Reducing energy demand in non-domestic buildings: integrating smart facades, ventilation, and surface heating and cooling

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ABSTRACT

This paper discusses an overall strategy for reducing energy demand in non-domestic buildings, mainly focussing on office developments. It considers four areas: reducing internal heat loads; addressing passive design through the building construction; using efficient and responsive HVAC systems and focussing on chilled (heated) surface systems; integrating renewable energy supply systems into the building design. The impact on comfort, energy use and carbon dioxide emissions will be discussed. The paper will draw from a range of design projects carried out in Europe, where this integrated approach has been applied, and then explore the benefits in relation to applications in the Middle East and China. Energy modelling results, to inform the design process will be presented, using energy simulation for three case study locations, in Zurich, the Shanghai and Abu Dhabi.

KEYWORDS: Building energy use, low carbon, energy simulation.

1. INTRODUCTION

Reducing energy demand in buildings requires an integrative and holistic approach to all aspects affecting energy performance, whilst ensuring comfortable healthy conditions for occupants, and within the context of the local climate. Achieving a low or zero-carbon building is a combination of reducing energy demand and providing energy supply from renewable sources. In many cases it may not be feasible to provide a totally zero-carbon building, and the concept of a near-zero-carbon building is used in Europe to provide a bridge to eventually achieving zero carbon performance within acceptable costs. This paper discusses the process of arriving at a low energy, near-zero / zero-carbon building design, using an office building type as an example. The paper takes as a baseline, typical European design standards and techniques, based on buildings that the authors have worked on. It then applies the same standards to China (Shanghai) and UAE (Abu Dhabi) in order to explore how these standards would compare under different climatic conditions. The paper discusses how energy demand can be reduced, and then how low carbon performance can be achieved through the additional application of renewable energy.

2. DESIGN PROCESS

The ‘low energy / low carbon’ design process should relate to climate and comfort and can be divided into four areas for consideration, as outlined in Figure 1. These are discussed in detail below.

2.1 Reducing internal heat gains

The first step in any low energy design should be to reduce the energy loads on the space from lighting, small power and any other incidental energy use. This will have the added benefit of reducing the cooling load demand needed to exhaust these heat gains. In locations requiring heating, these incidental heat gains will be reduced, however, for most modern designs there is little heat requirement in office spaces, and so these heat gains are generally not considered useful. Table 1 presents typical 'current' good practice and 'efficient' loads associated with internal heat gains. The use of low energy computers and LED lighting can result on overall space heat gains as low as 18 W/m^2. The values are for an occupancy density of around 1 person to 12m^2, which would represent a typical design standard in Zurich.

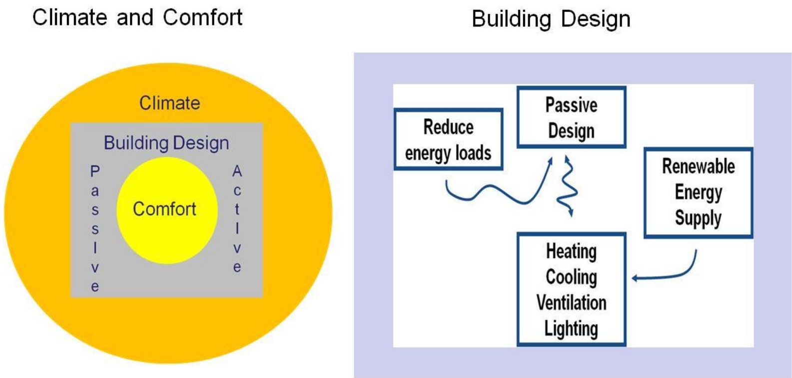


Figure 1. Climate and comfort and the design process for reducing energy demand, using passive and active processes, and achieving low carbon performance through renewable energy supply.

TABLE 1: Internal heat gains to space from 'current' good practice 'efficient' design (CIBSE (2006), Philips (2012)).

Internal heat gains (W/m^2)		
	Current	Efficient
Internal gain from people (~12m^2/person)	6.0	6.0
Small power	10.9	4.9
Lighting	12.0	7.0
Total	28.9	18.0

2.2 Passive design – smart facades

Low energy design should consider the passive design attributes that can modify the external climate to the benefit of the energy performance of the building, including orientation, solar control, daylight and use of thermal mass. Even in mechanically cooled and ventilated spaces, passive design can contribute to reducing energy use. The building envelop is a major part of the passive design approach, and the use of 'smart' layered facades can provide for good insulation, control of solar heat gains and daylight. Glazed facades can now be designed with high levels of thermal insulation (with U-values below 1 W/m^2/^{o}C), effective solar control (g-values typically down to less than 0.15), and good visible qualities to allow for the use of daylight (Alexander, Mylona and Jones, (2005)) Such facades can incorporate blind systems (Figure 2) located, externally, between pane, and internally, although the latter does not easily achieve lower g-values. External blinds are the best performers in terms of solar control and thermal insulation, as the solar heat gains do not enter the glazing system and there is no need for them to be dealt with by breaking the thermal insulation barrier (ventilated mid-pane) or through less effective internal shading. However, they may not be appropriate for certain climates and locations, such as polluted urban areas and high-rise.

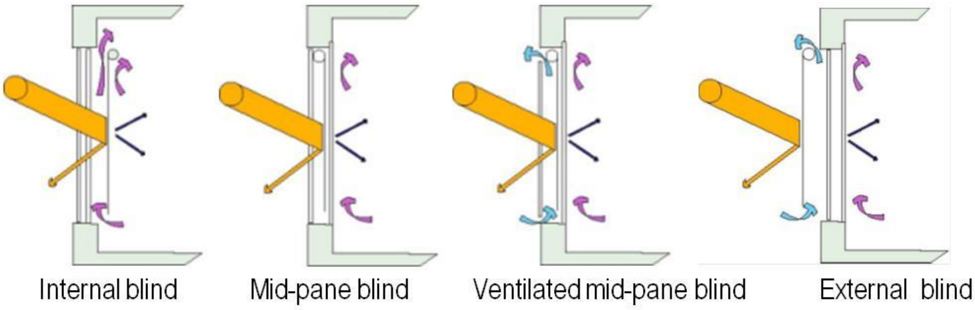


Figure 2. Range of layered glass facades incorporating shading.

There are good examples of adjustable external and inter-pane blind systems shown in Figure 3. The EMPA office in Zurich (Figure 3a) has external vertical diffuse glass blinds that move to accept daylight but control the sun (Jones and Kopitsis, (2005)). Ta-Media, also located in Zurich, has horizontal diffuse glass external blinds (Figure 3b), which are lowered when the solar radiation exceeds a specified value. The Hannover EXPO HQ has inter-pane blinds (Figure 3c). Although may be referred to as passive facades, they do include active features of moveable blinds. Facades become even more active if they include building integrated energy supply systems, such as discussed later in this section (2.4).

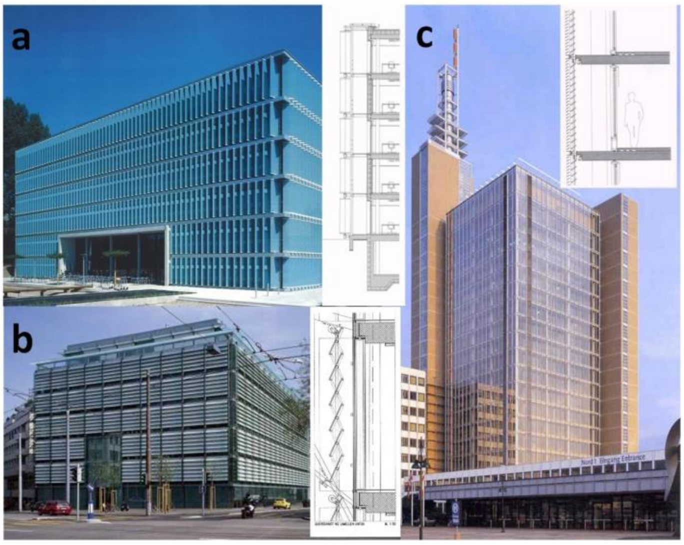


Figure 3. Adjustable external blind systems in (a) EMPA, (b) Ta-Media offices in Zurich, and (c) Hannover EXPO HQ.

2.3 Heating, cooling and ventilation

Once the internal gains have been minimised and the building envelope has been designed to reduce heat loss and control solar heat gains, the active processes associated with heating and cooling should become simpler and more efficient. The energy demand loads reduced, make it possible to decouple cooling (and heating) from ventilation, using chilled and heated surfaces (usually the ceiling). This has been an area of major development in Europe, with comfort and other benefits. A traditional air-conditioning system would use the air supply as the cooling means, therefore requiring large amounts of air delivery (typically 6ac/h or more). Reducing the cooling load, by reducing internal gains and solar gains, enables the main cooling to be achieved through ceiling surface cooling. The air supply is then mainly for occupants ventilation, reducing from typically ~6 ac/hour, for a more traditional system, to around 1 to 2 ac/hour. Figure 4 compares an all-air system with a decoupled chilled ceiling system. Dehumidification will often be required when the external relative humidity is high, and this can be achieved through the mechanical ventilation system, and as long as the façade is ‘airtight’, high external RH should not prove a problem.

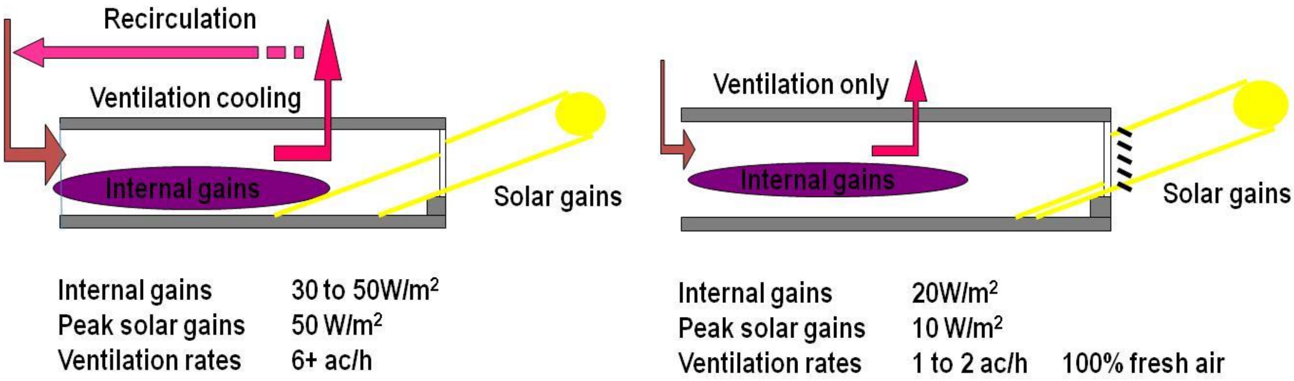


Figure 4: Comparison of a more traditional all-air ac system with a ‘decoupled’ chilled ceiling system, indicating the level of reduction in internal heat gains and solar heat gains, through the above design strategy, and not requiring any air recirculation.

Figure 5 presents typical options for chilled surface cooling depending on internal loads(Jones and Alexander (2003)). For lower loads thermal mass with night cooling may prove sufficient. The chilled ceiling system, with embedded pipes in the slab, can satisfy typical use (~ 30 W/m^2, as indicated in Figure 4). If there are areas with high heat gain, then a chilled beam solution might be more appropriate. However, the ceiling surface temperatures will be lower, typically 17 ^{o}C compared to the chilled ceiling option of around 20 ^{o}C.

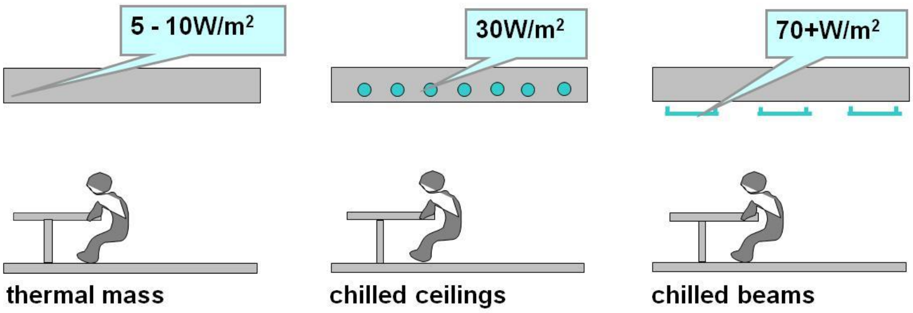


Figure 5. Chilled surface options: thermal mass (with night cooling), chilled ceiling and chilled beams.

The combination of the above design approach can result in: lower fan power due to the lower rate of mechanical air supply; higher Coefficient of Performance (COP) for cooling, due to the raised chilled water temperatures, better air quality due to no recirculation needs and easier air distribution to the occupied zone, less space for plant, due to the reduced air handling equipment size, less space for air distribution, due to the reduced duct sizes (potentially reducing floor to floor heights), higher space use for occupants, due to the reduction in glare and greater solar control, greater comfort, more stable conditions, due to simpler control**.** The main drawback is the need to control the RH of the supply air especially for chilled beam systems, and in relation to this, ensuring an airtight façade system, to avoid the infiltration of moist air.

2.4 Renewable energy supply and energy storage

If the above low energy design process has been followed, then the energy demand for the building will be considerably reduced making it potentially easier to supply the remaining energy from 'active' renewable energy systems, for both electrical and thermal energy. This will include the energy needed for cooling, heating, small power and lights. The energy supply needed to meet the demand will depend on the efficiencies and COPs of the various systems and the type of fuel used. Figure 6 illustrates the relationship between energy demand and supply, and also the link with CO_2 emission factors, to provide the total CO_2 emissions for the operation of the building. The CO_2 emission factors will depend on the carbon content of the local grid, which can vary considerably depending on the nuclear, hydro and other renewable contributions. When describing the building performance, a clear definition of energy use and CO_2 emissions is needed, for example, whether quoted values (say in kWh/m^2/annum) refer to demand or supply, and do they include heating, cooling, ventilation (fan power), small power, lights, etc.

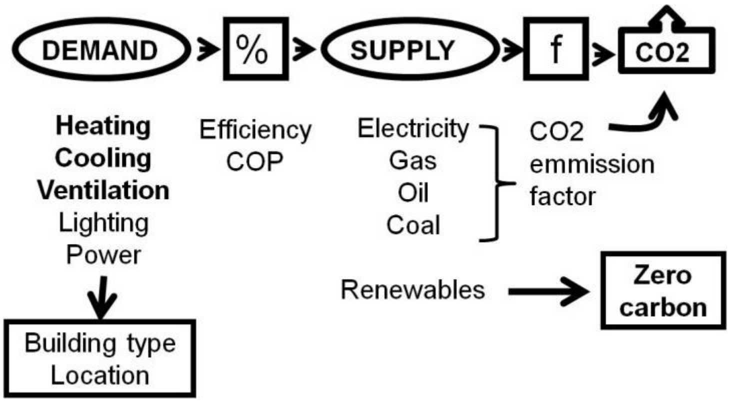


Figure 6. Relationship between energy demand, energy supply and CO_2 emissions.

In many cases renewable energy systems can be integrated into the design of the building envelope, such as transpired solar collectors (TSC's) for collecting thermal energy through south facing cladding systems for solar air heating (Figure 7a), or encapsulating thin film PV onto metal roof cladding, or using glazed PV systems as the roof material. In some cases, solar PV systems can be used as blinds, such as in the office facades of the Baglan Energy Park 'Gateway' industrial building (Figure 7b).

(a) (b)

Figure 7. (a) Transpired solar collectors (TSC's) for collecting thermal energy through south facing cladding systems for solar air heating. (b) PV system used as shading device.

The direct availability of renewable energy is usually dependent of the prevailing conditions, for example, solar and wind. So, unless some form of local storage is available, the grid will be needed to provide energy when renewable energy is not available. Net zero energy performance maybe achieved by input and export from the grid, often referred to as two-way flow. There is an increasing interest in energy storage systems, both thermal and electrical, to provide short and long term storage so that grid two-way flow is not needed. Figure 8 illustrates this for thermal and electrical storage, from a current project SOLCER in Wales (EU ERDF funded), which is investigating combining reduced energy demand, renewable energy supply and energy storage at a range of built environment scales.

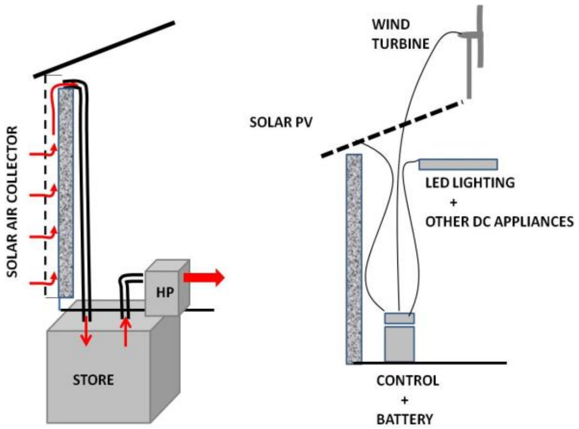
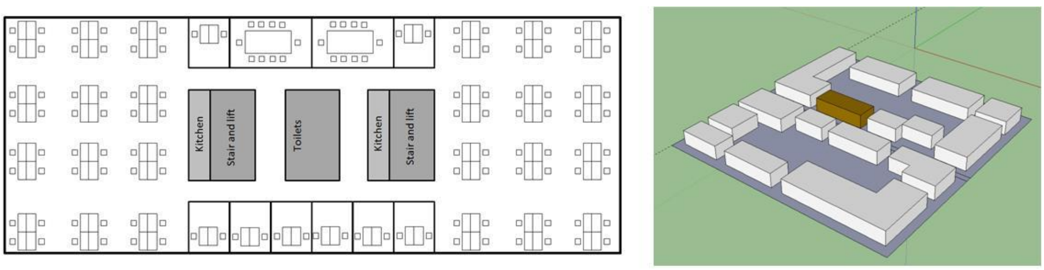


Figure 8. Example of building integrated energy supply and energy storage for a thermal system, using a TSC air collector, and an electrical system, combining solar PV and wind (SOLCER project, Wales Low Carbon Research Institute).

3. ENERGY SIMULATION

The above section has described the process of ‘low energy’ and ‘low carbon’ design, based primarily on offices. The examples used are from Europe and especially based on experience of office design in Zurich, Switzerland. This section presents some energy simulation results, of the type used in the design of a number of the above examples, but extending the analysis, firstly to consider applying European (Swiss) standards to two other locations, namely, Shanghai and Abu Dhabi, and secondly, to explore the energy demand and supply needs in relation to the availability of renewable solar energy.



(a) (b)

Figure 9. Building simulated: (a) Plan of typical office floor layout; (b) Site plan.

It takes as a basis for comparison a 6-storey office block (Figure 9a: typical floor layout) of overall dimension, 26 m by 68 m with a floor to ceiling height 3 m. This hypothetical medium rise design, is typical of what might occur in Europe, placed in the context of surrounding buildings to account for typical overshadowing and its impact on energy performance (Figure 9b: site plan). The main input data used in the simulation it summarised in Table 2. Figure 10 presents a summary of the monthly weather data for comparison; the actual simulation uses hourly weather data. The simulation was carried out using the building energy model, HTB2, which has been developed at the Welsh School of Architecture (Cardiff University) and applied in many research and design projects (Lewis and Alexander (1990)). Google SketchUp was used to construct the building development and to provide information on the shading of buildings by each other, and then the data is transferred from SketchUp to HTB2, which was run from within the SketchUp environment (Jones et al. (2013)).

Table 2. Simulation input data.

Internal gains (W/m^2)		**Building fabric**		**Systems**
Internal gain from people (12.2 m^2/person)	6.0	External wall	U-value=0.17 $W/m^2/K$	Mechanical ventilation 0.97 AC/H at 18 °C
Small power	4.9	Roof	U-value=0.17 $W/m^2/K$	Cooling COP = 4; Heating COP = 3
Lighting	7.0	Ground floor	U-value=0.17 $W/m^2/K$	Solar PV, 1768 m^2 at 15% efficiency.
Total	18.0	Glazing	U-value=1.0 $W/m^2/K$; G-value=0.15	

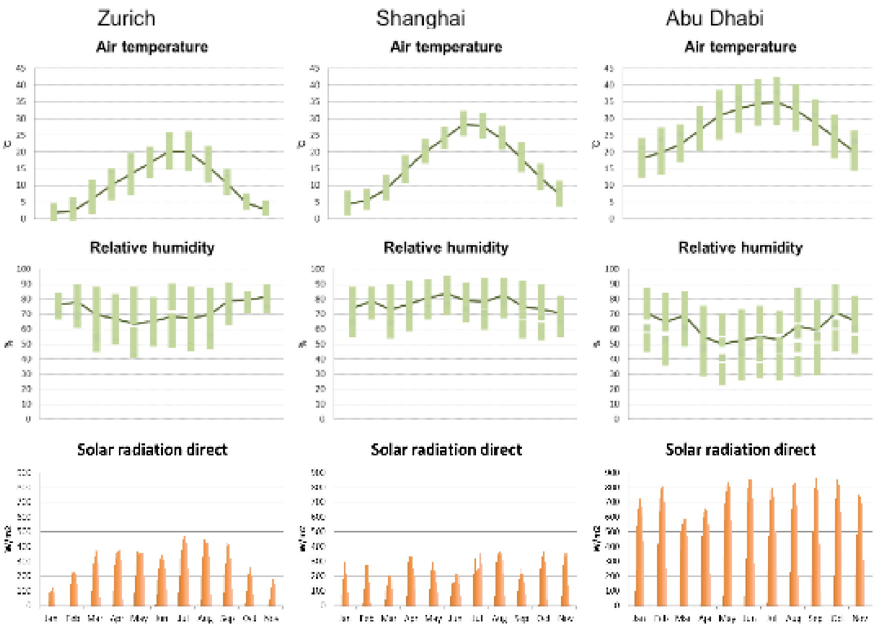


Figure 10. Weather data comparison for 3 locations.

The results from the simulation are presented in Figures 11 and 12 for the monthly energy supply and annual demand and supply, respectively. The energy supply relates to energy demand through applying COP value etc. as illustrated in Figure 6. They indicate that a relatively low energy demand and supply performance can be achieved if the 'Swiss' standards are followed. The availability of solar energy to power the building is abundant for all three situations based on the whole roof being applicable for solar PV systems (Table 2). The implication suggests that renewable energy supply and demand will be displaced in the operation of a building according to when solar energy is available and when energy is needed for lighting, heating, cooling and ventilation, some means of energy storage will be required. In Shanghai and Abu Dhabi only short term energy storage would be required for energy autonomy, whilst in Zurich longer term storage would be needed to cover the winter months, when the monthly energy demand exceeds the solar availability.

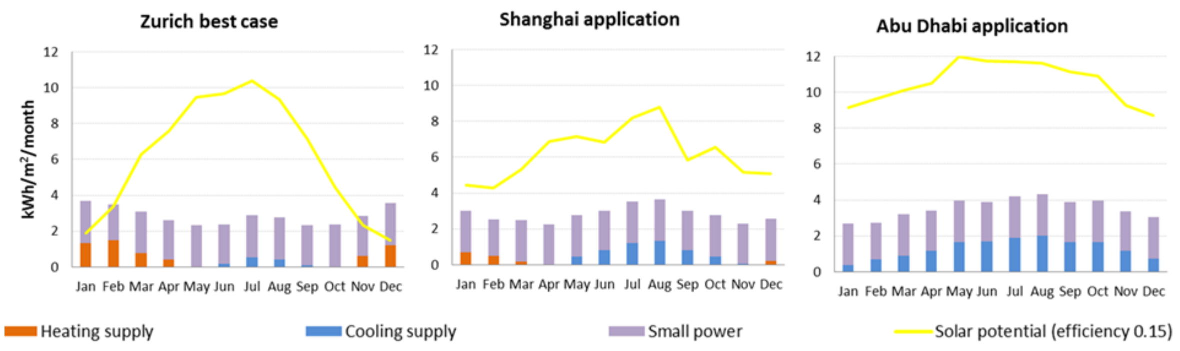


Figure 11. Monthly results for energy supply and solar PV potential (PV efficiency of 15%)

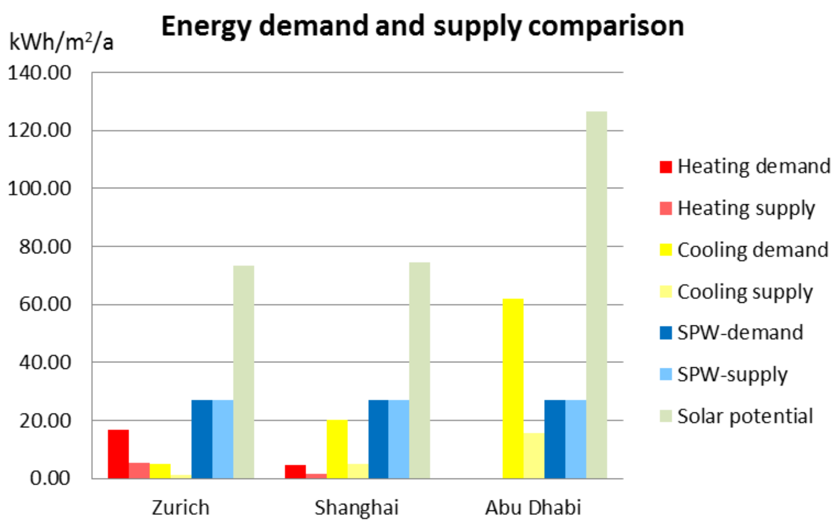


Figure 12. Summary of annual energy demand and the corresponding required supply accounting for heating and cooling system COP. The heating and small power use direct electric.

The results imply that there would be sufficient solar energy to supply building's reduced energy demand for heating, cooling and small power as discussed earlier. However, solar energy will not always be available to meet the demand at a specific time, for example at night. Therefore, research is required to explore storage capacity for both the short and long term needs for the above situations.

4. CONCLUSIONS

The paper has described a process of achieving low energy design through a combination of reducing internal heat gains, façade design, and innovative cooling and heating systems. It has also introduced a systems approach combining this reduced energy demand, with renewable energy supply and storage, and the use of building integrated renewable energy systems. It has used energy simulation to analyse the detailed energy performance and relating energy demand to the required energy supply, and to the potential for meeting this supply from renewable energy (in this case solar PV). The results indicate that short term storage may be sufficient for Shanghai and Abu Dhabi, whereas longer term storage may be needed for Zurich. The overall results also indicate, that a zero carbon design can offer additional benefits of improved comfort and air quality, and more efficient space use, especially relating to plan space and distribution. A holistic approach to zero-carbon building design will therefore lead to a more productive working environment, and be spatially more efficient, with associated cost savings relating to both the construction and operation of the building.

REFERENCES

Alexander D K, Mylona A and Jones P J, The Simulations of Glazing Systems in the Dynamic Thermal Model HTB2, IBPSA, (Canada), (2005) p 11-18. ISBN 2-553-01152-0

CIBSE, 2006. CIBSE Guide A: Environmental Design, Chartered Institution of Building Services Engineers, UK.

Jones P and Alexander D, Thermal Comfort and Innovative Office Design, Proceedings of the 7th Asia Pacific Conference, 18-19 November 2003, Hong Kong (2003) pp2, 16-2, 22

Jones P J and Kopitsis K, ,2005. The building physics design of the EMPA “Forum Chriesbach” low carbon office, CLIMA2005 Congress, pages 258-264 (Switzerland).

Jones P, et al. Intensive Building Energy Simulation at Early Design Stage, IBPSA, August 2013

Lewis, P.T. and Alexander D.K., 1990. HTB2: A flexible model for dynamic building simulation, Build Environment, 25 (1) 7-16.

PHILIPS, 2012, Office LED Lighting, Koninklijke Philips Electronics N.V.