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Using Dynamic Facade for Indoor Air Quality, Thermal Comfort and Energy Efficient Air Conditioning

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Abstract: Buildings present both a major impediment to reducing our reliance on the burning of dwindling reserves of fossil fuel and a real opportunity for achieving significant reduction in global carbon emissions. Dynamic facade, using Dynamic Insulation (DI), is an energy-efficient method of supplying pre-tempered filtered ventilation air to a building through an air-permeable dynamically insulated envelope or facade. One of the important features of DI is that it effectively decouples ventilation rate from energy use. In theory, it should work well with all buildings, including homes, schools, offices and sports facilities where high occupancy is the norm. This paper investigates the use of DI in a building facade for zone local insulation and ventilation. The savings in energy and CO_2 reduction are quantified against existing standards in the Gulf Region. The results show that DI can provide tempered fresh air, raise energy efficiency and reduce air conditioning energy demand without compromising Indoor Air Quality (IAQ) or thermal comfort level.

Keywords: Air conditioning; Carbon emissions; Dynamic insulation; Thermal comfort.

1. INTRODUCTION

Rising standards in the face of increasing pollution levels mean that higher volumes of clean, fresh air are needed in order to improve indoor air quality (IAQ). This gives the Heating, Ventilation and Air Conditioning (HVAC) engineer a higher thermal load to remove from the building and raises maintenance issues. This is especially true in very hot, humid climates such as in the Gulf Region, where outdoor air has to be conditioned to the desired comfort humidity and temperature before it can be supplied to indoor spaces. Air conditioning at high ventilation rate requires the use additional equipment and energy. The cooling process also very often requires some post-heating of the tempered air before it is supplied to indoor spaces. Qatar Sustainability Assessment System (QSAS) adopt International Organization of Standardization (ISO)-European Committee for Standardization (CEN) standard and Energy Performance Coefficient (EPC) approach for the Qatar energy code development, in addition some normative parameters used in CEN standards were changed for use in the Qatar local environment. It complies with the global trend towards performance-based code; using standardised normative calculation methods. The simplified calculation is preferred as it requires less input data, no deep simulation expertise and leads to transparent readily understandable calculations.

The performance based approach has been shown to lead several cycles; i) innovation driven by current minimum energy performance at the time; ii) wide market implementation driven by the adoption of the novel technology procedures; followed by more stringent minimum requirements, taking into account the improved cost-benefit ratio of novel energy saving technologies.

QSAS building energy rating standard has three levels of assessment. Building's thermal behaviour, technical systems and primary energy source have been taken into consideration by these three levels. Furthermore, Consecutive EPC rating scales are specified for the QSAS energy scoring system. For instance, the maximum score of 3, EPC<= 0.6, is earned when the building consumes at least 40% less than the average of the benchmarked buildings, EPC = 1. When compared to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) compliance level, the energy performance of a building with a score of 3 is at least 58% better than the ASHRAE 90.1-2004 compliance level.

The current rate of energy consumption for air conditioning and the high capital investment that is required are not sustainable. Neither is a building design methodology that relies on reduction of fresh ventilation air to reduce cooling energy at the expense of compromised IAQ. A building that uses an air permeable dynamically insulated external envelope, henceforth referred to as a Dynamic Breathing Building (DBB), can significantly cut energy use for both cooling and heating while at the same time allow higher than normal volumes of clean filtered ventilation air to be introduced to the building at all times.

This approach is at odds with systematic reductions in infiltration and ventilation rates to cut energy consumption that in recent years have led to the development of the air tight hermetically sealed building. It is however very much in line with the higher ventilation rate dictated both by better comfort requirements and by the most recent standards such as ASHRAE (62-2007), where it is recommended that ventilation rates in modern buildings have to be increased if we are to deliver to occupants the benefits of healthy indoors environments.

2. OVERVIEW OF DYNAMIC INSULATION

Dynamic insulation (DI) describes a novel, energy conserving method of delivering abundant volumes of pre-cooled (or heated) fresh filtered ventilation air to the interior of a building or to an air handling unit through an air-permeable and dynamically insulated envelope or facade. Using a proportion of the building envelope as the ventilation source means that the flow velocity through the intervening DI media required to deliver the number of fresh air changes per hour is very low. As a result, efficient conduction heat recovery and filtration of the incoming air take place as a function of air change rate – i.e., the more ventilation air is drawn in the higher the heat recovery.

The science of heat and mass transfer in DI was established in the mid-90s [1]-[3b]. Imbabi and Peacock [4],[5] extended this understanding to include the particulate matter (PM) filtration performance and service life of fibre-based DI. Imbabi [6a]-[7] reviewed the state-of-the-art underlying a new generation of modular dynamic breathing wall systems and their implementation in new and refurbishment building projects. Elsarrag *et al.* [8] reported the results from the first field trial of the dynamic cell in Abu Dhabi. Elsarrag *et al.* [9] tested a villa in two modes, bypass (static) and dynamic. They reported that static U value of the external envelop wall was reduced from 0.24W/m^{2}K in bypass mode to 0.125W/m^{2}K in the dynamic mode. The overall reduction in the fabric conduction gain was found to be 41%. The DBB concept is illustrated in Fig. 1.

3. DYNAMIC SIMULATION MODEL

A dynamic simulation model of an 11 storey hotel has been developed using Integrated Environmental Solutions (IES) simulation code version 5.92 (see Fig. 2). The total treated floor area is about 19,600 m^2. The building is fitted with a central air conditioning system using air cooled chillers and fan coil system, with fresh air supplied by balanced mechanical ventilation with heat recovery as typically used in the United Arab Emirates (UAE).

Two models were developed. In the first, conventional insulation was specified in accordance with UAE Building Regulations, with a U-value of 0.44 W/m^{2}K for external walls. In the second proposed DBB design, a slight pressure difference allows outdoor air to flow into the building envelope via appropriately located inlet vents in the outer leaf. The wall has an overall dynamic U-value of 0.16 W/m^2.K.. This ventilation air, scrubbed of particulate pollutants through Dynamic Filtration, passes to the air handling systems and is injected with the return air for distribution to indoor space. The design ventilation amount is controlled by a volume control damper (VCD).

As shown in Fig. 3, fresh air is extracted by the fan coil unit and mixed with return air. The design outdoor airflow required in the breathing zone of the occupied space is determined according to ASHRAE standard (62-2007) as:

$$V_{bz} = R_p \times P_z + R_a \times A_z \qquad (1)$$

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; and V_{bz} = breathing zone outdoor air flow rate

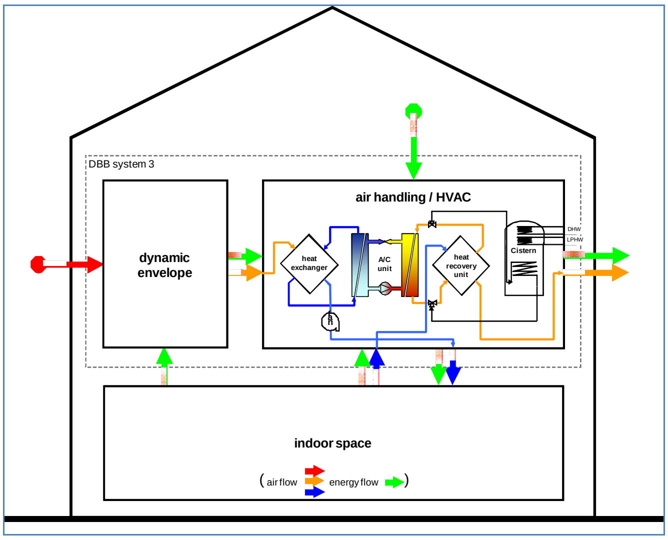

Fig. 1. DBB Concept and Implementation

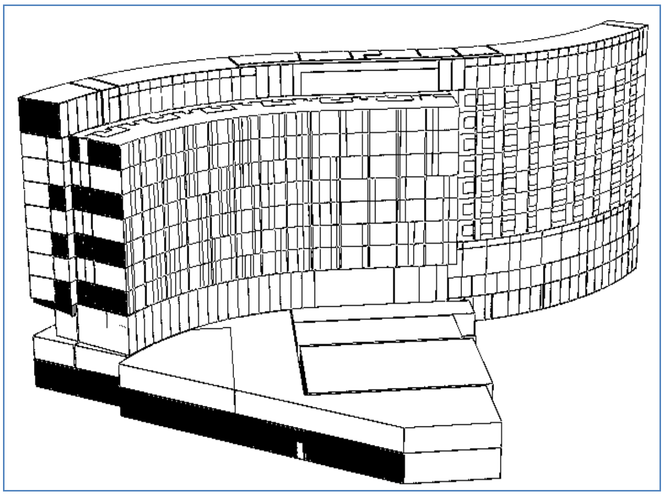

Fig. 2. IES Dynamic Simulation Model

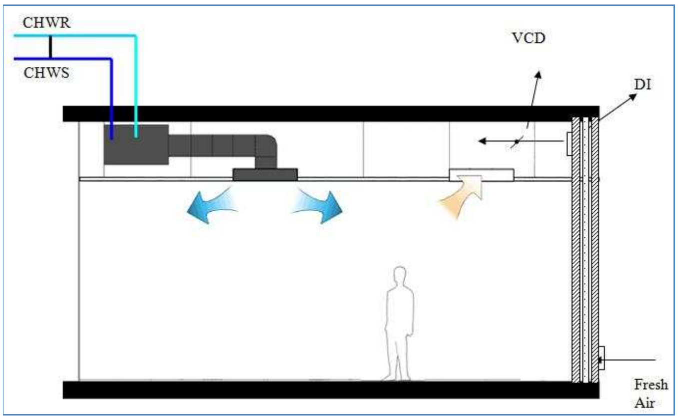

Fig. 3. The Proposed DBB System

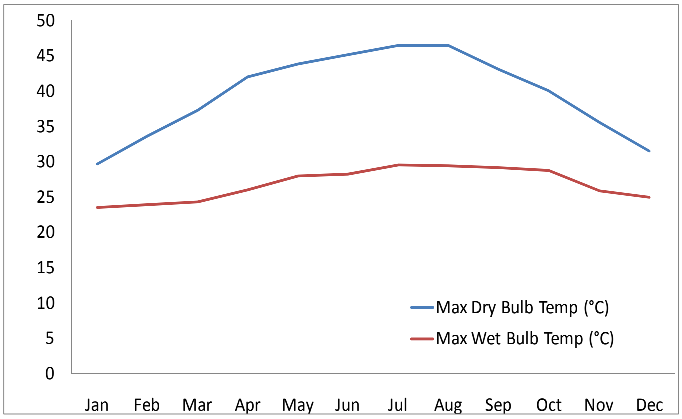

Fig. 4. Design Dry Bulb and Wet Bulb Temperatures

4. RESULTS AND DISCUSSION

Hourly values were used in simulation. The monthly design values of dry bulb and wet bulb temperature (in ^{o}C) from the DSM, ASHRAE data, are presented in Fig. 4. Fresh air supplied to the occupied space needs to be conditioned to match the target indoor air conditions for most of the year. This requires continuous removal of sensible and high latent loads from the incoming air. So a full range of air conditioning equipment is needed.

With reference to Fig. 5, it was found that the use of the DBB system reduced the annual room cooling demand by 6.2%. This reflects the extent to which fabric conductance affects the energy performance of the specific building design.

The dynamic cell is a multifunctional responsive building element that offers exceptionally low U-value thermal insulation but its effect does not end there. In the DBB system the extract air from the conditioned space (e.g. toilets, kitchens, etc.) has a temperature between 27 and 30^{o}C, which means it could be used as a cooling source in the air cooled chillers condensers. This will improve the COP by around 20% and save more energy in the chiller's energy consumption, as shown in Fig. 6.

The resulting cumulative annual reduction in the air cooled chiller's energy is thus around 25%. However, estimating the total carbon emissions reduction requires all energy demands to be considered. Figure 7 shows the total annual space cooling energy demand of a conventional building design (around 29% of the overall energy demand for the building). The total reduction in energy demand attributed to switching to a DBB building design – i.e., this single intervention – is slightly over 7%.

Fig. 7 points to Domestic Hot Water (DHW) provision and Equipment selection as prime areas for further improvement. The development of an integrated, truly sustainable building design would target efficiencies in these areas. Strongly indicated would be the use of roof-mounted solar thermal collectors and careful selection of equipment, where rule of thumb estimates suggest that 50% of the DHW and 20% of the Equipment loads could be added to the DBB effect,

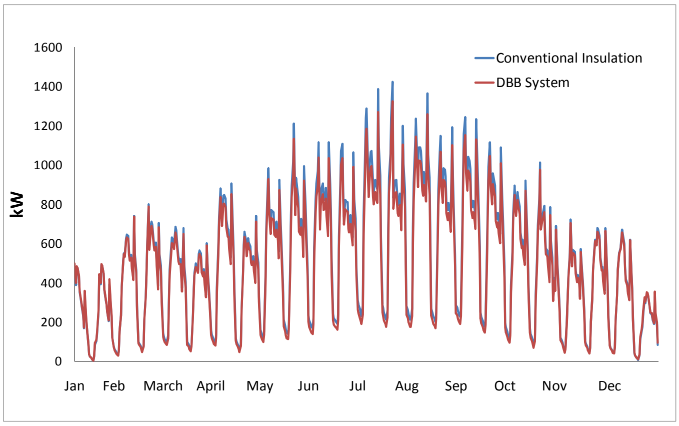

Fig. 5. Cooling Load Demand Comparison

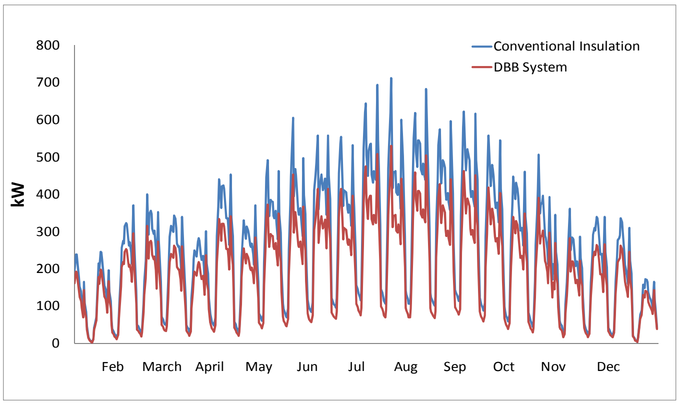

Fig. 6. Chiller Power Consumption Comparison

respectively. The carbon emissions from such a building would be around 1/3rd lower than its conventional counterpart.

5.

5. CONCLUSIONS

Industry-standard dynamic simulation code was used to evaluate the performance of an 11 storey hotel building in the UAE. Two design options were considered, one with and the other without Dynamic Insulation (DI) in the facade. The results show a direct reduction in fabric cooling load of 6.2% over the year accruing as a result of dynamic coolth recovery through the facade in the latter case.

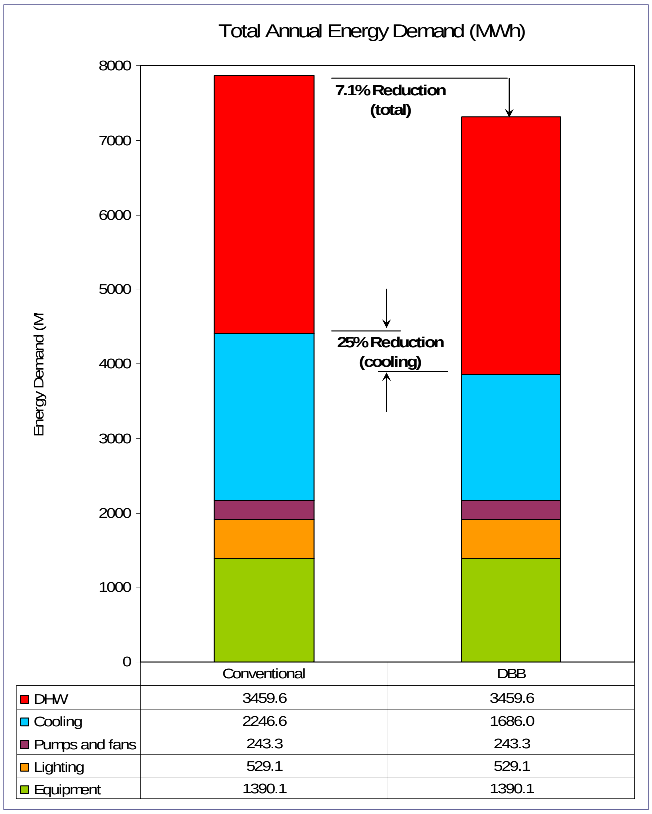

Fig .7. Annual Energy Demand Comparisons by Type

The use of DI in the facade, leads to the creation of a Dynamic Breathing Building (DBB) system that yields substantial indirect gains in the way the air conditioning system operates. On the one hand, the supply of pre-cooled fresh air to the chiller will boost the Coefficient of Performance (COP) to deliver a 25% reduction in cooling energy demand. At the same time, the supply of fresh air locally, through the dynamic facade, suggests that ducting for the provision of fresh air can be greatly simplified.

Furthermore, the savings linked to the use of DI and DBB system are 'front of pipe', which means that savings achieved elsewhere can be added. For example, the use of renewable energy to offset conventional energy use for DHW provision or use of more efficient equipment will contribute to greater energy efficiency and sustainability of the design. Our conservative estimate is that the total energy demand of an enhanced DBB building design can be reduced by 1/3rd or more compared to the conventional design.

REFERENCES

[1] Taylor, B J, D A Cawthorne and M S Imbabi, *Analytical investigation of the steady-state behavior of dynamic and diffusive building envelopes*, Building and Environment, Vol. 31(6), p519-525 (1996).

[2] Taylor B J, and M S Imbabi, *The effect of air film thermal resistance on the behavior of dynamic insulation*, Building & Environment, Vol. 32(5), p397-404 (1997).

[3a] Taylor B J and M S Imbabi, *Environmental design using dynamic insulation*, ASHRAE Transactions, Vol. 106(1), p15-28 (2000).

[3b] Taylor B J and M S Imbabi, *Dynamic insulation in multi-storey buildings*, Proc. CIBSE A, Building Services Engineering Research & Technology (BSERT), 20(4), p175-180 (2000).

[4] Imbabi M S, and A Peacock, *Smart breathing walls for integrated ventilation, heat exchange, energy efficiency and air filtration*, ASHRAE/CIBSE conference, Edinburgh, September (2003).

[5] Imbabi M S, and A D Peacock, *Allowing buildings to breathe*, Sovereign Publications, p85-95 (2004).

[6a] Imbabi M S, *Full-scale evaluation of energy use and emissions reduction of a dynamic breathing building*, Proceedings of WREC-IX, Florence, 19-25 August, (2006).

[6b] Imbabi M S, *Modular breathing panels for energy efficient, healthy building construction*, Renewable Energy, Vol. 31, Issue 5, p 729-738 (2006).

[7] Imbabi, M. S., *The performance of dynamic breathing buildings in the United Arab Emirates*, Invited keynote paper, Environment 2007 Conference, 28 January – 2 February, Abu Dhabi, UAE (2007).

[8] Elsarrag E., M. Aboulnaga, A. Peacock and M. S. Imbabi, *Dynamic insulation for energy conservation and improved indoor air quality in hot humid climates*, Invited keynote paper, ASHRAE 5th Chapter Regional Conference (CRC), 01 – 03 November, Dubai, UAE (2006).

[9] Elsarrag E., Alhorr Y. and Imbabi M. S., *Improving building Fabric Energy Efficiency in Hot-Humid Climates using Dynamic Insulation*, Building Simulation: An International Journal; ISSN: 1996-3599, in press.