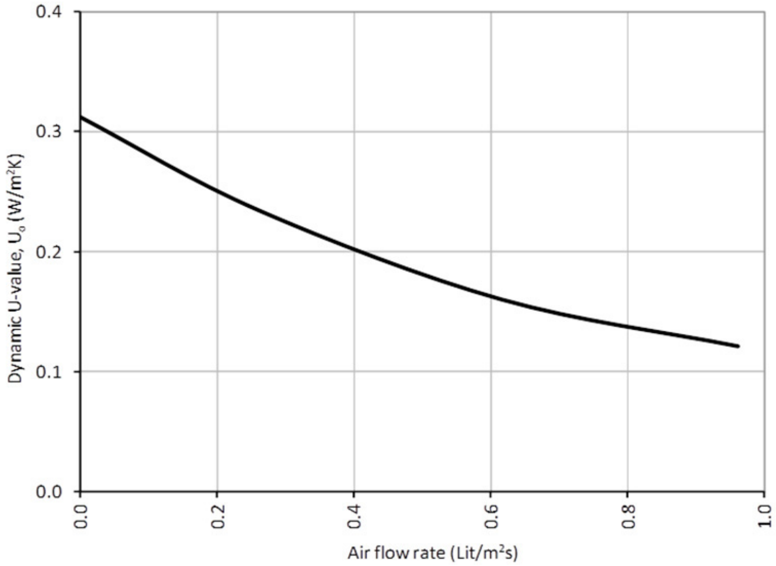


Fig. 2. Typical dynamic U-value plot for the VSTI

A dynamic simulation model using Integrated Environmental Solutions Software (IES) for a residential flat has been developed. It is assumed that the building has a ducted split system. It is assumed that the air cooled condensing units has a SCOP of 2.5. The fan coil unit has specific fan power of 2.5W/l/s. Two models have been developed: in the first model conventional insulation has been used. It is assumed that the overall U value of the external wall is about 0.4W/m2.K which is better than that specified by Kahramaa regulations. In the second model dynamic insulation, VSTI Panel, is used. The wall has an overall dynamic U value of 0.16W/m2K. As shown in Fig. 3, fresh air is extracted by the fan coil unit and the design amount is controlled by volume control damper (VCD). In operation, ventilation air flows through the rainscreen cladding via an inlet vent into an air cavity, then through the dynamic insulation cells into an internal air cavity, and thereafter through the dry wall cladding via an outlet vent or duct.The design outdoor airflow required in a breathing zone of the occupicable space is determined by ASHRAE standard (62-2010).

$$V_{bz} = R_p \times P_z + R_a \times A_z \quad (2)$$

Where: A_z = Zone floor; P_z = zone population; R_p = outdoor airflow rate required per person; R_a = outdoor airflow rate required per unit area; V_{bz} = breathing zone outdoor air flow rate

3. Results

The maximum monthly design values of dry bulb and wet bulb temperature (^oC) from the DSM, ASHRAE data, are presented in Fig. 4. The VSTI panel is a multifunctional responsive building element that offers exceptionally low U-value thermal insulation while supplying fresh ventilation air that has been pre-cooled. With reference to Fig. 5, the total peak room energy consumption in the absence of dynamic insulation is about 1.75kW and falls about 11.5% when using the VSTI panel. The annual room cooling demand also falls from 5.2 to 4.6 MWh achieving 12% reduction in the annual cooling demand. The air conditioning annual energy consumption benchmark reduced from 237kWh/m2 to 209kWh/m2. In order to count for CO_2 emissions other zone energy consumption systems should be calculated. The savings in energy and CO_2 reduction were quantified against existing standards in the Gulf Region. Fig. 6 shows the monthly energy consumption for that simulated zone. The overall carbon reduction due to the use of the void space insulation is found to be 4.5% based on carbon intensity of 0.448kgCO_2/kWh, as shown in Fig. 7.

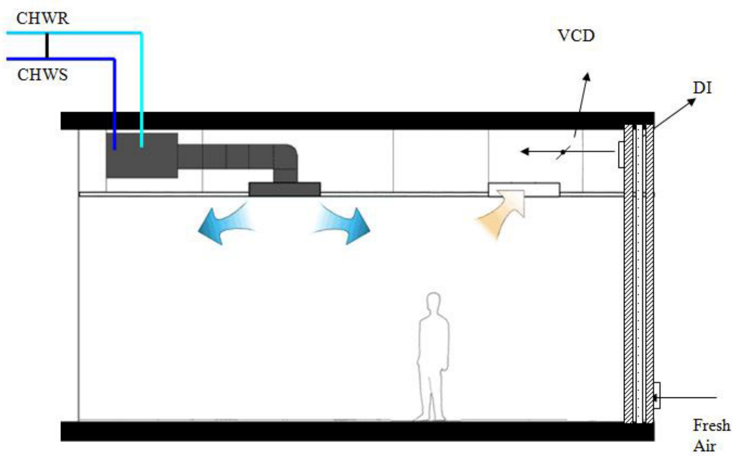


Fig. 3. Schematic of the modelled system

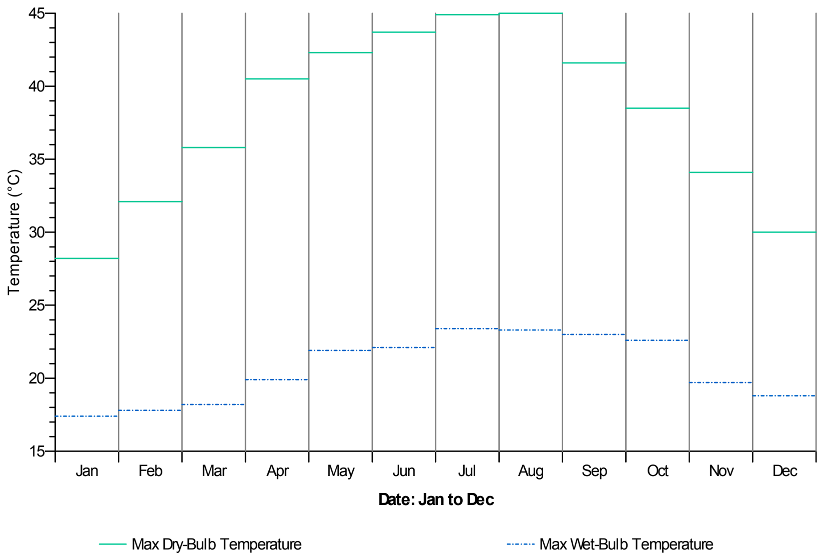
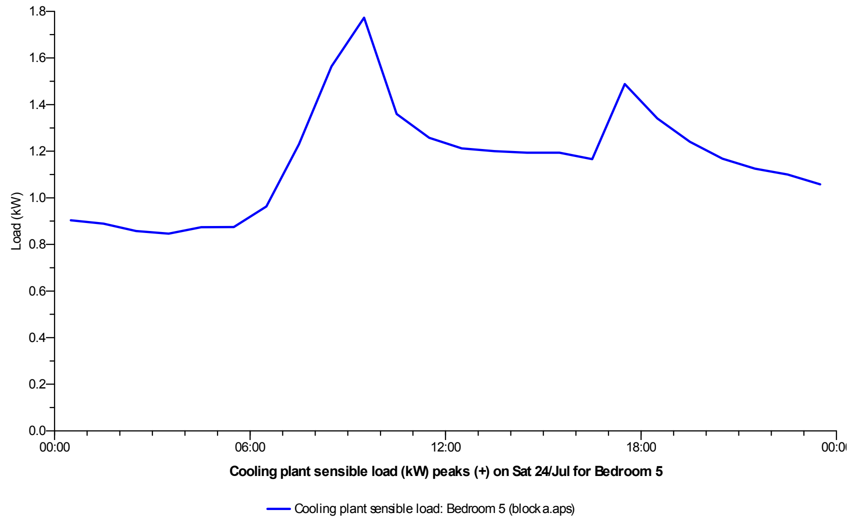


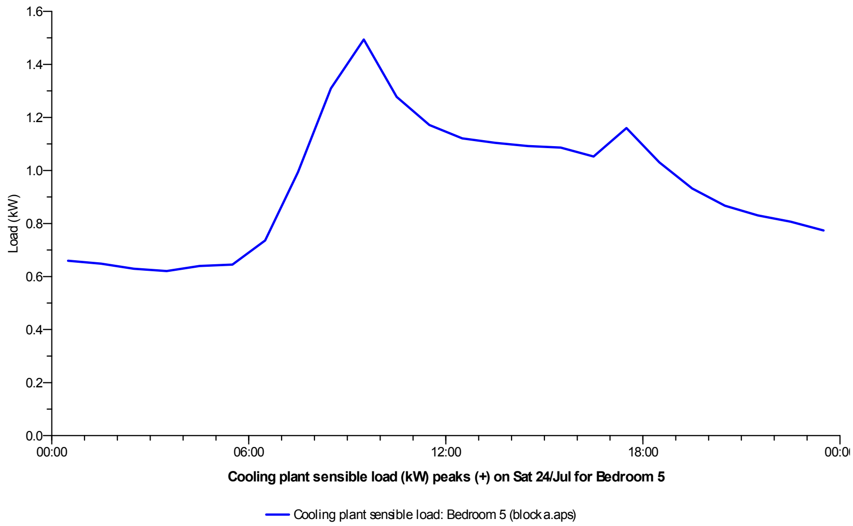
Fig. 4. Simulation weather data: average monthly temperature

4. Conclusions

Around 40% of the region CO_2 emissions are attributable to the built environment, with over 70% of these emissions caused by space cooling. A more recent article in Gulf News estimates that air conditioning comprises approximately 45% of a typical facility's energy use. The case for affordable, high performance thermal insulation as a means of de-carbonising the built environment is compelling. According to McKinsey & Company, “An additional 6 $GtCO_2e$ - almost a quarter of the total abatement potential at a cost of 40€ a ton or less - could be gained through measures with a zero or negative net life cycle cost. This potential appears mainly in transportation and in buildings [13]. Theoretically, the use of VSTI can reduce the cooling need with marginal percentage, i.e. more than 10% compared to the conventional wall construction. However, there is a need to verify these percentages experimental in hot humid climate.



(a)



(b)

Fig. 5. Peak day cooling load: a) Conventional; b) Dynamic

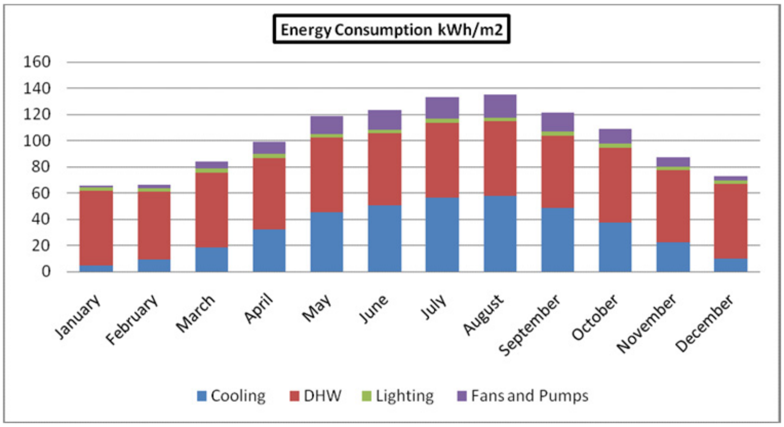


Fig. 6. Total monthly energy use for the dynamic case

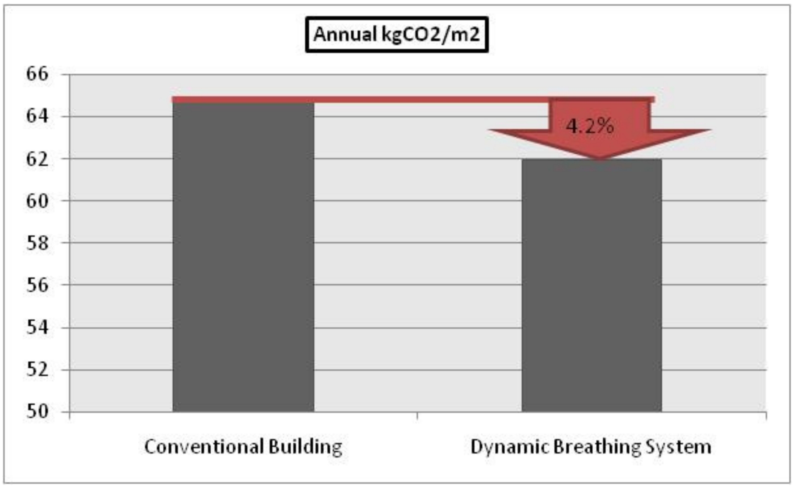


Fig. 7. Total annual carbon reduction

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