Minimising Hospital Acquired Infections using Good Design: Future Trends

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ABSTRACT

This paper touches on historic indicators of good hospital design such as sun, daylight and natural ventilation. Evidence is provided that recent trends in hospital design that lean towards more highly serviced buildings with fixed windows lead to higher levels of Sick Building Syndrome, nosocomial infections and SARS CoV-2 related infections and deaths than in naturally ventilated buildings with opening windows. The now soaring levels of nosocomial infections in hospitals make it imperative that we actively reassess such evidence and begin to evolve designs that actually improve the mental and physical health of staff and patients, not kill them. What are the roles in the poor health performance of many modern hospitals played by current building standards, regulations and assumptions based on outdated comfort models and dose related measures of Indoor Air Quality? Some simple suggestions on hospital design to help occupants survive and thrive in them in an uncertain future are offered.

KEYWORDS

Hospital, Design, Nosocomial Infections, Ventilation, Shade, Thermal Mass

1 INTRODUCTION

At the 28th AIVC Conference in 2007 I argued that hospitals were facing three perils: climate change, insecurity of energy supplies and pandemics. Poorer building design and construction standards were seen as a major problem. More extreme weather events were also a threat to energy supplies with the impacts of Hurricane Katrina cited as providing evidence of hospital system collapse across a whole city after flooding (Roaf et al., 2009). In 2007 a new approach to constructing hospitals was asked for using climate and site appropriate and passive designs that relied more or less on local natural energy to power ‘healing indoor environments’. This paper looks how that might happen and what was learnt from SARS CoV-19 experiences.

2. HISTORIC HOSPITALS: DESIGNED TO MAKE YOU BETTER

Traditional hospitals were built with high ceilings and large windows to ensure the purging of infectious pathogens and reductions in cross infections indoors (Hobday, 2020; Hobday and Dancer, 2013; Beggs et al. 2003). Florence Nightingale wrote in her report on the Health, Efficiency and Administration of the British Army in 1858 that fresh air and sunlight are essential for health, and reading in bed (Nightingale, 1858). In 1864, Britain’s Chief Medical Officer John Simon promoted the importance of natural ventilation in wards. Like Nightingale, Simon supported oblong wards with sash windows reaching to the top along the two long sides, with sufficient space for one bed between each window. At the time, it was believed that smallpox and other infections were contracted following the inhalation of airborne material.

3. MODERN HOSPITAL DESIGN AND VENTILATION

The evolution of more modern hospital design and ventilation in hospitals has been well covered by a number of authors (Short, 2017; Francis et al.,1999). Hospital design radically altered after the second world war. A major problem in traditional hospitals was seen to be inefficiently arranged nursing units where staff had to walk continually up and down long wards that held twenty patients or more in paired beds light and ventilated from both sides. Later double-loaded corridors that connected smaller six-, four- or two-bed wards and private rooms were introduced. Distances covered were onerous and wasted staff energy. Designs were centralised to reduce expensive exterior wall construction, facilitate the delivery of services, and minimized nurse staffing requirements by reducing travel distances. With the post-war advent of antibiotics and improved aseptic practices, the medical establishment began to believe that patient healthiness could be maintained regardless of room design. This is far from true argues Heschong (2021) in her Chapter 15 on Healthy Daylight.

De-coupling the indoor climates of buildings from their micro-climates was only possible with the inexorable rise of air-conditioning in buildings, initially by the 1960s in the USA, and later in the UK and Europe. The move was driven not least by regulations for Heating, Ventilations and Air-Conditioning (HVAC) of buildings written almost universally now by members of the HVAC professions who are normally paid in proportion to the amount of equipment that is installed in a building (Roaf and Nicol, 2022). As mechanical systems proliferated, so did fixed window hospitals because it was persuasively argued that:

a) people required and preferred indoor temperatures falling within a narrow comfort zone (eg. around 20^{0}C-25^{0}C) to remain comfortable, implying also to be healthy;

b) opening windows reduced the efficiency of mechanical systems so increasing energy use.

In reality the over-cooling of buildings became endemic although some doctors apparently even preferred the total environmental control offered by air conditioning, central heating, and electric lighting. Kisacky (2007) shows how windows were thought to be no longer considered necessary to healthy in hospitals and by the 1960s and 1970s even windowless patient rooms had appeared. This is despite the fact that research has demonstrated that patients in hospital rooms with windows improved at a faster rate and in greater percentage than did patients in windowless rooms. Kisecky (2007) also wrote:

> *The efficient, inhuman, and monotonous buildings of the second half of the 20th century bear witness to the extent to which hospital design became a tool to facilitate medicine rather than a therapy in itself. Today, a stay in a hospital room is endured, not enjoyed*.

Prior to 2007 a new generation of UK hospitals were funded as PFIs (Public Private Finance Initiatives). Companies were paid excessively to construct and manage hospitals over twenty to twenty-five year periods. Developers got rich. Hospital administrators were often left with structures and systems built cheaply to last at least twenty-five years after which they were handed over with high operational and system repair and replacement and energy usage. In the wake of such flawed initiatives hospitals became dependent on air-conditioning (AC), in sealed ‘envelopes’ around deep-plan buildings, designed with minimal regard to their location in urban or greenfield sites or local climates. Areas of poorly oriented and fixed glazing in a heating climate increasingly exacerbates the problem of peak summer energy usage, at times cause whole building systems to fail. Hospitals were traditionally considered to be places you went to in order to get better, what they have become was places where people get sick when they go there.

4. HOSPITALS THAT MAKE YOU SICK

4.1 Sick Building Syndrome

By the 1990s it was found that people in fully Air-Conditioned (AC) environments suffered much higher rates of sick building syndrome (SBS) and comfort-related illnesses than those in naturally ventilated offices (Seppanen and Fisk, 2002; Mendell et al., 2003). A constant narrative is floated about the dangers of poor Indoor Air Quality (IAQ) (Ghaffarianhoseini et al., 2018), but the definitions of IAQ concentrate on dosages of 'pollutant' contamination while ignoring the human and building dimensions of the environment. The same doses are regulated regardless of the construction or design of a building, the actual number or prefernces of its occupants. Many studies demonstrate that IAQ is better with fewer SBS symptoms reported in naturally ventilated buildings than in AC ones (Fisk et al., 2009) but time is also a confounding variable, with building uses changing regularly. SBS has also been linked to low ventilation rates in buildings but as Seppanen and Fisk (2002) conclude:

> *Because increases in ventilation may increase building energy consumption, research is also needed to identify practical methods of decreasing minimum ventilation requirements by reducing pollutant emissions from buildings and building air-handling systems. Methods to increase ventilation rates without increasing energy consumption, or to increase the effectiveness of ventilation in controlling pollutant exposures, should also be investigated.*

A simple way to do so is to open a window to purge spaces of pathogens or toxins. Mendell et al. (2002) in their seminal paper on the subject of how to improve the health of workers reinforce the urgent need for better research on the subject. Poor research blights this field.

4.2 Nosocomial Infections Soar in Fixed Window Buildings

Hospital acquired (nosocomial) infections are caused by common pathogens including bacteria, viruses, and fungi, a common one being the bacterium Staphylococcus aureus. Others common pathogens include Escherichia coli (E Coli), Enterococci, and Candida are common culprits, and all can be normally found on the skin and mucous membranes. Recent worrying outbreaks of antibiotic-resistant strains such as methicillin-resistant Staphylococcus aureus (MRSA) that can be especially dangerous, are difficult to treat and are increasing.

Health care-associated infections (HCAIs) are defined in the USA as infections that occur while receiving health care, developed in a hospital or other health care facility that first appears 48 hours or more after hospital admission, or within 30 days after having received health care. The scale of the problems they cause are huge. The US Centre for Disease Control and Prevention identifies that nearly 1.7 million hospitalized patients annually acquire HCAIs while being treated for other health issues and that more than 98,000 patients (one in 17) die due to these (Hague et al., 2022). Advice on reducing the impacts centres simply on hand washing, more often and better, completely ignoring the aerial transmission routes of pathogens. This also happened before the 6th July 2020 with SARS CoV-19 when a group of international scientists complained the World Health Organisation who were forced to admit that aerosols were the major transmission route for the pathogen (Morawska, 2020).

By May 2020 15.8% of people in the UK being treated for COVID-19 had actually acquired it in a hospital and over a quarter of those died from the disease (Read et al., 2021). By 2022 English researchers found that due to the delay from the onset of the infection, to symptom onset, to testing positive cases of nosocomial transmission of SARS-CoV-2 were missed under common definitions of HCIAs. Some 20% of symptomatic COVID-19 patients in hospitals in England in the first wave had acquired their infection in hospital settings and it was proposed that increased awareness and testing, especially of patients on discharge was needed to prevent hospitals becoming vehicles for SARSCoV-2 transmission (Knight et al., 2022). Tens of thousands of medical staff died globally in the pandemic having been exposed to the virus in the hospitals they worked in and must be universally praised for their dedication to service when they knew full well of the infection risks they faced at work.

4.3 Tuberculosis (TB) Transmission reduced in Naturally Ventilated Wards

In seminal studies on the transmission of tuberculosis in five pre-1950 hospitals and three modern ones built between 1960 and 1990 in Lima, Peru, Escombe (2007) found a disparity between the levels of TB cross infection in the naturally ventilated and the air-conditioned ward. Opening windows and doors maximized natural ventilation so reducing the risk of airborne contagion as well as the maintenance requirements of the mechanical ventilation systems, a key factor particularly in limited-resource settings and tropical climates, where the burden of TB and institutional TB transmission is highest. In settings where respiratory isolation is difficult and the climate permits, he recommended that windows and doors should be opened to reduce the risk of airborne contagion.

Natural ventilation created by opening windows and doors provided higher rates of air exchange, absolute ventilation, and theoretical protection against airborne TB infection. These factors prevailed in facilities built more than 50 years previously, even on days with little wind. By contrast, the mechanically ventilated rooms he studies had poor absolute ventilation even at recommended air exchange rates for high-risk areas, and consequently had higher estimated risks of airborne contagion.

5. LESSONS FROM SARS Cov-19 COVID-2 Pandemic

5.1 Cluster outbreaks of COVID-19

SARS-CoV-2 had been detected in air ventilation ducts in hospitals (eg. Ma, 2020). Window opening regimes have been shown to lower nosocomial infection rates. A study of four healthcare settings in Lanarkshire Scotland of COVID-19 of cluster outbreaks found nineteen COVID-19 clusters on fourteen wards at the newest Hospital W during the six-month study period. Each outbreak lasted from two to 42 days and involving an average of nine patients and seven staff in each. COVID-19 clusters in the two older Hospitals H and M reflected lower community infection rates. Forty clusters occurred across all three hospitals before a January window-opening policy was installed in the other two hospitals and despite multiple confounders it was apparent that having a window opening regime in place reduced cluster occurrence. In Hospital W, there were 17 clusters between 1st October and 25th January compared with just two from 25th January until 31st March when windows were opened, despite there being more patients than in the earlier period (Dancer et al., 2021).

Evidence that SARS-CoV-2 can be transmitted by aerosols via ventilation systems recorded in three COVID-19 wards at the deep plan Uppsala Hospital, Sweden. SARS-CoV-2 was detected the in central ventilation systems in that hospital in April and May 2020, distant from patient areas, showing clearly that the virus was transported long distances in airborne form, even with relatively low air change rates in these wards (Nissen et al., 2020).

5.2 CO2 is a Bad Proxy for Viral Load

The HVAC industry promotes the use of CO_2 levels in spaces as a proxy measure for 'pollution' or poor IAQ. CO_2 is not a pollutant and there is no reasonable published evidence as to what constitutes a safe level of CO_2 in doors. The European SCATS Study measured levels of CO_2 in Portuguese offices of 1000-300ppm without occupant complaints (McCartney and Nicol, 2002). The level at which submarine crews are mandated to take action to improve CO_2 levels is 5000ppm. The HVAC industry has often deemed 1000ppm CO_2 to be a trigger for increased need for ventilation in a space. No validated scientific evidence for choosing this level is provided but it strikingly coincides with the vague figure of 1000ppm of CO_2 was arbitrarily recommended as a safe level for the unhealthy gas in 1858 by Max von Pettenkofer, a German physiologist (Porteous, 2011).

The equating of CO_2 with viral load had tragic consequences. During a 2020 aerosol borne outbreak of COVID_19 in a Dutch nursing home seventeen (81%) residents from one ward with a recycling air ventilator, and two air conditioners were diagnosed with COVID-19 and subsequently seventeen (50%) healthcare workers of the same ward also tested positive. By contrast, all tests of the one hundred and six workers and ninety-five residents in the six other wards with mechanical fresh air ventilation only were negative. CoV-2 RNA was detected in dust present on the mesh of the living room air conditioners of the infected ward, and in the block filters of the ventilation cabinets. Healthcare facility managers were warned off ventilation systems recirculating unfiltered air (de Man et al., 2020). Setting CO_2 trigger points to recirculate air below 1000ppm also proved fatal because elderly patient have very shallow breathing and CO_2 did not reach trigger levels so the viral load in the space soared to dangerous levels. The HVAC industry now advises levels of 600 or 800ppm as triggers for increasing mechanical ventilation rates in wards but this can then cause energy usage and bills to soar at a time when the costs of that energy is also rising. CO_2 levels are a bad proxy for viral load or air pollution. A room with lethal IAQ may have only one person in it. A major problem with accurately estimating levels of indoor pollution is that the regulations provide 'dosage' indicators of individual substances like pathogens, formaldehyde or VOCs which are difficult and expensive to measure (Bluyssen, 2022) whereas CO_2 is cheap and easy to record, but of little use in measuring viral load or toxicity of space on the whole.

5.3 Does Filtration Eliminate Pathogens?

HVAC organisations like ASHRAE, REHVA and CIBSE put forward the use of induct filters including HEPA, MERV and UV filters to reduce the transmission of pathogens between rooms and this has been shown to be more or less successful in various studies of COVID_19 in buildings (Roaf, 2022a). The virus as aerosols largely is transmitted between individuals in the same space so duct cleansing is of only some use. Within wards filters can also be used but to date the knowledge base associated with the use of supplementary air filtration in hospitals is weak. Little is known about how filtration devices should be deployed or the likely health benefits that might arise. Based on the supposition that room air filtration might help to mitigate the nosocomial transmission of COVID-19 and also reduce aerial dissemination of pathogens around the clinical environment a team from Addenbrookes hospital in Cambridge set up the Air Disinfection Study (AAirDS) to test the hypothesis. Twelve room air filtration units were installed containing HEPA filters and UV-C lamps, on two wards for older patient's wards, along with sensors throughout the control and intervention wards to continuously monitor PM and CO_2 levels as well as the ambient temperature and humidity. Collectively, this indicates that aerosols were freely migrating between the various sub-compartments of the ward, suggesting that social distancing measures alone cannot prevent nosocomial transmission of SARS-CoV-2. Air filtration did reduce PM levels throughout the ward space, suggesting that filtration has the potential to mitigate the nosocomial transmission of COVID-19 and other harmful pathogens.

Again it is important that most current standards and guidelines for IEQ are focused on dose-related indicators such as temperature level and ventilation rate, while building-related indicators and occupant-related indicators have been rarely considered (Bluyssen, 2022). Previous studies show, however, that building-related indicators such as building layout and the amount of space can influence occupants' overall satisfaction with IEQ (e.g. Kim and de Dear, 2012), building materials and furnishings can affect health (e.g. Bluyssen et al., 2016). Moreover, these comfort and health effects are related to preferences and needs of the occupants (occupant-related indicators), and therefore can differ (Bluyssen, 2010). The fact that an in room filter works well in one ward with set dimensions and occupancy levels may not reflect its effectiveness on other conditions. That is the problem with much IAQ research. Therefore, there seems to be a need to include both building-related and occupant-related indicators, additionally to the dose-related indicators listed in most standards and guidelines.

6. WHAT TEMPERATURES ARE HEATLTHY FOR PATIENTS?

The study of thermal comfort has moved on considerably from the 20th century idea that there is an average person who is comfortable as temperatures dictated by limited steady state models like PMV, that results in similar comfort recommendations whether in Africa or Alaska (Humphreys, Nicol and Roaf, 2016). It is now widely recognised that people adapt to those conditions they normally occupy, which are largely determined by the local climate and the buildings they occupy. The Adaptive Comfort Model was established some fifty years ago (Roaf and Nicol, 2022b), and now forms the basis of the European Comfort Standard EN ISO 7730 and the US American ASHRAE standard 55. Field studies shown that people can be comfortable indoors in temperatures ranging between 10^0C and 35^0C (Nicol, 2022), but only when adapted to the temperature ranges question. Accepting a far wider range of daily temperatures encourages the use of open windows, while the narrow comfort limits dictated by the PMV method push designers and users into air-conditioning buildings.

Work being done now at Maastricht University focus on the relationship between human physiology and comfort under controlled laboratory conditions to explore how health is impacted by temperature. Research observations there show huge variations in how different people experience similar environments, for instance under identical thermal conditions, reporting comfort experiences ranging from *uncomfortable* to *very comfortable*, and from *very uncomfortable* to *comfortable* (Jacquot et al., 2014). These differences can be due to genetics, body composition, sex, age, cultural and habitual differences, and the amount of perceived control. Generally, the physiological changes, both in heat and cold responses appeared to have positive effects on metabolic health, not least by keeping related systems active and functioning, avoiding their atrophication (van market Lichtenbelt, 2022; Pallubinsky, 2022). Pallubinsky (2022) wrote:

> *The time has come to shift perspective, as this overprotective character and provision of omnipresent comfort are neither feasible nor desirable any longer, considering the enormous amount of energy and resources spent to provide tightly controlled thermal environments (often with the same target temperature all year round). On top of all that, research has shown that being in a constant state of comfort can actually have negative impacts on health and deteriorate our human capability to deal with thermal challenges.*

Historically temperatures have been used manage diseases, with fevers being sweated out, and tuberculosis wards wheeling patients outdoors to into freezing temperatures. There is no evidence that keeping people in a narrow thermal zone improves their health over time, whoever there is a growing body of evidence that exposing patients to thermal variety actually stimulates and benefits their thermo-regulatory systems. opening windows in hospital staff and patient’s rooms may not only improve indoor air-quality by flushing out real pollutants, but importantly purge viral loads at the same time.

7. BLINDED BY SCIENCE

In 1894 the nascent HVAC industry in the USA wrote its first Bye-Laws that explicitly stated that one of its main aims was to lock the general public firmly into paying for their products and services by a) developing standards mandating the use of their own heating and ventilation products for all classes of buildings, with minimum performance standards; b) promoting legislation compelling the ventilation of all public buildings in accordance with the standards of this society and c) opposing legislation that harms the business of the ASHVE engineer. The ASHRAE forefathers would have been delighted to see the extent to which they have succeeded. Around the world Standards and Regulations have locked designers into installing ever more HVAC equipment into homes and offices (Cass and Shove, 2018). Competing systems like the use of natural ventilation via opening windows for purging of room air and also comfort cooling have been effectively side-lined by many HVAC regulators (Roaf and Nicol, 2022B). Radiant systems for heating and cooling have been effectively eliminated by standards that underplay their value (Teitelbaum and Meggers, 2022) while over-promoting fan-driven air in ducted and non-ducted HVAC systems.

7.1 Affiliation Bias is Rife in the Regulations

The HVAC industry worked hard to keep people smoking indoors in the 1990s, underpinned by research paid for by the tobacco industry. An exhaustive study by Bero (2002) of the public commentary of the California environmental tobacco smoke risk assessment, and also the Washington and Maryland indoor air regulations in the 1990s found evidence of *systemic biases in the use of the risk assessment process* by critics and supporters of regulations using different criteria to evaluate the scientific evidence. It found that various interests *socially constructed evidence* to support their predefined positions. At one point, the tobacco industry suggested that mechanical ventilation is a good control measure for environmental tobacco smoke, referencing ASHRAE Standard 62–1989. This has some resonance now as the HVAC industry is now promoting higher airflow rates to reduce viral load in spaces in the COVID pandemic, despite the fact that most systems in larger buildings may simply be working with recirculated air so further forcing infections onto a wider range of people.

The Bero study confirmed the findings of other research that the attitudes of experts were influenced by their *affiliation bias*, recommending that sources of the research controversies and their data be independently investigated. Related court judgements highlighted risks arising from the different interest groups using different criteria to evaluate the research evidence and the dangers of not fully disclosing the special interests of the determination process, including those from corporate, public health and environmental groups. He urged that the policy and risk assessment process should be strictly controlled to eliminate influence of such *affiliation bias.* The problem must be seen as a whole body of evidence, rather than focusing on the minutiae of individual, often weak, studies.

7.2. The Pseudo-Precision Problem

The problem of decision makers being blinded by the pseudo-science presented as evidence in the passive smoking example. The use ‘hyper-precision’ and with it ‘pseudo-precision’ in the mandating of dose levels for IAQ substances makes evaluation of IAQ, and in turn its achievement, or even of the questioning, of the dose levels required, beyond the reach of ordinary building managers and many researchers. Thermal comfort temperatures required in high class buildings under some standards presented to one or two decimal places when everyone knows that such accuracy is impossible to achieve in real spaces, let alone across them, possibly not even in laboratory conditions. The trend to demanding hyper-precision in measures has been described as ‘is not quite mendacious, but on the path to being so’.

8. THE EXTREME WEATHER WILD CARD

Despite over thirty years of endeavour, and billions of investment in reducing greenhouse gas emissions, they are still increasing from all sectors, but increase is from the built environment which in 2019 totalled 34% of all man-made emissions. A large proportion of these emissions come from energy generated to heat, cool and ventilate buildings (IPCC, 2022). Many of these emissions are unnecessary. Most buildings do not need to be conditioned 24/7/365. IN 2012 in the USA alone the *over-cooling* of buildings wasted around 104,000 GWh of energy and produced some 57,000 kt CO_{2e} of emissions at a staggering cost of 10 billion USD (Derrible and Reeder, 2015). With escalating outdoor temperatures, the cost and climate impacts of over-conditioning challenge even wealthy organisations. For every wasted KWh of energy in a hospital the salary of a nurse or doctor is eaten away at. Extreme weather also closes down whole hospitals as we saw in Hurricanes Katrina in late August 2005 where some patients were abandoned in their beds by staff during flooding (Roaf, et al. 2009).

8.1 Grid Failures during Extreme Weather Events

The 1999 Southern Brazil blackout was a widespread power outage caused in Brazil on March 11th 1999, caused initially by a lightning strike affected up to 97 million people, some for hours and some for months. On Thursday, August 14, 2003 over 55 million people on the Eastern Seaboard of the USA lost power in the North Eastern Blackout that lasted in many places over 48 hours during a heatwave. On the 31st July 2012 the largest blackout in history affected more than 620 million people, about 9% of the world population, or half of India's population, spread across 22 states in northern and eastern India. The blackout triggered by a heatwave lasted hours in some places and days in other. These are extreme events all linked to extreme weather but every country is now experiencing grid failures due to extreme heat, cold, wind-storms and flooding. Hospitals typically have energy back-up provisions for 24 - 48 hours. Some extreme outages occur for longer than that. Grid failures often occur at peak load points in the morning or evening. Buildings with enough well-design thermal mass in them can thermally cruise through the peaks hours, to both avoid over-burdening local grids.

8.2 Extreme Heat Causes HVAC Failures

On Tuesday 19th July 2022 one of the UK's biggest hospital Trusts declared a 'critical site incident' because their datacentres both failed in the heatwave when their air-conditioning units failed. Guy's and St Thomas' hospitals had to cancel operations, postpone appointments and divert seriously ill patients to other hospitals in the capital (Guardian, 2022). As temperature rise in the heating world air-conditioning systems will increasingly fail and cannot be responsibly warranted because scientists simply do not know how hot it will get how soon.

9. THE MENTAL HEALTH ISSUE

Many people including the author, who have spent time in a hospital as staff or patients with no opening windows understand the need to re-think hospital design. Many know the mental distress caused by not being able to access fresh outside air as a prisoner breathing only recirculated air passing through rooms occupied by hundreds of other infected patients there. Also, inevitably, IAQ generally deteriorates as temperatures rise indoors increasing, causing fearfulness of the experienced conditions (Roaf, 2022a). Some control of IAQ must be given to occupants in an unpredictable world and local control over window opening is a good start.

10. GOOD HOPITAL DESIGN: FUTURE TRENDS

In 1858 Nightingale persuaded politicians to design better hospitals. So should we. She had good evidence to convince them. So have we. So why have recent decision makers chosen to build hospitals that have affected the mental and physical health of the billions who use them, and have demonstrably been responsible for hundreds of thousands of excess deaths during

COVID. Most hospitals today are ill-equipped to protect us in the inferno climates of the future. It is time to set aside the pseudo-science that underpins most current building conditioning and ventilating standards and regulations and take a long hard look at the strengths and weaknesses of current models. One way forward might be to remove the ducts air-blown systems and choose to heating and cooling buildings with wipe clean radiant hydronic systems that do not share potentially infected air between spaces.

All occupied spaces should have well designed, useful, opening windows supplying air for breathing, comfort cooling and room purging of pathogens and pollutants free of charge. Major passive measures should include avoiding occupied rooms on western facades, extensive external shading, shallow plan buildings that enable good access to fresh air, day and sunlight to most spaces in a hospital. Personal Comfort Systems (PCSs) that heat people locally, not the whole building, can be used against a thermal backdrop of providing seasonal use of higher and lower background temperatures. Individual patient heating and cooling can be supplied according to medical needs, eg. using suspended horizontal radiant panels above each bed thermos-set to the needs of hypo or hyper-thermic patients. Staff can use PCSs as needed, eg. floor or desk fans or in extremis local plug in air-conditioners. Extra room height gained from removing suspended ceilings may enable the use of low energy ceiling fans, and or high level hopper windows to create circulate natural ventilation paths in the space. Through the wall two way ventilators with heat exchangers in winter can evacuate viral and pollution loads from spaces. In high load spaces in-room HEPA filters can also be used if necessary with active window opening regimes in places, even in cold or hot weather at different times of day. Air-lock spaces like flexible sun/wind spaces on wards may be included to pre-condition air for wards and transient use by patients. Any hospital must include high levels of thermal inertia. Eg. with high mass materials involved to ensure that when the building continues to provide acceptable indoor conditions for as long as possible when the national or local grid fails.

Hospitals must make people better – not sicker, at an affordable price and during extreme weather. Hospitals can run largely on solar boosted energy systems on estates, possibly storing thermal inertial in high mass islands like morgues for emergencies (Todorovich, 2011). Designers of these hospitals will have to be brave, but the possibilities are many. The time to change is now and engineers and architects need to step up to the plate and make it happen.

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