Resilient hospital design: the zero carbon cooling challenge

S. Roaf
Heriot Watt University, UK

ABSTRACT

This paper outlines the need to increase the resilience of hospital buildings in the face of three growing perils, climate change, insecurity of energy supplies and the resulting potential for epidemics and pandemics. It is argued that there has been a trend to poorer building design and construction standards resulting in the increase in fossil fuel use to maintain adequate indoor temperatures. As extreme climate events increase in number and intensity, and are increasingly associated with power failures, the role of buildings becomes more central to our comfortable survival. No where more so than in hospitals in which we care for some of the most vulnerable in our societies. It is in hospitals that we must go beyond Low Energy Cooling to Low Carbon Cooling with systems in deeply passive buildings that can operate on embedded renewable energy systems even when power grids and back up generators fail. New holistic concepts for achievement of comfortable indoor climates for hospitals are being developed to improve the resilience of hospital buildings. Central to this aim is the need to control the transmission of infections in hospitals. This paper outlines the challenge and concludes that much more research is needed to produce a generation of Resilient Hospitals in which patients can remain safe in extreme weather events even when grid power systems do fail.

1. INTRODUCTION

In the front line of our battle against climate change are buildings. Not only are they responsible for over 40% of all climate change emissions but it is in them that we shelter from the worsening climate.

As the strength of the Climate related hazards grow so does the exposure in hospitals of many of the most vulnerable in our societies. Extreme weather events increasingly overwhelm the ability of civil society to cope with them as demonstrated in 2003 by the heat wave that killed over 35,000 people in Europe and the catastrophic collapse of society that unfolded before our eyes when Hurricane Katrina hit New Orleans (Fischer et. al, 2006). Yet hospitals, like many other buildings types, are becoming increasingly dependent on high-tech energy supply and management systems. In developed countries buildings typically account for at least 40% of total energy consumption and in the UK in acute hospitals this is typically over 60% of this energy is used in the provision of indoor climate comfort. Naturally ventilated (NV) buildings typically use less than half as much energy as those with AC. Recent years have seen an explosive development of air-conditioning markets in Europe suggesting it is moving towards the US model with the associated reduction in building quality and robustness (Nicol and Roaf, 2007). Reliance on mechanical cooling, however efficient, is also creating a general reduction of passive design skills amongst architects and engineers alike (Shove, 2003; Ackerman, 2002; Cooper, 2002. Nicol and Roaf, 2007)) resulting often in buildings that are uninhabitable during extreme weather events such as heat waves, floods, droughts or storms when the power fails. 21st century hospitals will have to be Resilient as well as Efficient.

2. RESILIENT HOSPITAL DRIVERS

21st century hospitals will have to be Resilient as well as Efficient driven by a range of increasingly pressing issues.

2.1 Climate Change

The health systems of nations stand to potentially suffer major impacts as a result of climate change including increased rates of hospitalisation resulting from extreme temperatures; flooding; UV exposure; vector and water borne diseases; food poisoning; storms and air pollution ( Roaf et. al. 2004; Stern, 2006; Lynas, 2007).

2.2 Cost and Security of Energy.

More expensive and less reliable energy supplies will lead to blackouts caused by inadequate and aging i-
fra-structure, climate events such as storms, floods and lightening or failures of grid and / or back up fuel supply systems (Roaf et al. 2005). Renewable energy systems may be able to provide reliable and continuous supplies.

2.3 Epidemic and Pandemic concerns
There have been increasing global levels of alert over the potential for Pandemics of a range of viral and bacterial infections such as Bird Flu, SARS and Tuberculosis (Yu et al., 2004). Collapse of electrical support and emergency systems could cause rapid cross-infection between patients if the building had not been also designed to passively protect occupants against cross infection.

2.4 Rising energy demands and costs
A clear trend in UK hospitals is towards the use of more energy year on year, with annual increases of up to 10% per annum reflecting trends to the use of higher levels of technology introduced to serve both medical and patient needs. The UK hospital sector (The Carbon Trust 2006) has experienced a dramatic cross over to the dominant use of electricity from that of gas in 2001 in hospital due in part to the move from radiantly heated buildings to air-conditioned premises that can use substantially more primary energy as a whole than traditional hospital buildings. The 10% increase in total energy use comes with a doubling of the energy costs of the hospital reflecting the move to the increased use of electricity in the energy mix for the existing buildings as well as the rise in energy prices.

2.5 Global economic trends.
As global populations soar and consumption rises, the issue of ‘embodied energy’, the energy used in the mining, manufacture and delivery of materials to sites, is becoming increasingly important. The price of Commodities, such as building steel, is soaring on the open markets. If building elements are designed, specified and built now they must be built to last. The unprecedented continuous growth of the stock markets over the last five decades is the only reason why hospitals can now afford to replace a relatively modern building that is already being demolished. This may not be the case in ten years time because of soaring build costs. Hospitals should thus be durable as well as resilient.

2.6 Poor hospital architecture
The design of the new generation of UK Private Finance Initiatives (PFI) hospitals provides many examples of poor quality of construction being typically driven by low client understanding and fabric performance aspirations and the need to bring in projects on time and on cost, to a standard that would ensure that the managing company could afford to run the building over time. Many of these buildings have been constructed of a light weight steel frame with thin over-glazed envelopes (a problem long understood but ignored, see: Loudon and Danter, 1965) and fixed windows needing increasing levels of air conditioning and energy running costs to maintain indoor comfort. A typical list of reasons cited by designers for increased electricity use include: Increased requirement for air conditioning/handling for clinical reasons; Increased perception of the need to ‘seal’ buildings, noise, pollution; more high load equipment eg imaging equipment gains generally; higher summer temperatures; upgrading of the acuteness of patients; higher public expectations for the internal environment, such as comfort cooling.

3. NEW APPROACHES

3.1 Sustainable hospital design
Many of the reasons for increasing energy use do not hold up against scrutiny, particularly in the context of the larger issue of the well being of patients. Some designers in the UK are work to break out of this mould by producing Sustainable Hospital designs with predominantly product driven strategies such as: CHP with 20% renewable provision Ground Source Heat Pumps 100% contribution of off-site power Further reduction demand through improved element performance eg. walls and roofs; reduced infiltration; triple ventilated facades Decentralised heating systems: local plate heat exchangers with reduce circulation losses; high efficiency plant (86%+). Total BMS system controls, variable speed drive, good zoning and local user control NV to over 50% of the building - wards, offices with low internal gains; shallow plans 6m deep for single side ventilation; increased external rooms on the façade; additional shading devices; solar reflective glazing; mixed mode provided; night cooling with thermal mass. Fresh air system with heat recovery, thermal wheels. Absorption cooling with zero ozone depleting refrigerants. Efficient air-conditioning.

3.2 Resilient hospital design
Resilient hospital aims to produce buildings that will operate under all conditions and their specification may include similar systems to those above but strive to meet resilience targets not just energy performance targets such as: Site: Minimise exposure of building to risk; above flood plain levels, sheltered from storms; low heat island potential; landscaped; water conservation and management; garden refuge in extreme heat waves; cool and...
non reflective surfaces.

Deeply Passive Building: Shallow plan / natural ventilation to all rooms. thick insulated walls; minimal west facing windows and those to have good shading / shutters; south facing windows to be well shaded and possibly to have balconies; weather lobbies on all entrances; 100% natural ventilation potential; thick roof; Robust structure usable during power outages.

Zoning: of spaces and functions by room performance, exposure and vulnerability of function.

Height: No higher than carry down height, c. four floors.

HIBRED buildings: Holistic Integrated Building Renewable Energy Design to provide low or zero carbon heating, cooling and power.

Resilient Building: incorporating protocols for worse case energy failures and extreme weather events at point of design.

Adaptable building: Audit process for recording and incremental modification of the building developed at design stage.

3.3. HIBRED hospitals

Design ideas around the Sustainable Hospital deal largely with the ability of mechanical systems to enable building performance targets to be met through efficiency. Demand reduction potentials achieved through good building design are in the main ignored because of the often poor levels of competence of architects in low energy design. Neither architects nor engineers are yet comfortable with working with HIBRED (Holistically Integrated Building and Renewable Energy Design) building strategies that rely on the finely tuned relationship between renewable energy and mechanical systems, building form and fabric and occupant behaviour and time to achieve optimal reductions in energy requirements to power buildings and carbon dioxide emissions from them. For instance a GSHP may provide optimal working efficiencies when used with some renewable electricity in low temperature under-floor heating and cooling systems and assisted night cooling systems that work in conjunction with building mass and occupant use patterns.

4. NOSOCOMIAL INFECTION PATHS

4.1 Limiting infection spread

A complicating factor for the designers of hospitals is the existence of patients within them with infectious diseases. Modern hospitals try to kill pathogens, remove or constrain them with high energy systems such as air extraction, high temperature sterilisation and ultra-violet systems. With the rise of concerns over pandemics and in the face of growing extreme weather events more research is needed into the passive control of paths of infection within hospital buildings.

The choice of ventilation systems by hospital designers is a critical one and that should be taken also by the hospital clinicians. One problem is that hospital spaces have to be increasingly flexible because clinical priorities for the spaces may change over time. Does this mean that every part of the hospital needs to have the maximum specification or does this require firm decision making from day two of the design process on level of ventilation provision for instance. What type of ventilation provision is best for different patient types? Does it hold that the more energy used the better the recovery environment for a patient is?

4.2 New work on infection paths

Many old hospitals were built with high ceilings and large windows to ensure the removal of infectious pathogens away from the environs of the patient and their expulsion through open windows via high ventilations rates. Such systems have been shown to still provide lower cross-infection rates than those in mechanically ventilated wards for tubercular patients (Escombe, 2007). Sunshine is also very good at killing a range of pathogens. TB bacilli are killed by only a few hours in direct sunlight, by the UV component specifically. This is relevant to design, as natural light needs to be maximised to contribute to surface disinfection in ambient working conditions. There is a strong case to be made for the use of opening windows in sunny wards for such patients to encourage rapid recovery.

Conversely concerns are growing about the healthiness of many mechanical ventilation systems in general. The design and maintenance of mechanical plant, filter and duct systems is obviously critical in hospitals. Poor indoor air quality, and unhygienic air supply conditions that can be directly associated with poorly maintained air conditioning systems (Mauderly, 2002; Clausen et al., 2002; Bjorkroth et. al., 2002). The age and maintenance status of a system is patently critical.

A range of scientifically robust studies have also shown that pressurised mechanical ventilation systems have been linked to the spread of a range of infectious diseases including MRSA, MDRBT, SARS, TB, Influenza, Varicella ( chicken pox) and measles (Cotterill et al., 1996; Kumari et al., 1998). In some of the cases cited on the subject by Li et al. (2007) the infections were the result of faulty mechanical systems. Clearly ducts, filters and fans must be easily accessible for maintenance, cleaning and inspection. A wide range of physical and managerial factors influence the rates of spread and transmission pathways of infections (Beggs, 2003a; Beggs et al. 2003b; Tang et al., 2006).

In some cases cited the route of infection was shown to be via open windows, driven by the thermal buoyancy
of air derived from an index patient in a ward below or from poorly located mechanical outlets. Such considerations could influence designers to relocate the infectious wards on the top floors of buildings where spaces could be mechanically ventilated using short duct runs but this in turn could imply a longer route from door to ward for highly infectious patients through the hospital. These recent studies do show that a wide range of factors influence cross-infection rates and that it would be wrong to assume that mechanically ventilated and cooled wards provide the least opportunity for cross infection between patients. Not only clinical, and climatic issues should influence ward designs but also the need to provide resilient protection of infectious and non-infectious patients in case of extreme events and building system failures.

5. CONCLUSIONS

Hospitals are in the front line of the 21st century battle to cope with more extreme weather events, increasing insecurity of energy supply and concerns about the rise and spread of infectious diseases. It is imperative that of all buildings hospitals at least should be resilient enough not to fail during related catastrophic events in order to reinforce our Social Resilience to unpredictable future conditions. To do this hospital buildings must be robust, passive buildings with the capacity to run vital services from embedded renewable energy systems. There is some evidence that naturally ventilated wards need pose no more threat to health than mechanically ventilated wards for many patients and for some pathogens may reduce the cross-infection rates of nosocomial infection. More work is urgently needed in the field of Resilient Hospital design in light of the increasing frequency and severity of extreme weather and energy failure events experienced around the world since the turn of the 21st century.

REFERENCES


