Building and Environment 141 (2018) 28–44

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Hospital wards and modular construction: Summertime overheating and energy efficiency

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ARTICLE INFO

Keywords:
Modular construction
Hospital ward
Energy demand
Summertime overheating
Measurement

ABSTRACT

The UK National Health Service (NHS) is continually under pressure to provide more bed spaces and to do this within a tight budget. Therefore, NHS Trusts may turn to modular buildings, which promise faster construction and low energy demands helping the NHS meet its stringent energy targets. However, there is growing evidence that thermally lightweight, well insulated and naturally ventilated dwellings are at risk of overheating during warm UK summers.

This paper examines the energy demands and internal temperatures in two 16-bed hospital wards built in 2008 at Bradford Royal Infirmary in northern England using modular fast track methods. The two-storey building used ceiling-mounted radiant panels and a mix of natural and mechanical ventilation with heat recovery to condition patients' rooms. Monitoring showed that the annual energy demand was 289 kWh/m^2 ± 16%, which is below the NHS guidelines for new hospital buildings.

It was observed that the criterion given in Department of Health Technical Memorandum HTM03-01 can lead to the incorrect diagnosis of overheating risk in existing buildings. Assessment using other static and adaptive overheating criteria showed that patient rooms and the nurses' station overheated in summer. To maintain patient safety, temporary air conditioning units had to be installed during the warmest weather.

It is concluded that thermally lightweight, well insulated, naturally ventilated hospital wards can be low-energy but are at risk of overheating even in relatively cool UK summer conditions and that this needs to be addressed before such buildings can be recommended for wider adoption.

1. Introduction

The UK National Health Service (NHS) is responsible for around 4.5% of all UK emissions with annual carbon emissions in 2015 of 22.8MtCO_{2e} [1] compared to a UK total of 495.7 MtCO_{2e} [2]. The NHS is required by law to reduce its carbon emissions [3] and stringent targets for energy demand have been set. Around 20% of the NHS emissions were from buildings and whilst NHS emissions have fallen by 11% overall since 2007, building emissions have fallen by just 4% [1]. Around 44% of the energy used in a typical UK hospital is attributable to air and space heating [4].

The original NHS carbon reduction strategy, "saving carbon improving health" stated that the NHS aimed to reduce their carbon emissions by 10% by 2015 compared to 2007 levels [5]. This goal was met, with emissions reductions of 11% being achieved [1] despite activity levels within the organisation increasing by 18%. As the NHS continues to become more specialised [6], electrical energy consumption continues to rise, and now accounts for double the emissions of all other fuel types [4].

Although the NHS met their carbon reduction targets, the savings in building energy demand were just 4%, but there is considerable potential for savings. Refurbishing all NHS buildings using low carbon technology could reduce building energy consumption by 25%, and replacing all NHS buildings with a super-efficient stock could save another 25%. This would contribute up to 12% of the NHS's 2020 emissions reduction target of 34% [4,7]. Replacing the entire NHS stock is a huge task, and it is unlikely this will happen in the near future, however, increasing the efficiency of the existing stock, and ensuring that new buildings are as efficient as possible are realistic goals.

Climate change, whilst reducing wintertime heating demands, will increase the risk of summertime overheating. However, despite the diversity of UK healthcare buildings' constructional form, age and servicing strategy, very little of this stock is air-conditioned. In fact, Health Technical Memorandum HTM03-01 [8], which is concerned with 'specialist ventilation for healthcare premises', states that '*natural ventilation is always the preferred solution for a space, provided that the*

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https://doi.org/10.1016/j.buildenv.2018.05.041
Received 19 March 2018; Received in revised form 2 May 2018; Accepted 18 May 2018
Available online 19 May 2018
0360-1323/

quantity and quality of air required, and the consistency of control to suit the requirements of the space, are achievable'. This, combined with the pressure to reduce carbon emissions and initial and running costs, means that those commissioning health care facilities try to avoid air-conditioning. Thus health care spaces and wards in particular tend to use hot water heating systems, combined with natural, mechanical and/or hybrid ventilation to maintain air quality, for infection control and to prevent overheating in the summer '*wherever possible*' [4].

During periods of high ambient temperature, hospitals are expected to provide a safe haven for citizens who are suffering from the heat. It is recommended that they provide cool areas that remain below 26 °C for use during heatwaves [9]. They must also continue to provide comfortable conditions for existing patients, who may have compromised thermoregulatory systems (the elderly, the chronically and severely ill, those on certain medications that impair perspiration) or may not be able to take action in the face of high temperatures (small children, the bed-bound, patients with mental illnesses). Finally, hospitals must also provide a safe, healthy and productive working environment for clinical, nursing and other staff. Thus, hospitals must provide respite from summer heat for the most vulnerable people at precisely the times of the year when it is most difficult to do so.

The ability of hospital buildings to provide summertime thermal comfort is one of the most important considerations, but a consideration that often gets little attention when designing and commissioning new hospital buildings. The risk of overheating in hospital buildings has been highlighted by the Adaptation Sub-committee of the UK Committee on Climate Change [10,11].

New buildings are needed to meet the growing demand for NHS services. However, because the NHS is under continual financial pressure, it operates at near full capacity virtually all the time, e.g. over 87% of its 128,000 beds were occupied between July and September 2017 [12]. New buildings must therefore be extremely cost effective and delivered with minimum disruption to hospitals' services. Fast track, modular construction is one approach that promises shorter construction times and, importantly, less time on site, and less noise, dust and dirt, and so less disruption to the operation of the hospital site.

The modular construction of hospital wards is not new of course, the classical example being the Renkioi hospital, built in 1855, in the final months of the Crimean war for Florence Nightingale. It was assembled from prefabricated wooden huts designed by Isambard Kingdom Brunel, which were transported out from Britain by ship [13]. Currently called 'modern methods of construction' (sic), prefabrication has gained popularity for the construction of flats, student accommodation etc., but it is an approach that is also applicable to hospital wards. There is emerging evidence that thermally lightweight, well-insulated, airtight, single aspect, cellular residential spaces built using modern methods of construction are particularly susceptible to overheating [14,15] and that this is exacerbated by poorly designed and operated mechanical ventilation systems [16]. But will hospital wards built using similar techniques also overheat?

The primary purpose of this paper is to investigate the capability of modular methods of construction to produce hospital wards that remain thermally comfortable and safe for patients, staff and visitors during UK summers. It is important however, to determine if such buildings are capable of meeting the energy standards set by the NHS for new buildings. The new hospital wards built in 2008, using modular construction methods at Bradford Royal Infirmary (BRI) in the north of England acted as the case study. The internal temperatures in seven bedrooms in one of the two wards were recorded from 2010 to 2013 [17]. The values recorded in 2012, and during the 108-day period from 15th June to 30th September in particular, are reported and analysed using a range of overheating risk assessment criteria. The building's heat and electricity demands were monitored during 2012 and early 2013, and the demands for 2012 estimated.

The work was part of the EPSRC/ARCC-funded project '*Design and Delivery of Robust Hospital Environments in a Changing Climate*' (DeDeRHECC) in which, altogether, 111 spaces in nine hospital buildings across four hospital trust were monitored [18–23]. This paper adds to this body of knowledge, by specifically quantifying the energy demands of a well-insulated, thermally lightweight, pre-fabricated, modular healthcare building but also highlighting the serious risk of overheating intrinsic to this form of construction.

2. Energy demand and indoor environment: benchmarks and guidelines

Benchmarks for the energy demands and CO_2 emissions of healthcare buildings have been set out in the Chartered Institution of Building Services Engineers (CIBSE) Technical memorandum, TM46 [24]. For spaces providing long-term accommodation, such as hospital wards, which include sleeping, day-use spaces, some offices and domestic facilities, the benchmark is $124 kgCO_{2e}/m^2$ per annum, based on 65 kWh/m^2 for electricity and 420 kWh/m^2 for fossil thermal energy.[1] An analysis of all available UK display energy certificates between 2008 and 2012 (as reported in [4] indicated that the actual median consumption of 35 residential hospital buildings was 308 kWh/m^2 for fossil fuels and 93 kWh/m^2 for electricity; somewhat less overall than the TM46 benchmarks.

Importantly though, in 2006, targets were set for all healthcare trusts in Health Technical Memorandum HTM07-02, EnCO2de [25], requiring that the total energy uses of new buildings and major refurbishments should be less than 35–55GJ/100 m^3 and for less intensive refurbishments of existing facilities, less than 55–65GJ/100 m^3. These targets are reiterated more recently in HTM07-07 [26]. The figure of 55 GJ/m^3 is equivalent to about 413 kWh/m^2 for the BRI building, which is not, therefore, especially stringent.[2]

The target wintertime operative temperature to which general wards should be heated are given as 22–24 °C in CIBSE Guide A [27], whilst HTM03-01, Appx. 2, gives a surprisingly wide range, 18–28 °C, but 18–25 °C in critical areas, such as birthing rooms, operating theatres, etc. [8].

Natural ventilation is preferred in the general wards of UK hospitals [8]. Specified ventilation rates for occupied spaces vary from over 15ls^{-1}/person in a high quality environment, class IDA1 of BSEN13779 [28],[3] to less than 6ls^{-1}/person for low indoor quality, class IDA4. Minimum standards are largely set in within the IDA2, IDA3 range [27], which are, respectively, 10-15 ls^{-1}/person and 6-10 ls^{-1}/person. These values are very similar to the basic ventilation rates set in BSEN15251 for Cat I and Cat II buildings, 10 ls^{-1}/person and 7ls^{-1}/person, respectively [29]. In occupied naturally ventilated buildings, the ventilation rate can be estimated from the measured increase in the indoor CO_2 level above ambient - the value of which in 2012/13 is memorable, as it was first time that 400 ppm was exceeded in the northern hemisphere. The indoor CO_2 levels corresponding to classes IDA2 and IDA3 during the monitoring period are thus 800–1000 ppm and 1000–1400 ppm respectively. Areas such as the bathrooms in the single and multi-bed rooms, the communal washrooms, and other area of foul waste need to have mechanical extract ventilation of at least 3ach^{-1} [8].[4]

[1] TM46 explains how these figures can be adjusted to account for differences between the ambient temperatures prevailing during a monitoring period and the standard year to which the TM46 benchmarks apply. In this work, no such adjustments were undertaken but comparisons made, between measurements and benchmarks, were cognisant of this approximation.

[2] The conversion uses a ceiling height of 2.7 m, as in the BRI modular wards.

[3] Standard applicable up to 2018 when replaced by BS EN 16798-3.

[4] Ventilation rates of 6 ach-1 are recommended if mechanical rather than natural ventilation is adopted, which is, of course, very high by the standards used in most other buildings.