# Hospitals wards in low energy buildings: Paying heed to patient thermal comfort





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Healthcare facilities need to become more energy efficient in order to reach upcoming nearly zero energy requirements (nZEB). However, for hospitals, comfort and wellbeing of the patients is paramount.

**Keywords:** nZEB Hospitals, Indoor Climate, Measurements, Questionnaires, Building Simulations

In this research, these two perspectives are included in examining the lowering of building energy use. In situ measurements are compared with thermal comfort feedback from 169 individual patients, who participated voluntarily, in two hospitals during summer and autumn. Energy demand is determined with dynamic building performance simulations and energy performance calculations. Independent of hospital or season, for most patients (76%, N=156), indoor temperatures between 21°C and 23°C were experienced as comfortable. Warmer indoor temperatures must be possible for patients who may need it due to personal preference or health conditions. Operable windows are desired by half of the patients and could contribute to reducing overheating hours and cooling demand when opened at prescribed outdoor conditions. The findings show that design solutions for transforming hospital wards from multi-patient to single patient rooms, while simultaneously improving the measured and perceived indoor climate and reducing energy consumption to contribute towards realisation of nZEB Hospitals, are possible and available.

## Introduction

An important aspect for hospitals is gaining a competitive advantage in providing a more comfortable recuperating environment to patients (Glind, Roode, & Goossensen, 2007). Simultaneously, awareness of the physical environment's contribution to the healing process and wellbeing of patients is increasing (Huisman, Morales, Hoof, & Kort, 2012). Single bedded rooms could contribute to this, because they improve privacy, improve sleep quality and reduce noise and may reduce cross-infections and length of stay (Glind, Roode, & Goossensen, 2007). The way hospitals are used is thus expected to rapidly change in the upcoming years, including a transition from multi-bed to single-bed patient rooms.

To reduce environmental impact, energy performance requirements for hospital buildings are also being tightened. From 2021, new buildings must fulfil nearly zero energy building (nZEB) standards in the Netherlands. By 2050, existing building stock must also fulfil these requirements (Blok, 2015). nZEB requirements for healthcare facilities is given in **Table 1**.

Energy efficiency aside, the indoor environment is the key to successful building design. Thermal comfort is defined by ASHRAE as that condition of mind which expresses satisfaction with the thermal environment (ASHRAE 55, 2013). It helps to stabilize the emotional

**Table 1.** nZEB demand healthcare facilities in the Netherlands (Blok, 2015).

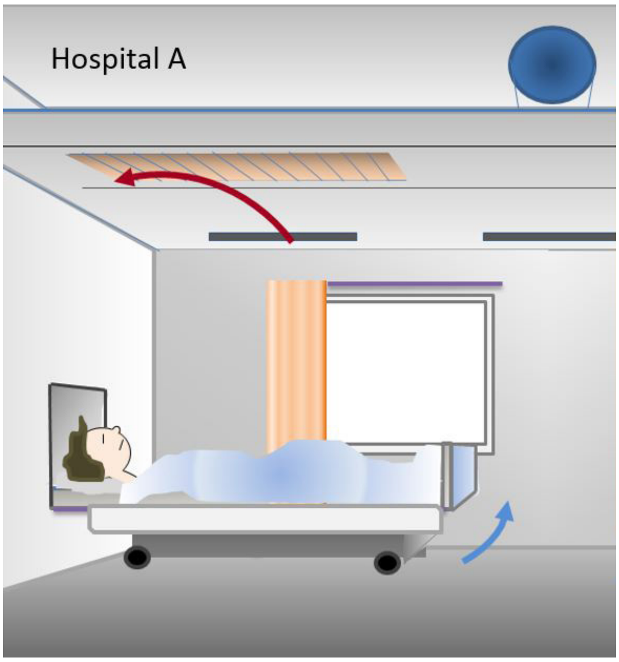
| nZEB demand | |
|---|---|
| Energy demand [kWh/m²] | 65 |
| Primary energy consumption [kWh/m²] | 120 |
| Share renewable energy sources [%] | 50 |

moods of patients and assists with their healing process (Khodakarami, & Nasrollahi, 2012). Thermal comfort models exist, (e.g. PMV and ACL) however some researchers show discrepancy for patients in hospitals. Therefore, the main objective of this research was to advice on the form of a new system for the wards of hospital A, based on comfort needs of medium-stay patients, while giving due consideration to energy demand.

## Method

Physical and empirical data are collected in the nursing wards of two hospitals, see **Figure 2**, that have different climatizing systems. **Figure 1** gives an impression of the two wards. In hospital A the orthopedics-, traumatology- and vascular surgery wards are investigated. They are mainly multi-bedded wards. The air is conditioned with an all-air system. In hospital B the orthopedics ward is investigated; it has only single patient rooms. The building, except the floor heating, is heated and cooled with concrete core activation (CCA), providing a stable indoor climate. Patient rooms have operable windows.

Measurements were conducted during a period of three weeks in summer and autumn, each. Three indoor condition measurement systems (ICMS) are used to measure indoor thermal conditions at 1.1 m height, which is approximately the location of body's center of mass for standing people and people lying in bed. The ICMSs are placed within 1 m around a patient



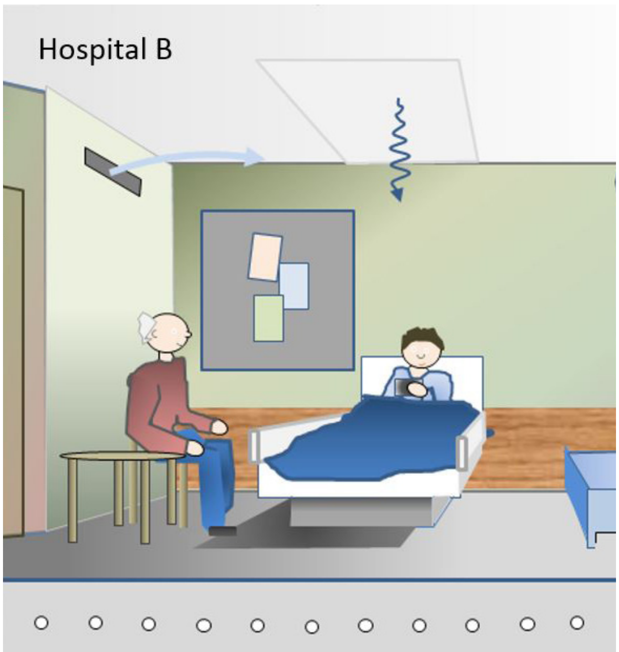




**Figure 1.** Hospital A: all air system; Hospital B: concrete core activation, conditioned air and openable windows.

**Figure 2.** Impression of Hospital A (left: University Medical Center, Utrecht, the Netherlands) and Hospital B (right: Meander Medical Centre, Amersfoort, the Netherlands).

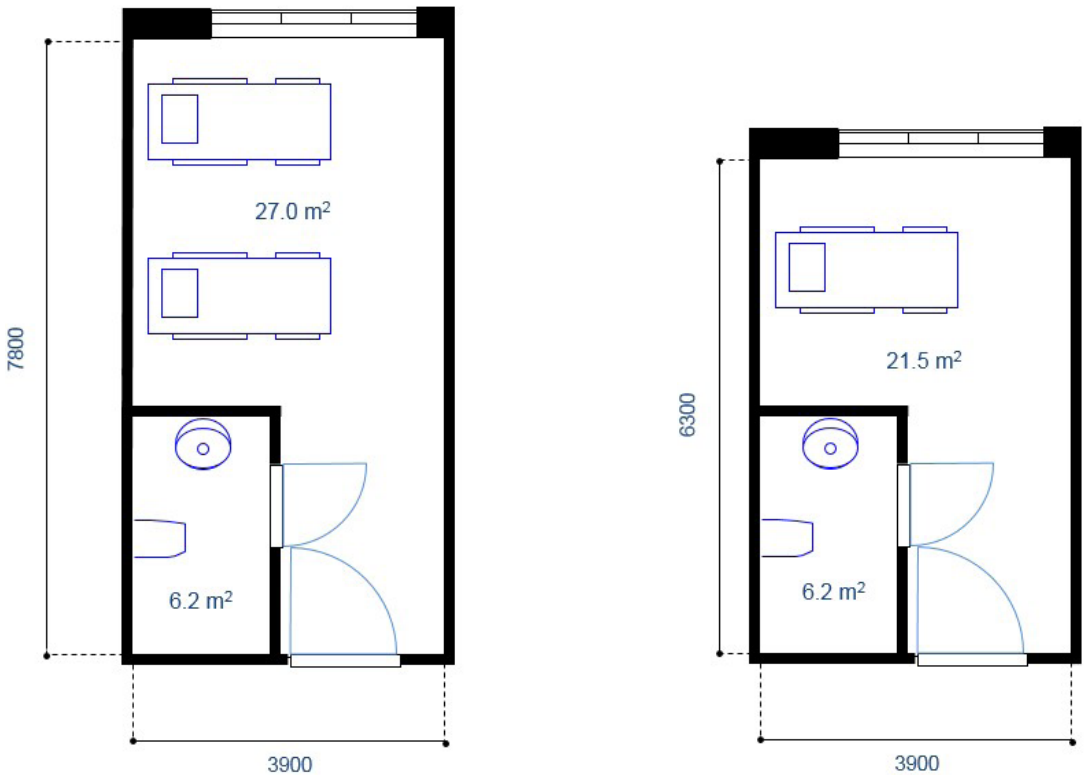



**Figure 3.** Floorplan of a two-bedded room and single bedded room used for the simulations.

locations. Additional temperature and RH sensors are placed in rooms in the building with different orientations.

During the survey, patients were asked to fill in a questionnaire to investigate their thermal comfort sensation using the 7-point ASHRAE scale, overall thermal comfort, and their experience of controllability in the room. Patients were interviewed when they were not able to fill in a questionnaire.

## Dynamic Building Simulations

With the dynamic building simulation program IES VE, heating and cooling demand of patient room and number of overheating hours were estimated. The simulations used room dimensions and building properties of hospital A. The ASHRAE IWEC Weather File for Amsterdam was used, it being the closest location to both hospitals. Simulations started with a two-bedded room and were later modified to a single bedded room in a renovated building – floor plan in **Figure 3**.

Building properties for the different cases are given in **Table 2**.

Situations for windows facing north and south were both simulated. In the base case scenario, heating and cooling set points are based on ASHRAE recommendations (ASHRAE, 2003). Adapted temperature ranges are based on this research outcome. Besides 8 W/m² lighting energy (35 kWh/m² per year) must be taken into account. From the energy point of view the temperature may be lowered during the night, which is simulated with a temperature set-back to 18°C between 9:00 p.m. – 6:00 a.m.

## Energy Performance

Energy performance calculation (EPC) using ENORM (software implementation of NEN-7120:2012), provides an indication for the energy demand, primary energy consumption and share of renewable energy sources. With the EPC, it is aimed to investigate if the ward satisfies current building regulations and upcoming tightened requirements. The current hospital wards of hospital A are modelled with a total gross floor area of 32,000 m². Different building functions are divided, i.e. healthcare with bed area (42%), offices (13%), healthcare without bed area (42%).

The indoor conditioning system of hospital A and hospital B are compared in "REF system A" and "REF system B". The scenario with best energy performance is optimized in "VAR I" with thermal insulation, lower infiltration, external sun shading, and $CO_2$ controlled ventilation. In "VAR II", windows can be opened for ventilation. In "VAR III", PV-panels are added as well, covering half of the roof. The PV generated energy in "VAR III" is partly used for the building system and partly used by non-building related equipment (which is not rated in the EPC). The remaining part of generated energy is exported back to the grid. The non-renewable generated energy by a gas fired CHP for "REF system A" is completely exported.

## Results

The physical and empirical data showed that the indoor air temperature is significantly warmer for hospital A in both seasons ($p<0.001$) when compared to hospital B, as may be seen in **Figure 4**. During Summer, difference in median temperature was 1.1°C and during Autumn 0.8°C. Most of the patients (54%, N = 169) were sleeping or reclining in bed just before being asked to complete the survey questionnaire. Some patients (36%) had been sitting on a chair, and a small number (10%) had been walking about the room or corridor. In hospital A, 60% of the patients indicate that they found all general aspects of their room comfortable against 94% of the patients in hospital B.

## Thermal comfort

A Mann-Whitney U Test of the comfort votes shows that patients in hospital B found the indoor temperature more comfortable during summer ($p<0.001$) and autumn ($p=0.015$) than patients in hospital A. In summer, thermal sensation is significantly differently experienced in the two hospitals ($p=0.046$) and is in hospital B, on average, closer to neutral. During autumn, thermal sensation votes ($p=.594$) are not significantly different. In both hospitals and both seasons, more than 10% of the patients find the indoor temperature uncomfortable and warm at 23±0.5°C. More influence on temperature and air quality is expe-

**Table 2.** Building properties as applied for the building simulation cases.

| | Current situation | Renovated building | |
|---|---|---|---|
| Overall heat resistance external walls | 2.3 | 5.0 | m²K/W |
| U-value windows (area 4.3 m²)t | 2.6 | 1.1 | W/m²K |
| Sun shading when incident radiation > 500 W | Not present | Present | |
| | | | |
| | Two-bedded room | Single bedded room | |
| Internal gain patient | 80 | 160 | W |
| Internal gain visitor (3 – 8 p.m.) | 200 | | W |
| Internal gains equipment | 15 | | W/m² |
| Airflow rate | 200 | 80 | m3/h |
| Infiltration | 0.4 | | ACHH |
| Floor to floor height | 3.8 | | M |

rienced by patients lying in a single patient room with the ability to open a window ($p<0.01$). 38% of the patients in hospital A (N=112) experience no influence and find it necessary to have influence. More patients find it necessary to have influence on controlling temperature and ventilation during summer. During summer, 40.6% (N=32) of the patients in hospital A and 66.7% (N=44) of the patients in hospital B want the possibility to open a window. During autumn this was 53.5% (N=45) in hospital A and 50% in hospital B (N=46). In this group, 7 patients have cold sensations and 8 patients have warm sensations. In hospital B, this percentage is only 8% (N=90). In this group 1 patient has cold sensations and 4 have warm sensations. The fraction of patients who find it necessary to control indoor temperature increases with the length of stay of the patient ($p=0.03$).

## Building simulations

The heating and cooling demand of the building is determined by the heat losses and heat gains of the building. In **Figure 5** results from different scenarios are summarized for allowed temperature ranges of 21–23°C during the day and 18–23°C during the night, when temperature set back is introduced, compared with the base case scenario with allowed temperatures of 24±1°C. nZEB requirements for energy demand can be reached when the building is renovated.

The additional natural ventilation of 1 and 2 ACH when the outside temperature is between 18°C and 24°C increases the heating demand with 0.3–0.8%. Cooling demand will be reduced with 6.9–56.8%, corresponding with an energy reduction up to 4 kWh/m² on cooling demand (net reduction indication: 3.85 kWh/m²).

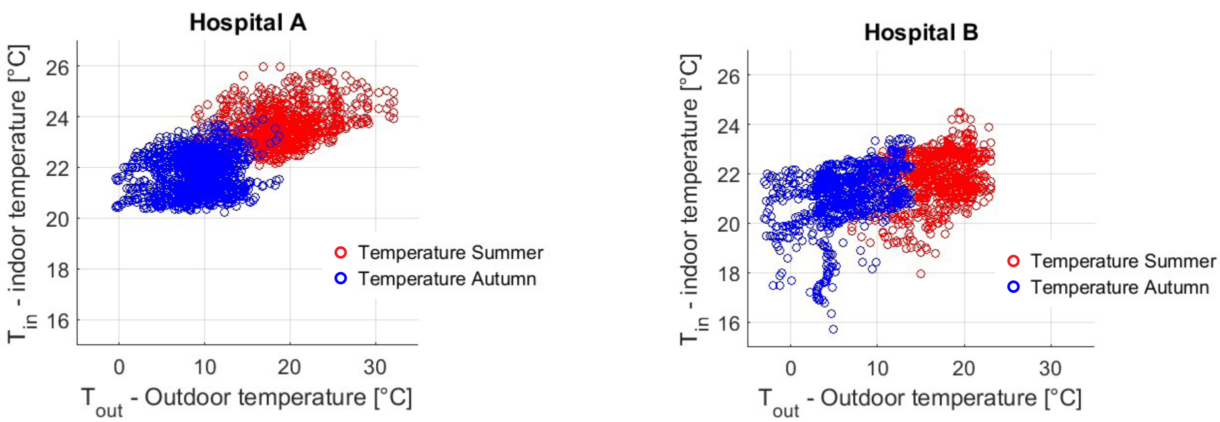



**Figure 4.** Comparison between indoor and outdoor temperature for hospital A (a) and hospital B (b) based on mean hourly data of all measured rooms.

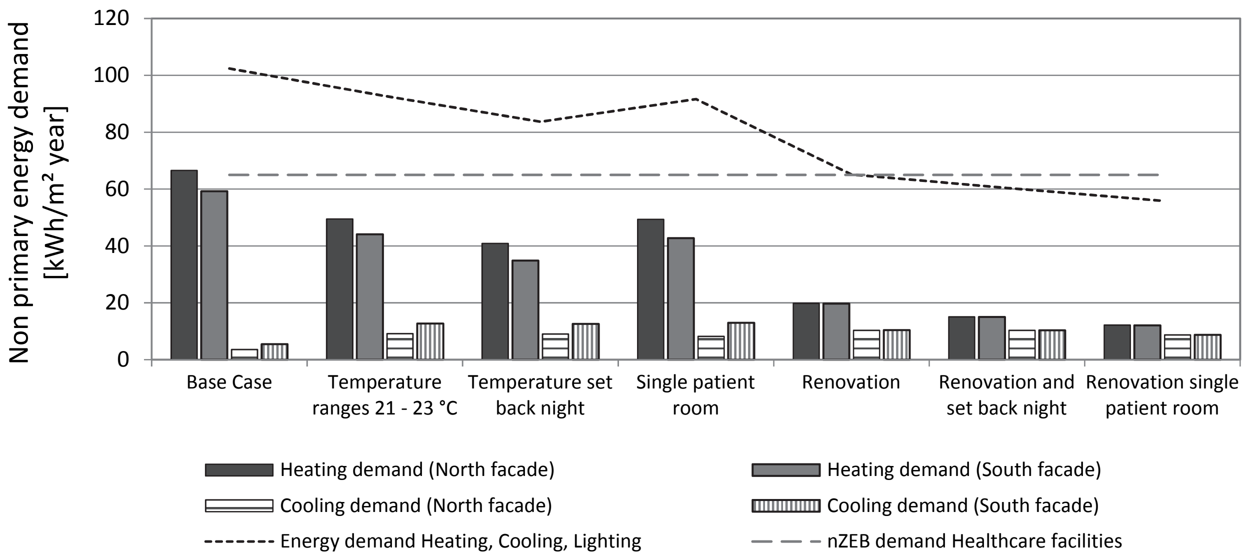



**Figure 5.** Heating and cooling demand per square meter for different scenarios with heating and cooling set-point of 23–25°C for the base case and 21–23°C for the other scenarios. For the scenarios with temperature set back, heating set point is 18°C during the night (9:00 p.m. – 6:00 a.m.).

## Energy performance calculation

The heating and cooling demand is supplied by the indoor conditioning systems. The primary energy consumption is dependent on system capacity, efficiency, storage type, and fuel type. Primary energy consumption and EPC rating for different scenarios is given in **Figure 6**. The reference building with system B consumes 18% less energy than the reference building with system A. nZEB requirements for maximum energy demand and primary energy consumption are reached when the building is renovated and half of the roof is covered with PV. For this case also, EPC requirements are reached.

## Discussion

The outcome from the surveys showed that there is more need of cooling possibilities in the hospitals since over 10% of the patients have warm sensation at indoor temperatures above 23°C. Larger volume of convective cooling increases the energy consumption and can cause draft. With radiant cooling systems (ceiling and floor cooling) air flow can be reduced and can contribute in reducing energy consumption of the systems (Causone, Baldin, Olesen, & Corgnati, 2010). In hospital B, CCA is used as radiant heating and cooling system, however, with slow response. Previous studies support the idea that non-uniform environments are experienced as equal to or even more comfortable than uniform indoor environments (Schellen, Loomans, de Wit, & Olesen, 2013). However, there is presumptive evidence that people lying in bed are more sensitive to radiant sensation (Nagano & Mochida, 2004). Radiant cooling ceilings have a fast response time of three to five minutes, although attention must be paid to condensation on cold surfaces (Mumma, 2001). To address condensation issues, chilled ceiling with desiccant cooling could save up to 44% of primary energy compared with an all air system (Niu, Zhang, & Zuo, 2002).

Besides radiant cooling technologies, elevated air speed could improve thermal comfort (ASHRAE 55, 2013). Draft from increased convective cooling could therefore be experienced as comfortable at warmer indoor conditions. According to Schiavon et al., energy can be saved by allowing higher indoor temperatures while using a small desk fan or personal ventilation system with, for most cases, fan input power lower than 15 W (Schiavon & Melikov, 2008).

Allowing broader temperature ranges, irrespective of the fact whether this is desirable, is not enough to reach the nZEB requirements for energy demand. When the building is renovated as described, primary heating energy consumption is reduced by 62.7% (15.5 kWh/m²). However, primary energy consumption for cooling increased by 10% (0.8 kWh/m²) when windows cannot be opened. Radiant cooling to lower operative temperature and or elevated air speed could be a solution for allowing higher air temperatures and decreasing energy consumption at the same time. Besides, openable windows at prescribed outdoor conditions can contribute to reduced overheating hours and cooling demand of the building and is also better rated in the EPC. When natural ventilation by openable windows is applied, energy demand reduces with 12% for the renovated building in the energy performance calculation.

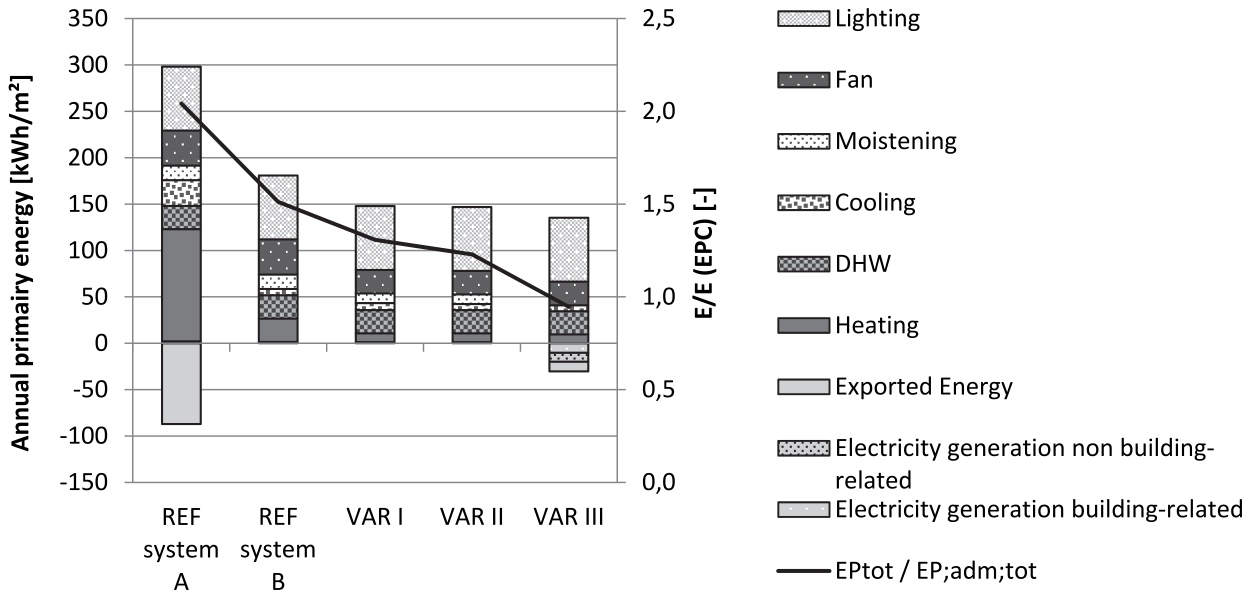



**Figure 6.** Annual primary energy consumption and EPC rating.

The requirements for maximum primary energy consumption are met when PV is introduced, although this is not enough to reach the share of 50% of renewable energy. Besides the share of heat pumps, PV, and ground storage, biomass, solar water heater, wind energy, and external heat supply from renewable sources could also be used to increase the share of renewable energy, reducing the primary energy consumption for heating and cooling (Harmelink, 2015).

## Conclusion

Indoor climate is experienced as more comfortable in hospital B and patients experience better control of their rooms within the single patient rooms by opening windows and closing sliding doors. A low standard temperature between 21 and 23°C is experienced as comfortable, wherein most patients can adapt themselves with clothing or blankets. In order to reach personal preferences, control over the indoor temperature is preferable in single patient rooms. When doors are closed, it is possible to heat or cool the room to desired temperature, with respect to system's capacity. Over 50% of the patients want the possibility to open a window, for fresh air or cooling in the summer. Measurement results and simulation results show less overheating in the situation for prescribed outdoor temperatures. The energy consumption per square meter of a hospital with single bedded rooms is comparable to a hospital with multi bedded rooms. The amount of energy saved solely by broader temperature ranges is small compared to the effect of building renovation. A lower cooling set point of 23°C increases the cooling demand, however this is only a small part of the total energy demand. Greater controllability of indoors is preferred when patients stay for longer time in the hospital. The findings show that design solutions for transforming hospital wards from multi-patient to single patient rooms, while simultaneously improving the measured and perceived indoor climate and reducing energy consumption to contribute towards realisation of nZEB Hospitals, are possible and available. ■

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