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Performance of hospital spaces in summer: A case study of a ‘Nucleus’-type hospital in the UK Midlands.

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Abstract:

Nucleus-type Hospital in Glenfield comprises connected cruciform blocks with numerous small courtyards between. The hospital has mechanical ventilation and perimeter heating. The wards have a hybrid ventilation strategy with a low rate of mechanical ventilation. Ventilation through windows is the main source of summer time cooling. This paper investigates the summer time performance of spaces that are mechanically ventilated but passively cooled. The paper presents the measured indoor temperatures in selected hospital spaces and compares them with thermal comfort criteria. Finally, future summer conditions for the ward space are predicted using a calibrated multi zone dynamic thermal model.

During June to September 2010, the maximum indoor temperatures in the case study spaces varied between 27.3 °C and 29.3 °C. The nurse station was found to be the hottest area. During this period the performance of most of the monitored spaces was reasonably within the thermal comfort threshold as defined by HTM03-01. The simulation results demonstrate that light-touch low carbon interventions could produce comfortable conditions in bedrooms into the 2050s in UK Midlands.

Keywords: summer; hospital; overheating; thermal comfort; natural ventilation; simulation; calibration; low carbon.

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1. Introduction

In UK, due to intensity and scale of development, Hospitals on most occasions form deep build environments. These environments can experience overheating during the summer, especially when the outdoor temperature is more than 20°C [1,2,3,4]. The Design and Delivery of Robust Hospital Environments in a Changing Climate (DeDeRHECC) research project is investigating the impact of summer overheating in hospital campuses operated by four National Health Service (NHS) Acute Trusts. The sites under examination are: Addenbrooke's (Cambridge); Bradford Royal Infirmary; Glenfield Hospital (Leicester); and St Albans City Hospital. In each of these hospitals, 125 spaces within 3 to 4 wards in 2 or more buildings have been monitored since June 2010.

The degree and duration of overheating, especially in hospital, will depend on geographical location, building design, ventilation strategy and internal gains [3,5,6,7]. Geographically, the Addenbrooke's tower² block is exposed to a climate which is similar to Southern England (warm summer³) conditions. The building has a hybrid ventilation strategy with a high rate of mechanical ventilation (4 ach⁻¹) while radiant ceilings provide space heating [2]. On the other hand, the Nightingale⁴ wards (open wards) in Bradford are exposed to a Northern England (cool summer) climate and they are naturally ventilated with perimeter heating [3]. This paper will focus on Nucleus type hospital, which has a hybrid ventilation strategy with low rate of mechanical ventilation (1.2 to 1.8 ach⁻¹) and located in the UK Midlands so that one could have reasonably good understanding on performance of a third commonly occurring hospital building types and its responsiveness to the respective climatic conditions.

The Glenfield⁵ Hospital design, developed in the late 1970s and opened in 1984, was based on the 'Nucleus' concept (Fig. 1). 'Nucleus' is the name given to a way of planning hospitals that was widespread in the UK between the late 1970s and the early 1990s; more than 100 whole 'Nucleus' hospitals or part-schemes were constructed [9,10]. 'Nucleus' was a template-based approach which accommodated hospital departments within a standardised cruciform floor area of 1000 m². These templates were laid out on one or both sides of a connecting corridor (the 'street') to a maximum of two storeys. In theory, any template could be placed above or alongside any other, creating a low-rise regular 'mat plan' [11] with numerous courtyards. One intended feature

² Built in 1960s

³ This research considers 1st May to 30th September as summer.

⁴ Built in 1900s

⁵ Construction was carried out in two phases. 1st and 2nd phases were completed in 1984 and 1989 respectively.

of the chequerboard layout was that areas could be naturally lit and ventilated from the courtyards where clinically appropriate [12].

At Glenfield, the principal cooling for the wards is by natural ventilation through window openings. This paper investigates the performance of a naturally cooled Nucleus ward in the UK Midlands, during summer 2010, and simulates light touch low carbon strategies to reduce overheating during future summers. Glenfield Hospital is located in a climate which is transitional between northern and southern England. The historical climate data⁶ for Leicester (UK Midlands), covering the period between 1971 and 2000, shows that the summertime mean maximum and the mean temperatures were in the region of 20.0 °C and 14.5 °C respectively [13]. Detailed analysis of 10 years hourly summer data⁷ prior to 2010 shows that only in 2003 were there 9 hours above 30 °C with a maximum temperature of 31.9 °C (Fig. 2). Generally, there were fewer than 90 hours over 25.0 °C in each summer, except for 2003 (97 hours) and 2006 (150 hours). In 2010 there were 36 hours over 25.0 °C with mean and maximum temperatures in the region of 14.3 °C and 27.3 °C respectively. When compared with all the summers of the last decade, it appears that the 2010 summer was mild (Fig.2) and the findings should be viewed taking this into consideration.

2. Methodology

The ‘DeDeRHECC’ research team has developed a standard methodology to study the performance of the hospital environments [1]. A brief description of the methodology is presented here. Firstly, representative recurring ‘type’ buildings are identified on case study sites and information on their geometry, construction, service strategy and environmental controls is sourced from construction drawings, discussions with facilities managers, and field visits. Secondly, internal temperatures are monitored in selected representative spaces, with the exact choice of spaces for each building being made in consultation with ward staff and facilities managers. Thirdly, the downloaded data are cleaned and results are compared with the thermal comfort criteria described in Health Technical Memorandum 03-01⁸ [15], BSEN15251⁹ [16] and CIBSE¹⁰ Guide A [17]. Thresholds for these criteria are presented in Table 1. For a year, the HTM03-01 limiting value is 50 hours. The study assumes that indoor temperatures do not rise above 28°C outside the summer period (May to September). Therefore, 50 hours are assumed for the summer period. For any performance evaluation carried out for less than five months

⁶ Information is extracted from the climate maps produced by the Meteorological office for the Midlands [13].

⁷ Cottesmore Meteorological Station, Oakham, Rutland, Leicestershire.

⁸ Hours over 28° C.

⁹ Adaptive criteria.

¹⁰ Night time sleeping condition.

of the summer period, the HTM03-01 limiting value is adjusted proportionately for the corresponding period. For the monitoring period¹¹ 1st June to 30th September, the threshold values for HTM03-01, BSEN15251 and CIBSE are 40, 147 and 12 hours respectively. Finally, a sample ward space is modelled using the IES dynamic thermal model [18]. Since the focus of the research project is overheating, the model is calibrated by comparing predicted with measured internal temperatures for the monitored period while keeping HTM03-1 threshold as principal guidance (section 5).

The simulation weather files for the year 2010 (Cottesmore¹²), current¹³ (Cottesmore) and future (Leicester) were created by the ‘Prometheus’ research team at Exeter University. The future probabilistic weather files were derived using UKCP09 data [20]. A detailed account of this process has been presented elsewhere [1].

3. Case study description

At Glenfield Hospital there are 18 wards. The monitoring scope was limited to Wards 18, 19, 27, and 32, and the main waiting area (Fig. 1). This paper focuses on ward 27 because of its relatively high level of overheating (Table 2 and Appendix A) and as a case study to demonstrate the effect of subdividing (section 4) a previously open ward. The construction information and the service strategy are presented in Table 3 and 4 respectively.

At Glenfield fresh air is heated¹⁴ to 18 °C and supplied to spaces. The hot water for heating is supplied from the central plant, which has two gas combined heat and power (CHP) units and four gas boilers [23]. The mechanical ventilation rate in Ward 27 is 1.2 ach⁻¹ (135 l/s) [22]. In the bed bay areas, especially in single bed rooms, it is possible to control the perimeter radiator through ‘on/off’ valves.

4. Performance of monitored spaces: June to September 2010

There were 7 ‘Hobo’ loggers in Ward 27 (Fig. 3). The Hobos were cleaned at the time of each installation and prior to the downloading of data by a person assigned by the infection control department using alcohol-based cleaning tissues. The summary of the performance of Ward 27 during the summer of 2010 is presented in Table 2.

¹¹ Total number of hours: 2928. Total number of night time (21:00 to 6:00) hours: 1220.

¹² Cottesmore Meteorological Station, Oakham, Rutland, Leicestershire. The station is located about 20 miles north-east of Leicester. This is the nearest meteorological station that provides all the data that are necessary to create simulation weather files.

¹³ Current TRY is based on 1984 to 2004 weather data while the current DSY is 2004. Refer Levermore and Parkinson [19] for the method.

¹⁴ When the outdoor temperature is greater than or equal to 18 °C, the mechanically supplied air is not heated. Between 1st June and 30th September there were 724 hours above 18°C out this 583 hours account for daytime (06:00 to 20:00 hrs). BSEN15251 could be applied for this period.

The maximum temperature of 29.3 °C was observed on 30th June in the space 2W27-SB2 when the outdoor temperature was 24.3 °C (Fig. 4). During the study period, the maximum outdoor temperature of 26.9 °C was recorded on 27th June, however on that day 2W27-SB2 recorded 28.3 °C (Fig. 4). There thus appeared to be a lag of three days between the outdoor maximum and the subsequent internal maximum being reached in 2W27-SB2. However, 2W27-SB2 demonstrates unusual performance (discussed below), so the above finding should be viewed cautiously. Among the bedrooms, the second-maximum temperature of 28.4 °C was recorded in 2W27-MB1 on 29th June when the outdoor temperature was 23.9 °C (Fig. 5). This space shows a lag of two days. In general, all spaces in ward 27 reached the maximum between 26th and 29th June¹⁵. The maximum internal¹⁶ diurnal temperature range of 6.2 K was recorded in 2W27-MB1 on 4th July when the outdoor maximum and minimum temperatures were 21.5 °C and 12.1 °C respectively (Fig. 5). But, during the study period, the maximum outdoor diurnal temperature range of 14.7 K was recorded on the 4th June¹⁷. All the other spaces recorded maximum internal diurnal temperature ranges between 3.7 K and 5.0 K. However, different spaces recorded the maximum internal diurnal temperature ranges on different days even within the same ward. Generally, the internal maximum diurnal temperature range occurred when the outdoor daily maximum temperatures were above 20.0 °C (Figs. 4, 5 & 6). The occurrence of maximum internal diurnal temperatures on different climatic condition days and differences in maximum diurnal temperature within the same ward might be directly attributed to outdoor temperature of that day, degree and duration of window opening. This argument is further strengthened by the occurrences of minimum temperatures. The minimum indoor temperature of 18.2 °C was recorded in 2W27-SB2 on 15th July (01:00 hrs) when the outdoor temperature was 14.7 °C (Fig. 4). However, on 17th July (00:00 hrs) when outdoor temperature was identical to that on the 15th July (01:00 hrs), the indoor temperature of 2W27-SB2 was much higher, 23.2 °C.

All the bedrooms met the HTM03-01 and BSEN15251 Cat II threshold except 2W27-SB2. The single bedroom 2W27-SB2 marginally exceeded the HTM03-01 threshold (Table 2). In contrast, 2W27-SB1, 2W27-SB2 and 2W27-6MB1 exceeded the CIBSE threshold. However, only 2W27-SB1 met BSEN15251 Cat I (Fig.7).

All the bed rooms experienced night time overheating. It appears that night time overheating contributed to the exceedance of BSEN15251 Cat I in bedrooms (Fig.7). When the outdoor air temperature exceeded 18 °C, fresh air was supplied without heating (Table 3). During the monitoring period, there were 91 night time hours over

¹⁵ Most of the spaces reach their peak temperature within a few hours of the outdoor peak.

¹⁶ Internal maximum and minimum temperature on that day were 26.4 °C and 20.2 °C respectively.

¹⁷ Daily maximum and minimum outdoor temperature on that day were 25.3 °C and 14.7 °C respectively.

18 °C [14]. Further, whenever there were a few hours during the night in excess of 18 °C, the maximum day-time temperatures on that day and during the preceding days were in the region of 23 °C to 26 °C (Figs. 4, 5 & 6). As a result, the eventual supplied air to the wards could have been further a few °C higher since the supply ducts pick up heat from the fabric. Therefore, for 91 hours, the wards could have been continuously warmed to a higher temperature at night even if the perimeter heaters were turned off. During this period, if the windows were kept closed, the problem could have been aggravated further. The results indicate that windows were kept closed or partially closed for much of the warm nights [23]. The above factors could have resulted in the exceedance of CIBSE threshold.

The nurse station was the hottest area and 2W27-NS exceeded HTM03-01. The nurse station in Ward 27 functioned as a heat sink, because, after use, all the medical equipment, including the machines used for special treatment, light therapy etc are stored here for quick access. At times, in the nurse station, equipment was left connected to power and kept in standby mode to be used when the need arose. As a result, heat from the equipment slowly dissipated into the nurse station. This is not standard practice [23] but was observed on visits to this ward to download data. Further, the nurse station also houses non-medical equipment such as two computers, a photocopier and printer. The heat released from this equipment might also have contributed to the overheating of the nurse station.

The area under study in Ward 27 encompasses a typical arrangement in a part of a cruciform ('Nucleus') template (Figs. 1 & 3). In the original plan there were no single rooms in this part of Ward 27. There was a five-bed open bay instead of single bedrooms [23]. The nurse station was an open island and there were two multi-bed rooms with six beds in each. Ward 27 was refurbished in 2009 to create two single bedrooms [23]. As a result the nurse station became an enclosed space with openings towards the corridor. This new arrangement could theoretically have changed the ventilation flow pattern and enhanced the heat trapping tendency (section 7). However, in reality, refurbishment is not the cause for the high temperature in 2W27-SB2. The single bedroom 2W27-SB1 is similar to 2W27-SB2 in terms of service strategy, construction and geometry, but it had very comfortable conditions during summer 2010. It appears that 2W27-SB2 (Fig. 4) encountered additional heat gains compared to 2W27-SB1 (Fig. 6), especially between 22nd June and 2nd July. All 70 hours above 28 °C in 2W27-SB2 occurred during this period (Figs 4). The outdoor temperature during this period was between 26.9 and 10 °C with a mean of 18 °C. The outdoor temperature reflects a warm period. Therefore, overheating could have occurred if the room radiator was kept 'on' continuously during the warm period or if there was a

large amount of medical equipment present. In discussions with the Facility Manager it was suggested that the first reason was the likely cause [23]. Further, if the patient kept the windows closed, heat could also have been trapped. In this respect, the trend of 2W27-SB2 (Fig. 4) was in line with 2W27-SB1 (Fig. 6) after 2nd July. This is an indication that the results could be traced to the preferences of an individual patient. It is beyond the scope of this paper to investigate the reason that this particular patient preferred a high indoor temperature, or whether indeed the patient made a conscious choice of this kind. However this observation argues for adaptive criteria to analyse the hospital performance. But such criteria should accommodate heating and cooling conditions (section 7). Overall, the spaces operated within the limit of reasonable comfort conditions especially with respect to HTM03-01 while maintaining mean temperatures in the range of 23.7 to 25.2 °C.

5. Modelling and calibration

To predict the likely temperatures as the climate changes, a multi-zone thermal dynamic model of Ward 27 was constructed and calibrated for 135 l/s mechanical ventilation rate. In the calibration process priority was given to achieve reasonably close alignment between measured and predicted hours over 28 °C since it is the NHS benchmark [1,2]. The calibration was carried out by focusing on three spaces; 2W27-SB1, 2W27-MB1 and 2W27-NS. The single bedroom 2W27-SB2 was not considered for the calibration exercise since this space had unusual heat gains for a short period (section 4).

Sensitivity analysis was carried out to identify the critical variables necessary to tune the model. The model is sensitive to internal gains in the nurse station, especially heat gains from the equipment, the degree and duration of window openings in all the bedrooms and the degree and duration of door opening¹⁸ in single bedrooms.

At night, model assumes that in any one hour, 50% of the doors were opened for five minutes. The window opening regime (Table 4) is one of the most uncertain assumptions but is very critical, especially in making night time predictions. The model cannot accurately reflect an individual's preferences i.e. the window opening regime will not change in line with each and every occupant decision. Nonetheless, in calibration, the predicted data should have a good fit with the measured data over an array of reasonably accurate operating conditions [24]. Therefore, the model used a generalised window opening profile that reasonably reflects the overall trend in the ward (Table 4).

¹⁸ The degree and duration of door opening in single bedrooms determines the level of cross ventilation.

Experiments have shown that the largest difference between measured data and predictions occur during periods of high solar radiation intensity (solar gain) and high air flow rate [24]. On most occasions, in bedrooms, during periods of high solar radiation intensity, the predicted temperatures were high compared to those measured (Figs.8 & 9). A similar trend was observed in nurse station. However, the deviation is marginal in the nurse station due to relatively low solar gain (internal space). The deviations during high solar radiation intensity could be attributed to the weather file used for the simulation i.e. in real situation; solar radiation intensity could have been less than that in the Cottesmore simulation weather file. Furthermore, the model does not take into account the shading of the adjacent wings of the Nucleus building. Overall the deviations of the predicted temperatures during high solar radiation intensity are not significant¹⁹. The model-predicted temperatures were not very sensitive to prevailing mechanical ventilation rate but were sensitive to high natural ventilation through windows. The model shows that the deviations in the nurse station are due to changes in the internal gains. The model assumes high equipment gains throughout at nurse station but, in the real situation there could have been occasions when the equipment gain was less than or higher than what is assumed.

The predicted maximum temperatures of all the spaces were in reasonable agreement with the measured values (Table 5). In overheating studies, the reliable prediction of peak temperatures is important and any deviation should not exceed 2°C [25]. The mean night-time temperature and hours over 28° C (HTM03-01 threshold) also show a good agreement with the measured values for all the spaces (Table 5).

6. Predicted current and future performance

Predictions were made by assuming that internal gains, occupancy character, window and door opening strategy and services regimes remain unchanged for current as well for future weather periods. In reality, there could be changes, and so the predicted results do not indicate the optimal performance, but they do help to gauge relative performance of different interventions. In addition, hospital services may not be upgraded for long periods of time. The facilities managers have indicated that, since the completion of Glenfield in the 1980s, there have been no major changes to service regimes except in Ward 27 (discussed below); there have only been minor plant upgrades [23].

In late 2011, facilities managers [23] decided to enhance the mechanical ventilation rate by 0.6 ach⁻¹ (70 l/s) temporarily so that they could protect the ward 27 from construction activities related to new research complex (Fig. 1). In order to gauge the impact of this change, the mechanical ventilation rate of the calibrated model was

¹⁹ Maximum deviation is 1.8°C. Deviation within 2.0°C is acceptable [25]

changed to 205 l/s and the results predicted for summer 2010 (Appendix B). A major reduction is shown in the hours over 28 °C in 2W27-NS. This indicates that a slight increase in mechanical ventilation has the potential to reduce the impact of internal gains. However, the predicted reduction in maximum, minimum and mean night time temperatures were marginal for all the spaces as were the reductions in hours over for CIBSE and BSEN15251 Cat I and II threshold.

The thrust of the DeDerHECC research project is to test low carbon adaptive/refurbishment measures as a way to improve thermal comfort in hospital buildings [1,2,3]. Light touch measures are favoured by NHS Trusts, which are concerned about losing capacity for extended periods of time and of the impact of construction on hospital function [1,3]. Therefore paper investigates the impact of: reducing internal gains at nurse station, horizontal shading above the windows and use of user controlled fans. These interventions are incrementally incorporated in to the calibrated (135 l/s) model in three stages.

Considering the high internal heat gains at the nurse station, the **stage-1** intervention looks at the impact of lowering the internal heat gain to the range²⁰ 33 W/m² to 44 W/m² by reducing the equipment maximum sensible heat gain (total) from 600 W to 200 W. **Stage-2** introduces a horizontal shading device above the windows in addition to the stage-1 conditions. The projection of the shading device is 1m while the thickness is 100mm. **Stage-3** adds to stage-2 a slow-moving fan. The fan becomes operational when the indoor temperature goes beyond 26 °C [1]. It is assumed that the fan moves to create an air speed of 0.3m/s and decreases the operative temperature by 1.2 °C [27]. The results presented here were achieved by post processing the stage-2 data i.e. 1.2 °C was deducted whenever the temperature exceeded 26 °C in stage- 2. The HTM03-01 threshold is not applicable to this option [1]. The predicted results for typical (TRY) and extreme (DSY) summer weather conditions are presented in Table 7. Although the predicted data are processed with respect to CIBSE night time criterion and presented in the Table 7, the results will not be discussed in detail because overheating risks arise during the day, and at night window opening has a substantial effect on internal temperatures, which is difficult to model. However the results could be used to gauge the relative effectiveness of the proposed interventions in the night.

The above-mentioned staged interventions show gradual improvements in terms of the thermal comfort in each space. The improvements during typical years are substantial when compared to extreme years (Table 7). In

²⁰ In a day, the proposed internal gain fluctuates between 33 W/m² and 44 W/m². The fluctuation is largely due to changes in lighting requirement and occupancy level. For the existing internal gain level refer Table 4.

typical years, all the way to the 2050s, in terms of the HTM03-01 criterion, 2W27-SB1 becomes completely comfortable after stage-2 while 2W27-6MB1 attains marginally uncomfortable, however, 2W27-6MB1 could be made comfortable after the stage-2 intervention by improving the window controls. In contrast, 2W27-NS is above the threshold even after the stage-2 intervention, however, after the stage-2 intervention, the overheating hours are reduced by 70% when compared to the existing condition. In terms of BSEN15251 Cat I, 2W27-SB1 and 2W27-6MB1 become completely comfortable after stage-1 and stage-2 respectively. In contrast, in terms of BSEN15251 Cat II without any interventions, 2W27-SB1 and 2W27-6MB1 are comfortable all the way to the 2050s.

In extreme years, all the way to the 2050s, in terms of the HTM03-01 criterion, none of the spaces will be comfortable even after all three stages of interventions. In terms of BSEN15251 Cat I, 2W27-SB1 and 2W27-6MB1 could achieve complete comfort after the stage-3 intervention; however, it is possible to make 2W27-SB1 completely comfortable after the stage-2 intervention by improving the window controls since the deviation is very marginal. In terms of BSEN15251 Cat II, 2W27-SB1 and 2W27-6MB1 become comfortable after stage-1 and stage-2 interventions respectively; however, it is possible to make 2W27-SB1 and 2W27-6MB1 comfortable with the existing condition and stage-1 interventions respectively by improving the window controls.

7. Discussion

During the monitored period, the maximum indoor temperatures of the spaces under investigation varied between 27.7 °C and 29.3 °C while the minimum indoor temperatures varied between 18.2 °C and 22.5 °C. The maximum indoor diurnal temperature ranges between 3.7 K and 6.2K and these ranges did not occur on the same day even within the same ward. The analysis of the monitored data and the modelling work showed that the degree and duration of window opening has a major impact on the occurrence of maximum diurnal temperature range on different days within the same ward. This has implications both in terms of comfort and energy consumptions [1,2]. It is good to have a large indoor diurnal temperature range on hot days since it helps to slow down the overheating process [3]. The data shows that a maximum diurnal temperature range of 4K or more with a minimum internal temperature of 20 °C could lead to comfortable conditions. In contrast, low indoor diurnal temperature range during hot days will accelerate overheating process. The dynamic thermal models were able to capture this trend. Furthermore, during calibration the model showed that overheating in one room could impact on adjacent rooms, especially when a space has a very low level of mechanical

ventilation rate similar to that prevailing in Glenfield Hospital. It is important for the ward staff to be aware of this issue and manage the window-opening, the heat-radiating equipment and perimeter heater controls during hot days. This issue is highlighted in UK Carbon trust report on Hospitals [4].

During study period, single and multibed rooms met the HTM03-01 and BSEN15251 Cat II thresholds except 2W27-SB2. However, during this period both single and multibed rooms did not meet the CIBSE night time criterion. At the same time, these spaces did not meet BSEN15251 Cat I criterion except 2W27-SB1. However, if the monitored results are considered within an annual perspective while assuming that the overheating does not occur outside May to September period, the all bedrooms could meet BSEN15251 Cat I criterion²¹. The UK Midland climate during 2010 summer was relatively mild (Fig.2) and spaces were able to meet reasonable comfort conditions, except in the night. However, it is very clear that in hot summers like 2003 and 2006 (Fig.2) the spaces will not be comfortable without additional means of cooling. On the other hand, in hospitals, eliminating heating periods from data sets and applying BSEN15251 is very difficult due complex service strategies. Study was able to apply BSEN15251 by considering the data set from overall service strategy (Table 1). The application of adaptive criteria, especially considering the future hot summers, is more suitable for less sensitive (in terms of infection) wards and the general areas, and they account for large part (60%) of the hospital spaces [1]. Therefore, there is need to develop hospital specific adaptive criteria. It should be noted BSEN15251 Cat I limits which are suitable for wards, overlap with CIBSE adaptive band for office buildings with heating and cooling for reasonable range of running mean [16,17]. Therefore, one could argue that, in principle, CIBSE adaptive band for office buildings with heating and cooling has the potential for application in hospital environment. But this needs to be validated and it could be done by pooling large number of hospital performance data. The case studies carried out by DeDeRHECC could form a platform for such an exercise.

Wards 27 showed a nighttime overheating trend. This will have a significant negative impact on the patient sleeping ability [1]. The model calibration showed this could be avoided to a great extent if the single bedroom doors are kept open while windows in both single and multi-occupancy bedrooms are opened to enhance the cross ventilation across the ward i.e. multibedroom doors are opened all the time and if the single bedroom doors are kept open, these wards could move towards an open ward character²². Further, the model shows that if the nurse station (NS) is made an open island, there will be only 14 hours above 28°C as opposed to 53 hours

²¹ Spaces were monitored for four months out of five summer months. The missing month is May and occurrence of overheating in May is relatively few compared to other summer months.

²² Currently total window area is approximately 15% of bedrooms floor area (Table 4).

during summer 2010 (Table 6). However, the NHS is currently converting open wards into multiple single bedroom wards in order to address patient privacy and infection control. Converting open ward into multi single bed ward could results in over heating if the new partitions are not adjusted at the bottom and top to allow cross ventilation. The model shows that partition work carried out in 2009 did not take this into consideration (section 4). However results presented here should be viewed cautiously since the model has its own limitations. The model cannot accurately reflect an individual's preferences. In the model, all the windows follow the same opening profile. This could be corrected by creating window opening profiles that reflect the changes in relation to time, space or quasi-random decisions. However, such an exercise requires considerable time and resources, and most importantly information from clinical staff on occupancy. Furthermore, the model cannot capture the periodic intervention of the facility managers to decrease or increase the heating provision (set point adjustment etc) at the request of the ward staff. There were also periods when the single rooms were unoccupied and multibed rooms were under-occupied. These changes will also influence the control of radiators and window-opening, but this model cannot capture the impact of such changes. There is further uncertainty in the assumptions relating to background infiltration²³ and the air change rate between room and ceiling²⁴. These deviations are unavoidable considering the complexity of the hospital environment, the scope and nature of the service strategies, and regular changes in the patient's (occupant's) character. However, the focus of the paper is to investigate the relative differences in the performance due to the interventions and the model is capable of capturing this change.

The predictions were made assuming that ventilation rates are the same as at the commissioning²⁵ stage for current and future. However, the plant and the system are 20 years old and there could be some loss in the ventilation rate due to leakages in the ducting system and reduction in fan efficiency. In order to picture this uncertainty the space was modelled with 0.8 ach^{-1} (85 l/s) as part of the calibration work. The results of this exercise show that the maximum temperatures²⁶ of the spaces for summer 2010 were similar to that of the 135 l/s model (Table 5) for the same period. Furthermore, except for the nurse station, all the spaces met the

²³ The model assumes background infiltration as 0.35 ach^{-1} .

²⁴ The air change rate between the rooms and void above the ceiling is assumed to be 0.75 ach^{-1} .

²⁵ In 1989 the ventilation rate was 135 l/s for the area under study.

²⁶ The maximum temperature of 2W27-SB1, 2W27-SB2, 2W27-6MB1, 2W27-6MB2, 2W27-NS and 2W27-CD were 28.5°C , 28.5°C , 29.5°C , 29.2°C , 29.8°C and 28.5°C respectively.

HTM03-01 threshold²⁷. Therefore, results presented in the Table 7 should be viewed taking the above issue into consideration.

It is important to note that the mechanical ventilation is well below the current HTM03 guidance of 6 ach^{-1} , though there is some supplementary flow of air through windows (though these are restricted to 100mm opening for perceived patient safety). Predictions showed that the combined (natural and mechanical) maximum ventilation rates in 2W27-SB1, 2W27-SB2, 2W27-MB1 and 2W27-MB2 were 31.2 ach^{-1} , 31.2 ach^{-1} , 8.2 ach^{-1} and 16.2 ach^{-1} respectively. Further, the combined mean ventilation flow rates in these spaces were 3.5 ach^{-1} , 3.5 ach^{-1} , 2.4 ach^{-1} and 4.7 ach^{-1} respectively. However, by maintaining minim 1.2 ach^{-1} at any time, the space was able to achieve reasonable overall comfort condition (section 6). The HTM03-01 does not indicate a flow rate for hybrid ventilation. However it states 6 ach^{-1} is mandatory in wards for natural as well as for mechanical ventilation strategies. The results of this study indicate that the HTM03-01-prescribed 6 ach^{-1} mechanical ventilation rate may not be necessary to create comfortable conditions in Leicester. Our previous research work on Bradford also demonstrated a similar finding [3]. Generally in the Midlands, northern England and Scotland, hospitals could achieve comfortable conditions by combining natural ventilation with a low rate (say 1.5 ach^{-1}) of mechanical ventilation. In this scenario, the mechanical ventilation will primarily improve the quality of the indoor air rather than creating comfort. Such a strategy could contribute to huge reductions in CO₂ emissions. Since 2008 Glenfield Hospital has won carbon reduction award presented by Carbon Trust of UK [23]. A strategy to operate the hospital under low rate of mechanical ventilation could be a prime contributor to achieve this award in addition to use of CHP.

Some parts of the internal courtyards are being converted into additional ward/clinical spaces (Fig. 1). This development, common in many UK Nucleus-type hospitals and driven by a wish to maintain adjacencies between medical functions, is resulting in deep plan buildings and diminishing the prospects of cross ventilation and daylight. However detail investigation on this issue is beyond the scope of this paper.

The light touch measures proposed for Glenfield could be achieved without compromising bed space, patient comfort and safety. Similar light touch measures were proposed for Nightingale wards in Bradford [3]. The predictions for Ward 27 show that light-touch low carbon interventions could have a positive impact on indoor comfort conditions in hospital wards in UK Midlands, where the impact of climate change is not severe. The

²⁷ The hours over 28.0 in 2W27-SB1, 2W27-SB2, 2W27-6MB1, 2W27-6MB2, 2W27-NS and 2W27-CD were 10, 8, 35, 18, 103 and 13 respectively.

predictions also indicate that internal and solar gains play a major role in overheating the ward spaces with a low rate of mechanical ventilation. To a large extent the overheating due to internal gain could be avoided through proper management/storage of heat radiating equipment. The horizontal shading (1m projection) over the west facing windows could reduce the maximum and total summer time solar gain by 25% and 30% respectively at Glenfield²⁸ Hospital, even during extreme years. Similarly, introduction of ‘butter fly’ shading device on southern façade of Addenbrooke’s tower²⁹ reduced the maximum and total summer time solar gain by 75% and 65% respectively, even during extreme years [2]. Further reduction in overheating could be made if the restrictions on window opening were relaxed, perhaps with the provision of an appropriate ‘guard’ for patient safety [2], or if louvred panels, separate from the windows, were used for ventilation. This was demonstrated in the Bradford study [3]. On the other hand, for the current and future Midland climate, the impact of a slow-rotating fan on reducing the overheating hours in hospital wards is substantial. Furthermore, fans are a low energy and low cost approach to reducing overheating hours in hospitals [1]. In UK, some hospitals have adapted fans for summer time cooling. However there is need for further research on dust and infection control in fan operated environment.

8. Conclusion

The paper has summarised the performance of ward 27 at Glenfield Hospital during June to September 2010. As per the monitored results, the major deviation from the comfort criteria was observed in the incidence of night-time overheating. Partitioning the open wards hampers the summer time cooling in Nucleus type hospitals. Study demonstrates the need for hospital specific adaptive criteria which could accommodate heating and cooling conditions.

For the calibration period, the predicted results of the model show reasonable agreement with measured maximum and mean temperatures, and the HTM03-01 threshold. The study also demonstrates the complexity in calibrating a multi-zone hospital model, especially when there are regular variations in occupancy level, internal gains window opening etc. The results indicate that reasonable comfort conditions could be achieved with a mechanical ventilation rate as low as 1.5 ach⁻¹ when there is adequate provisions for window opening.

²⁸ For the existing condition, maximum and the total solar gain during summer 2010 were 2 and 1000 kW respectively.

²⁹ For the existing condition, maximum and the total solar gain during summer 2010 were 3.8 and 2029 kW respectively.

Three sequential interventions show that in UK Midlands the overheating could be controlled into the 2050s for both typical and extreme years through light touch low carbon interventions in Nucleus type hospitals. Proposed interventions could be carried out without compromising on bed spaces and patient's safety. Beyond 2050 these light touch measures may not work and more fundamental interventions may be required. Further research should focus on the impact of encroachment of courtyards in the Nucleus type hospitals.

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Figures

Fig.1: Aerialview of Glenfield Hospital (source: Google earth image modified [8]). The light shade (yellow) areas indicate the locations of the case study wards and the waiting area. The black patch is the proposed new research centre.

Fig.2: Frequency of occurrence of outdoor temperature between 2000 and 2010, Cottesmore, Rutland, Leicestershire, UK [14].

Fig. 3: Logger locations in ward 27 on the first floor. The multibed (MB) room 1 and 2 have 6 beds, room 5 and 6 are single bed.

Fig. 4: Internal temperature in W27-SB2, external temperature, its running mean and solar radiation intensity.

Fig. 5: Internal temperature in W27-MB1, external temperature, its running mean and solar radiation intensity.

Fig. 6: Internal temperature in W27-SB1, external temperature, its running mean and solar radiation intensity.

Fig. 7: Internal temperatures of 2W27-SB1 compared to BSEN15251 category limits.

Fig. 8: Measured and predicted temperature in 2W27-SB1, external temperature, and solar radiation intensity for calibration period.

Fig. 9: Measured and predicted temperature in 2W27-MB1, external temperature, and solar radiation intensity for calibration period.

Tables

Table 1: Criteria for assessing internal temperatures in naturally ventilated spaces [2].

Assessment metric	Source	Criterion	Applicability	Comment
Total hours, dry-bulb temperature over 28°C.	HTM03-01 [15]	Limiting value 50 hours.	All spaces and buildings.	Weather year to be used in simulations not stated.
Night time hours operative temperature over 26°C.	CIBSE Guide A [17]	No more than 1% of hours above value.	Sleeping spaces only.	Value based on homes and not health care facilities.
Adaptive comfort Cat. I and Cat II envelopes. Thresholds of operative temperature vary with running mean of ambient temperature.	BSEN15251 [18]	No more than 5% of hours outside envelope, in any day, week, month or year.	Naturally ventilated buildings with operable windows and mechanically ventilated building without conditioning the air.	Cat I is applicable to spaces with vulnerable individuals, such as wards, Cat II for 'normally' occupied spaces, such as offices, consulting rooms, etc.

1. The limiting value for a year is 50, 37 (night time) and 438 hours for HTM03-01, CIBSE and BSEN15251 respectively.
2. Between June and September 2010, the outdoor temperatures were 724 and 356 hours above 18°C and 20 °C respectively [14]. During this period fresh air was supplied to the rooms without heating and the perimeter heaters were off (Table 3). General policy is to keep the perimeter heaters off from May to September [23]. However there could have been few occasional hours during the above said period where the room heaters could have been kept on based on individual preference. The results should be viewed keeping this limitation.

Table 2: Comparison of internal temperatures measured between 1st June and 30th September, 2010, with BSEN15251, CIBSE and HTM03 overheating criteria: Glenfield Hospital.

Space	Space reference	Maximum temp °C (24 hours)	Minimum temp °C (24 hours)	Mean daytime temp °C (7:00 to 20:00)	Mean night time temp °C (21:00 to 6:00)	Maximum diurnal range (K)	Hours over 25 °C (24 hours)	HTM03: Hours over 28 °C (24 hours)	Hours over 24 °C (21:00 to 6:00)	CIBSE: Hours over 26 °C (21:00 to 6:00)	BSEN15251: Hours over Cat I / Cat II upper
Ward 27, level 2											
Corridor (CD)	2W27-CD	27.7	21.5	24.5	24.3	3.9	770	0	769	NA	NA
Multi bedroom 1 (MB1), 6beds	2W27-6MB1	28.4	20.5	24.7	24.6	6.2	1050	7	859	110	255/ 60
Single bedroom 1 (SB1)	2W27-SB1	27.3	19.6	24.1	23.9	3.7	406	0	384	35	59/ 02
Single bedroom 2 (SB2)	2W27-SB2	29.3	18.2	23.9	23.7	5.0	455	70	348	112	206/ 102
Nurse station (NS)	2W27-NS	29.0	22.5	25.2	25.0	4.2	1419	57	936	NA	NA

1. Total number of hours: 2928. Total number of night time (21:00 to 6:00) hours: 1220
2. For the space 2W27-SB1, the monitored data is available for 2247 hours which includes 937 night time hours. Error in data after 2nd September 14:00 hrs.
3. The space 2W27-6MB2 not monitored.
4. The limiting overheating values for the monitored period are: HTM03, 40 hours over 28 °C; BSEN15251, 147 hours above category upper threshold and CIBSE, 12 night time hours over 26°C.
5. For the space 2W27-SB1, the limiting overheating values are: HTM03, 31 hours over 28 °C; BSEN15251, 113 hours above category upper threshold and CIBSE, 10 night time hours over 26°C.
6. CIBSE night time condition is not applicable to nurse station corridors and waiting area since there is no provision for sleeping in these spaces.
7. Bold and italic values with grey shade: criterion limit exceeded

Table 3: General construction information of Glenfield Hospital.

Description	Material	Thickness (mm)	Thermal transmittance ($Wm^{-2}K^{-1}$)	Opening size (mm)	General information
Wall	Brick/cement block	300	0.4	-	Total floor area of Ward 27 is 1200m ² . The area under investigation is 216m ² . The floor to floor height and floor to ceiling height are 3.9 m and 2.7 m respectively. The window opening is restricted to 100mm for patient safety [21].
Roof	In-situ RCC on steel frame	300	0.26	-	
Floor	In-situ RCC on steel frame	250	0.16	-	
Window	Double glazed aluminium	-	1.9	1600mm×1800mm, 1600mm×900mm or 800mm×900mm	

Table 4: Model characteristics.

Description	2W27-SB1	2W27-SB2	2W27-MB1	2W27-MB2	2W27-NS	2W27-CD
External wall area (m ²)	13.2	13.2	18.2	37.4	NA	NA
Floor area (m ²)	14.6	14.6	49.0	49.0	18.2	45.6
Volume (m ³)	39.5	39.5	132.3	132.3	49.1	115.0
Window area (m ²)	2.2	2.2	5.8	8.6	NA	NA
Internal heat gain (W/m ²)	5.4 to 15.1	5.4 to 15.1	8.6 to 19.6	8.6 to 19.6	54 to 65	0.7 to 4.4
Perimeter heating	Yes	Yes	Yes	Yes	NO	NO
Window opening strategy	The occupants were assumed to open the windows. The maximum opening is 100mm. The opening area assumed to be 0% if the $T_{out} \leq 10^{\circ}C$, and 50% if $T_{out} > 10^{\circ}C$ and $T_{in} \leq 18^{\circ}C$, then ramps up to 100% at $T_{in} \geq 20^{\circ}C$				NA	NA
Perimeter heating regime	Set point temperature is 23°C. Set point is 100% at $T_{out} \leq -3^{\circ}C$ and it ramps down to 80% at $T_{out} = 16^{\circ}C$. It is off at $T_{out} = 20^{\circ}C$.				NA	NA
Ventilation heating regime	Continuous supply of fresh air at the rate of 135 l/s for the area under study. There is only one supply grille and it is located on the nurse station ceiling. Supply air is heated to 18°C. Set-point ramped down from 100% at $T_{out} \leq 16^{\circ}C$ to zero at $T_{out} \geq 18^{\circ}C$.					
Extract regime	There are four toilets in this area. Each toilet has the facility to extract 25 l/s continuously. The balance supplied air (35 l/s) escapes through windows.					
Occupancy	Maximum staff members at nurse station were 6. In addition, between 7:00 and 9:00, and 18:00 and 20:00 at every hour there were two staff members at each of the multi bedroom and one staff member at each of the single bedrooms for five minutes. The rest of the time at every hour there was one staff member at each of the single and multi-bedrooms.					

Table 5: Comparison of measured and predicted results of ward 27 for the calibration period.

Space reference		Max. temp (°C)	Min. temp (°C)	Mean night time temp (°C)	HTM03: Total hours over 28°C	CIBSE: Night time hours over 26°C	BSEN15251: Total hours above Cat I upper limit	BSEN15251: Total hours above Cat II upper limit
2W27-SB1	Measured	27.3	19.6	23.9	0	35	59	2
	Predicted	28.3	22.7	23.5	4	24	61	3
2W27-6MB1	Measured	28.4	20.5	24.6	6	98	305	71
	Predicted	28.9	23.0	23.8	16	51	163	52
2W27-NS	Measured	29.0	22.5	25.0	57	NA	NA	NA
	Predicted	29.4	24.3	25.1	49	NA	NA	NA

Notes (Table 5):

1. Calibration period for MB1 and NS is 1st June to 30th September 2010.
2. Calibration period for SB1 is 1st June to 2nd September 2010.

Table 6: Summary of predicted performance of Ward 27 during the summer of 2010.

Space reference	Max. temp (°C)	Min. temp (°C)	Mean night time temp (°C)	HTM03: Total hours over 28°C	CIBSE: Night time hours over 26°C	BSEN15251: Total hours above Cat I upper limit	BSEN15251: Total hours above Cat II upper limit	Max. natural vent. rate (ach ⁻¹)	Mean natural vent. rate (ach ⁻¹)
2W27-SB1	28.1	22.9	23.5	4	25	148	20	30	2.3
2W27-SB2	28.1	22.9	23.4	4	22	140	17	30	2.3
2W27-6MB1	29.1	22.9	23.8	18	55	289	94	7	1.2
2W27-6MB2	29.0	22.8	23.5	11	32	265	89	15	3.5
2W27-NS	29.4	24.7	25.4	53	NA	NA	NA	-	-
2W27-CD	28.1	23.1	23.8	3	NA	NA	NA	-	-

Notes (Table 6):

1. The HTM03 threshold is based on dry bulb temperature and rest are based on dry resultant temperature.
2. CIBSE night time condition is not applicable to nurse station and corridors since there is no provision for sleeping.
3. BSEN15251 conditions are applicable only to spaces with operable windows.
4. It is assumed that during the period of October to April the spaces will not overheat due to elevated ambient temperature and solar gains. Therefore the limiting overheating values are: HTM03, 50 hours over 28 °C; BSEN15251, 438 hours above category upper threshold and CIBSE, 37 night time hours over 26°C.

Table 7: Summary of predicted performance of ward 27 for current and future, test reference (TRY) and design summer (DSY) years.

Scenario	Space reference	Year	Max. temp (°C)		Min. temp (°C)		Mean night time temp (°C)		HTM03: Total hours over 28°C		CIBSE: Night time hours over 26°C		BSEN15251: Total hours above Cat I upper limit		BSEN15251: Total hours above Cat II upper limit	
			TRY	DSY	TRY	DSY	TRY	DSY	TRY	DSY	TRY	DSY	TRY	DSY	TRY	DSY
Existing	2W27-SB1	05	27.5	28.4	22.8	22.7	23.4	23.5	0	7	10	30	154	108	4	6
		30s	28.9	31.6	22.6	22.8	23.9	25.3	26	559	72	557	257	870	56	334
		50s	30.8	33.2	22.7	22.6	24.5	26.0	168	935	225	745	556	1224	129	631
	2W27-6MB1	05	29.2	30.5	22.9	22.9	23.9	23.9	19	40	53	81	387	255	119	65
		30s	30.5	32.5	22.9	23.0	24.4	25.9	80	775	167	707	469	1129	169	602
		50s	32.1	34.2	22.9	22.9	25.2	26.7	348	1147	424	893	897	1514	421	879
	2W27-NS	05	29.3	30.5	24.8	24.7	25.5	25.5	49	78	NA	NA	NA	NA	NA	NA
		30s	30.6	33.2	24.8	24.8	26.0	27.4	180	1254	NA	NA	NA	NA	NA	NA
		50s	32.5	34.8	24.8	24.7	26.7	28.2	595	1662	NA	NA	NA	NA	NA	NA
Stage 1: low internal gain plus existing	2W27-SB1	05	27.1	28.1	22.6	22.6	23.3	23.4	0	3	4	17	73	36	2	0
		30s	28.6	31.1	22.5	22.7	23.7	24.9	11	393	31	433	110	562	25	175
		50s	30.1	32.6	22.5	22.5	24.2	25.6	97	740	158	610	280	868	69	365
	2W27-6MB1	05	28.7	30.0	22.9	22.9	23.6	23.6	6	18	24	46	252	153	57	42
		30s	29.9	32.1	22.9	22.9	24.0	25.4	43	557	78	571	303	804	101	404
		50s	31.4	33.7	22.9	22.9	24.7	26.1	215	908	266	777	623	1125	243	598
	2W27-NS	05	28.2	29.4	23.9	23.9	24.6	24.6	6	26	NA	NA	NA	NA	NA	NA
		30s	29.4	31.9	23.9	23.9	25.0	26.3	52	748	NA	NA	NA	NA	NA	NA
		50s	31.1	33.6	23.9	23.9	25.6	27.0	292	1140	NA	NA	NA	NA	NA	NA
Stage 2: Horizontal shading plus option 1	2W27-SB1	05	26.3	27.8	22.3	22.4	23.2	23.2	0	1	0	9	16	10	0	0
		30s	28.2	30.4	22.4	22.5	23.4	24.5	4	232	12	303	33	226	4	62
		50s	28.9	31.9	22.3	22.3	23.9	25.2	38	503	102	477	88	452	19	130
	2W27-6MB1	05	27.8	29.1	22.9	22.9	23.4	23.5	0	6	4	20	89	59	6	11
		30s	28.8	31.3	22.9	22.9	23.8	25.0	9	357	33	461	130	483	29	187
		50s	30.1	33.1	22.9	22.9	24.3	25.7	98	671	176	612	285	741	70	312
	2W27-NS	05	27.5	28.8	23.9	23.9	24.4	24.4	0	10	NA	NA	NA	NA	NA	NA
		30s	28.8	31.4	23.9	23.9	24.7	25.9	16	526	NA	NA	NA	NA	NA	NA
		50s	30.1	33.0	23.9	23.9	25.2	26.6	163	907	NA	NA	NA	NA	NA	NA
Stage 3: Fan: active above 26°C plus option 2	2W27-SB1	05	26.0	26.6	22.3	22.4	23.2	23.2	NA	NA	0	0	14	1	0	0
		30s	27.0	29.2	22.4	22.5	23.4	24.3	NA	NA	1	123	15	48	0	5
		50s	27.7	30.7	22.3	22.3	27.4	24.8	NA	NA	22	290	17	104	0	26
	2W27-6MB1	05	26.6	27.9	22.9	22.9	23.4	23.5	NA	NA	0	6	58	26	4	1
		30s	27.6	30.1	22.9	22.9	23.7	24.6	NA	NA	4	204	56	152	4	28
		50s	28.9	31.9	22.9	22.9	24.2	25.2	NA	NA	67	380	85	257	10	88
	2W27-NS	05	26.3	27.6	23.9	23.9	24.4	24.4	NA	NA	NA	NA	NA	NA	NA	NA
		30s	27.6	30.2	23.9	23.9	24.6	25.4	NA	NA	NA	NA	NA	NA	NA	NA
		50s	28.9	31.8	23.9	23.9	25.0	25.9	NA	NA	NA	NA	NA	NA	NA	NA

- 05, 30s and 50s represent 2005 (current) and 2030s and 2050s respectively.
- The HTM03 threshold is based on dry bulb temperature and rest are based on dry resultant temperature.
- CIBSE night time condition is not applicable to nurse station and corridors since there is no provision for sleeping in these spaces.
- BSEN15251 conditions are applicable only to spaces with operable windows.

5. HTM03 standard not applicable for fans.
6. Night time hours are 21:00 to 6:00.
7. Simulated hours (3672) are for May to September.
8. It is assumed that during the period of October to April the spaces will not overheat due to elevated ambient temperature and solar gains. Therefore the limiting overheating values are: HTM03, 50 hours over 28 °C; BSEN15251, 438 hours above category upper threshold and CIBSE, 37 night time hours over 26°C.
9. Un-shaded values indicate that they are within the threshold limit, dark grey shade indicate that the exceedance is substantial, and light grey shade indicates exceedance is minor.

Appendix A: Comparison of internal temperatures measured between 1st June and 30th September, 2010, with BSEN15251, CIBSE and HTM03 overheating criteria: In Ward 18, 19 and 32, and main waiting area at Glenfield Hospital.

Space	Space reference	Maximum temp °C (24 hours)	Minimum temp °C (24 hours)	Mean daytime temp °C (7:00 to 20:00)	Mean night time temp °C (21:00 to 6:00)	Maximum diurnal range (K)	Hours over 25 °C (24 hours)	HTM03: Hours over 28 °C (24 hours)	Hours over 24 °C (21:00 to 6:00)	CIBSE: Hours over 26 °C (21:00 to 6:00)	BSEN15251: Hours over Cat I / Cat II upper
Main Waiting area (WA)	1WA	26.9	20.2	23.9	24.1	3.6	442	0	678	NA	13/0
Ward 18, level 1											
Open ward (OW), 22 beds	1W18-22OW	26.6	20.0	23.8	23.3	4.3	182	0	243	0	45/1
Nurse station(NS)	1W18-NS	28.9	21.4	25.4	24.7	4.3	1617	2	1017	NA	462 / 103
Ward 19, level 1											
Open ward (OW), 24 beds	1W19-24OW	26.8	20.3	23.8	23.5	4.3	284	0	330	2	106/2
Nurse station (NS)	1W19-NS	27.8	22.1	24.2	24.0	3.8	290	0	625	NA	86/0
Ward 32, level 2											
Corridor (CD)	2W32-CD	28.0	21.9	24.5	24.2	3.8	718	2	712	NA	NA
Multi bedroom 1 (MB1), 4 beds	2W32-4MB1	28.3	22.2	25.1	24.8	3.2	1326	6	950	158	244 / 33
Multi bedroom 2 (MB2), 4 beds	2W32-4MB2	28.0	21.5	24.8	24.6	3.8	997	0	906	94	166 / 8
Multi bedroom 3 (MB3), 4beds	2W32-4MB3	28.6	20.5	25.2	25.0	4.8	1547	14	1049	187	397 / 58
Single bedroom 1 (SB1)	2W32-SB1	28.3	21.0	24.5	24.4	2.8	838	4	712	177	253 / 39
Single bedroom 2 (SB2)	2W32-SB2	28.6	20.5	24.7	24.7	3.2	1017	26	885	193	280 / 60
Nurse station (NS)	2W32-NS	28.0	21.9	24.8	24.5	3.9	1062	1	889	NA	NA

Notes (Appendix A):

1. Total number of hours: 2928. Total number of night time (21:00 to 6:00) hours: 1220
2. The limiting overheating values for the monitored period are: HTM03, 40 hours over 28 °C; BSEN15251, 147 hours above category upper threshold and CIBSE, 12 night time hours over 26°C.
3. CIBSE night time condition is not applicable to nurse station corridors and waiting area since there is no provision for sleeping in these spaces.
4. BSEN15251 conditions are applicable only to spaces with operable windows. Nurse station in open wards (OW) benefit from operable windows since they are open islands in the wards.
5. Bold and italic values with grey shade: criterion limit exceeded.

Appendix B: Summary of predicted performance of Ward 27 during the summer of 2010 with enhanced air supply (205 l/s).

Space	Max. temp (°C)	Min. temp (°C)	Mean night time temp (°C)	HTM03: Total hours over 28°C	CIBSE: Night time hours over 26°C	BSEN15251: Total hours above Cat I upper limit	BSEN15251: Total hours above Cat II upper limit
2W27-SB1	27.8	22.9	23.4	0	18	105	12
2W27-SB2	27.7	22.9	23.4	0	14	98	10
2W27-6MB1	28.8	22.9	23.5	10	29	206	59
2W27-6MB2	28.7	22.8	23.4	5	19	199	61
2W27-NS	29.0	24.4	25.0	19	NA	NA	NA
2W27-CD	27.8	22.8	23.3	0	NA	NA	NA

Notes (Appendix B):

1. The HTM03 threshold is based on dry bulb temperature and rest are based on dry resultant temperature.
2. CIBSE night time condition is not applicable to nurse station and corridors since there is no provision for sleeping
3. BSEN15251 conditions are applicable only to spaces with operable windows.