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jh@rehva.eu

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Nearly Zero Energy Hospital Buildings

Hospitals throughout the world are major energy consumers, so REHVA and TVVL started in 2015 a preliminary study to find the answers and the directions to help owners of hospital buildings to comply with future regulations on nearly zero energy hospital buildings. This preliminary study on nZeb Hospitals was handed over to the Technology and Research Committee of REHVA in 2017 and is now available via the REHVA Restricted Area – TRC Documents.

One part of the preliminary study included a workshop that was held during CLIMA 2016 in Alborg, Denmark. During that workshop, the input was provided by the participants from different REHVA members. The intent of the workshop was also to find collaborators for the preliminary study.

The collaborators of the workshop and a team of international researchers and practitioners were willing to work on this REHVA Journal October issue on nZeb Hospitals.

We present a broad pallet of visions from case studies based on the five steps: "trias energetica" method to the Pareto analysis that can help the designers to find the directions to the nZeb Hospital. The patient is not forgotten in all these energy saving matters as you can read in the article that's paying heed to the patients' thermal comfort and in a special article that pays attention to the impact of the engineering of ventilation grills. A thorough energy analysis is presented to you to find the theoretical approach to nZexhb. Also, we have tree articles that inform you about new design ideas, about a code reform from US, a UK perspective to move hospital design to an nZeb, an interesting idea to look further than nZeb and take a look of the impact of waste generated by hospitals. After all the saving issues, we must be aware that there is no energy gap between what we have planned and finally realize.

After the preliminary study on nZeb Hospitals, REHVA decided to have further research on this important topic resulting in a REHVA Guidebook. All the information gathered in the preliminary study and the content of the REHVA Journal October 2017 issue on nZeb Hospitals will form the basis of the REHVA Guidebook that is planned to be ready in 2019. If you are interested to participate, or want to help us realizing this project, we still are looking for co-financers to finance this important project, please contact me by e-mail.

It was a pleasure for me to be the guest editor of this REHVA issue on nZeb Hospitals and many thanks to all that gave their extensive contribution. ■

HANS BESSELINK
REHVA Fellow
International Delegate TVVL
Senior Consultant RoyalhaskoningDHV
hans.besselink@rhdhv.com

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Roadmap to nZEB Hospital – a Case Study: VUmc Policlinic

RICCARDO CAPPERUCCI
Royal HaskoningDHV
The Netherlands
riccardo.capperucci@rhdhv.com

WIM MAASSEN
Eindhoven University of Technology
The Netherlands
wim.maassen@rhdhv.com

WIM ZEILER
Eindhoven University of Technology
The Netherlands
w.zeiler@tue.nl

Hospitals need to substantially reduce energy consumptions and CO_2 emissions to fulfil requirements for the EU directive on nZEBs. This study assesses the great challenge of realizing energy reduction within a hospital, considering its far lower priority compared to the performance to be delivered for medical purposes.

Keywords: Hospital energy demands; Building energy efficiency; nZEB; Energy savings; User-Oriented; Control systems; Building energy simulation, Building Services.

Introduction

In the Energy Performance of Buildings Directive (EPBD) [1], the EU has set nZEB requirements to new buildings (2020) and all existing buildings (2050), which applies also to hospitals. Hereby, it is essential to guarantee appropriate functionality while saving energy. Therefore, achieving these requirements in hospitals is a greater challenge than, for example, in office buildings.

In the Netherlands, the healthcare sector consumes approximately 1.6% of the energy consumption, of which 64% is consumed by academic medical centers (AMCs) [2,3]. The approaching EPBD requirements and the expected increase of energy costs have driven AMCs to review their energy policies resulting in the MJA3 energy covenant 2005-2020 (2% energy efficiency per year, compared to 2005) [3].

A case study was performed on VU Medisch Centrum (VUmc): an academic hospital located in Amsterdam, the Netherlands. The energy management (CCE) faces severe challenges to satisfy the MJA3 requirements both at campus, building and departmental level. Preliminary research has shown several lacks in: monitoring activity, building energy performance and user– oriented services. This study aims to indicate the potential of energy savings that can be achieved in the outpatient department of the VUmc Policlinic. The existing Policlinic building (**Figure 1a**), built in 1986 with a gross floor area of 80000 square meters, was chosen as case study according to a preliminary analysis and client issues. The building is extensively used and, although its lifetime has been extended (from 10 to 30 years, referred to 2014), any thorough re-commissioning has not been performed and maintenance is minimal. These circumstances occur in many AMCs and their campuses, which are in continuous transition to upgrade primary processes according to the latest developments.

Methods

The project objectives were obtained through a three-step methodology: first, in-depth analysis of case study; second, development of an nZEB-design approach and third, building energy simulations. The analysis of VUmc includes interviews with energy management staff, site visits and a literature study [4-11] on specific requirements for indoor environment and energy consumption in hospitals.

In-Depth Analysis of Case Study

In the in-depth analysis, the aim was to comprehend how VU, VUmc and Policlinic are organized and how they operate. Then the major features related to energy demands, management and issues (e.g. **Figure 1b**) are examined. The investigation of the aforementioned points has been conducted through site visits, interviews to management staff and data analysis (e.g. MJA3 results, energy monitoring activity etc.).

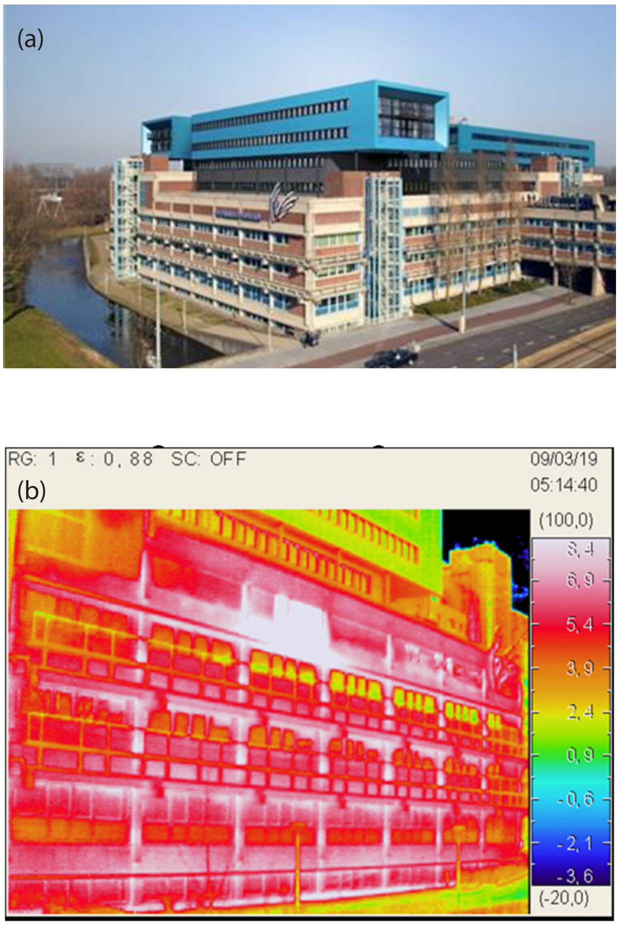

Figure 1. (a) VUmc Policlinic building. (b) A thermal picture of policlinic's façade highlighting, as bright patterns, the several thermal bridges within the envelope.

nZEB-Design Approach

In the Netherlands, a commonly used approach for an energy-efficient building design is the three-step strategy called 'Trias Energetica' [12]. At Royal HaskoningDHV, due to increasing concern and evolution of techniques, the approach has been upgraded to a 'Five-Step Method' [13] (**Figure 2**) with two additional steps:

- user demand and behaviour
- energy exchange and storage.

The 'user-oriented' concept, realizable through smart building designs and controls, aims to improve indoor climate and productivity while substantially decrease energy wastage.

The approach developed in this research focuses mainly on two principles:

1. Minimize the demand of energy,
2. User demand and behaviour.

In addition, the methodology must consider a few aspects strictly related to the case study at hand: those having relevant impact over design success. With respect to our case study building, the following aspects are also considered:

3. Case study analysis (issues, requirements and potential),
4. Building life expectance and maintenance costs.

In light of these four aspects, a list of measures for upgrading performance and indoor comfort is determined and project steps were based upon their consideration.

Methods: Building Energy Simulations

A set of VABI Elements© building energy simulations is determined in order to validate the aforementioned measures and to provide insights about energy flows and controls over the case study. The plan of the policlinic presents a variety of rooms modularly designed (see **Figure 3a**), thus the base module is adopted for the VABI model (see **Figure 3b**) and oriented to West in light of a set of sensitivity simulations.

Air-conditioning in the modelled space resembles the current system (see **Figure 3b**): conditioned air is supplied by the central system (central heating and cooling) and occupants can adjust temperature by a

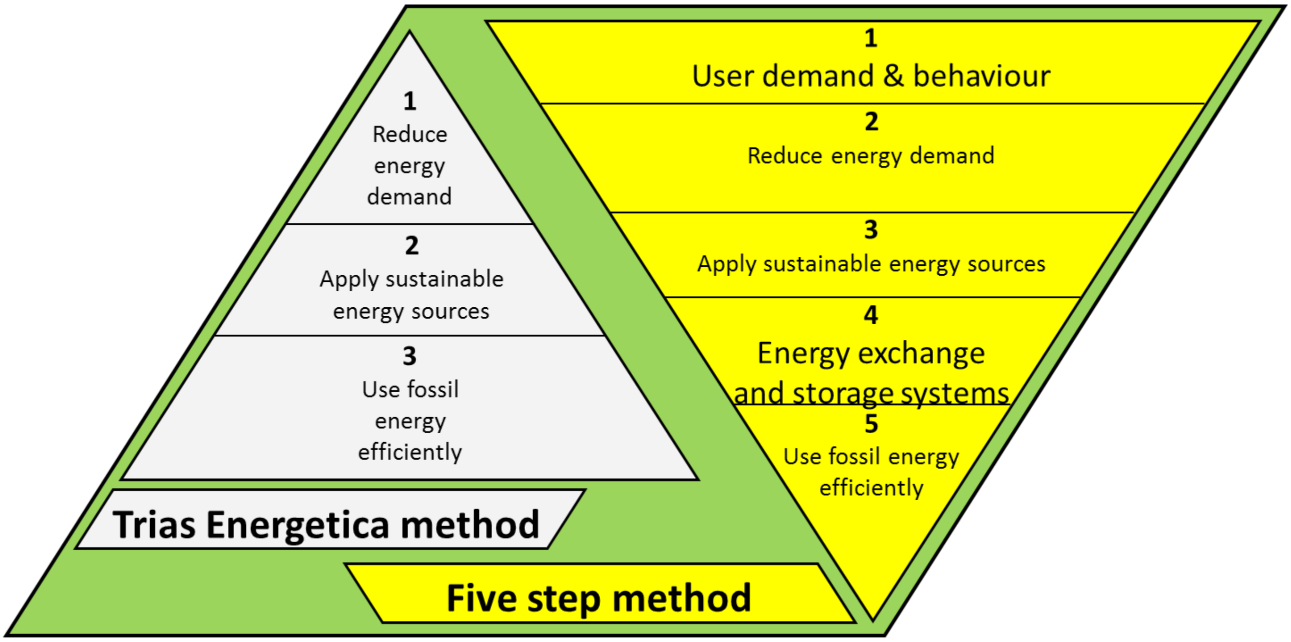

Figure 2. Building design approaches: 'Trias Energetica'[10] and the upgraded 'Five Step Method'[11].

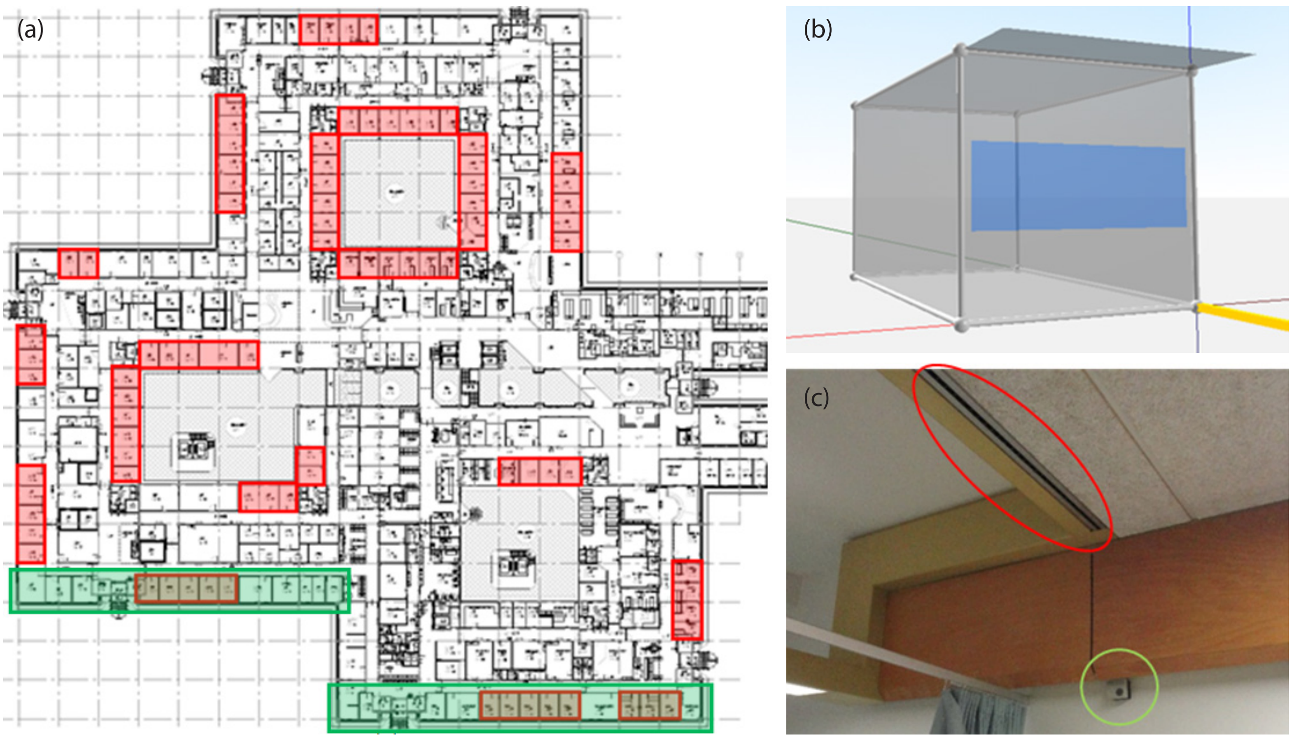

Figure 3. (a) Plan of policlinic building with highlighting of modelled space (red) and western façades (green). (b) VABI Elements© model. (c) Local re-heating system: air inlet (red) and temperature set-point control (green).

local re-heater (local heating). The external conditions are modelled with the climate file for year 1964-1965 at De Bilt, the Netherlands. Building simulations are performed for an entire year period and the focus is oriented on energy consumptions and indoor thermal comfort.

The set of simulations is composed by eight scenarios involving the variation of three major groups, which are modelled as currently operating and, then, in an improved configurations. The groups are:

1. HVAC: The existing system is a Constant Air Volume (CAV) and the improved is a Variable Air Volume (VAV) system. The CAV has only an 'On-Off' modality with a constant airflow rate. Differently, the VAV has a high-low ventilation rate controlled by CO_2 set-points.
2. Occupancy profile: Currently the systems consider a constant occupancy opposed to a more realistic random occupancy. The average number of people per hour in a week is equal between the two profiles. The profiles are based on building opening schedule and controlling the internal heat loads of equipment (non- medical) and lighting.
3. Building envelope: The current envelope is defined by lump-sum values for R_c (opaque) and U (transparent) related to Dutch standards at the time of construction while the improved is designed to satisfy current standards.

The set of simulations is presented in **Table 1**.

Table 1. Simulation set scheme.

SIMULATION NUMBER	HVAC		OCCUPANCY		ENVELOPE	
	Type	I – CAV II – VAV	Type	0 – Constant 1 – Random	Type	0 – Current 1 – Improved
I.0.0	I		0		0	
I.1.0	I		1		0	
I.0.1	I		0		1	
I.1.1	I		1		1	
II.0.0	II		0		0	
II.1.0	II		1		0	
II.0.1	II		0		1	
II.1.1	II		1		1	

Results

In-Depth Analyses of Case Study

In typical hospital buildings energy consumers, flows and wasting components are often unknown or disregarded, resulting in uncertain parameters for investments in sustainable energy reduction and higher operation costs.

The research on VUmc and policlinic showed that little attention is directed on inefficient processes and part of the buildings present obsolete building systems and services. Current systems are coarsely monitored and not user-oriented with little focus directed toward occupant's requirements (e.g. indoor comfort) and occupancy.

In the policlinic, the current energy management method is not fulfilling MJA3 requirements for both short and long term; therefore, requiring additional measures to address the requests of lower energy demands and better indoor comfort. The extended life of policlinic highlights the necessity to upgrade both components and services (severe issues in building envelope, HVACs and ducting design) in the building considering the constantly increase of energy costs and demands of new and more specialized healthcare treatments.

nZEB-Design Approach

The application of the approach resulted in list of energy saving measures, suitable to both typical hospital and to the policlinic case, in consideration of:

- Current energy demands per type: total amount, total cost and cost per unit.
- Positive outcomes for indoor environment: improvement of comfort and healing conditions.
- Current condition and performance of systems and components.

A selection of five high-potential solutions was based on these criteria and supported by a literature review on related previous research [4-11]. It was found that the ventilation load in hospitals, due to the processing of outdoor air in the AHUs, is the greatest demand. In conclusion, the top five solutions for hospital buildings are:

1. Upgrade of the HVAC system (from CAV to VAV system);
2. Application of occupancy-based controls to HVAC;
3. Upgrade of the building envelope;
4. Upgrade of the lighting;
5. Application of occupancy-based controls to lighting and devices.

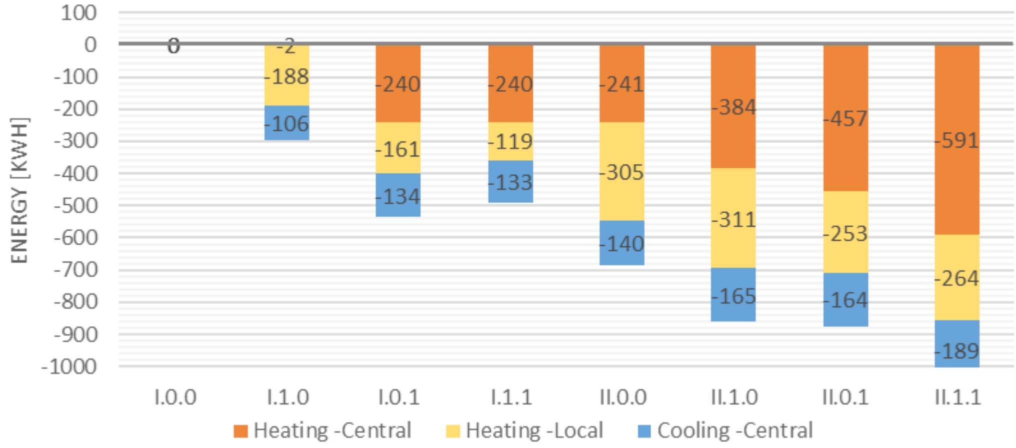

Figure 4. Yearly energy reductions of energy demands (central heating, central cooling and local heating).

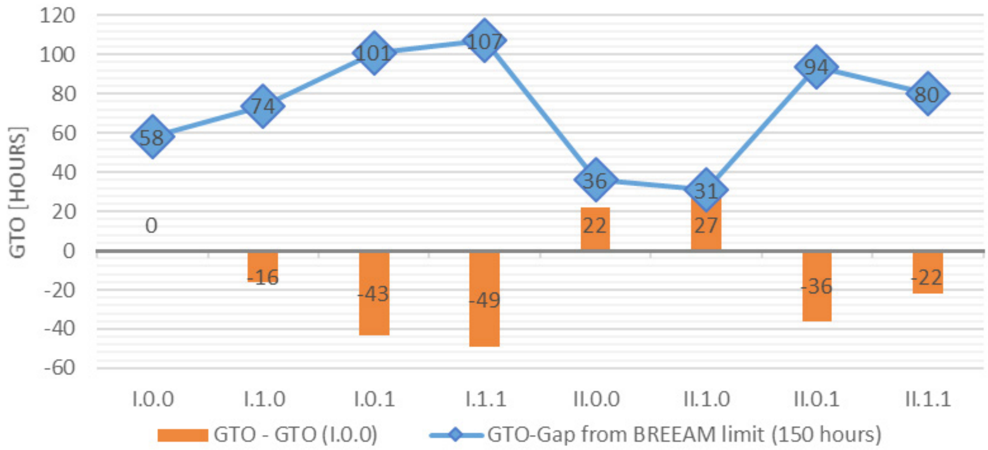

Figure 5. GTO index amount for one-year simulation compared to simulated current conditions for a single room and to BREEAM temperature comfort requirement.

The first three measures are chosen to be implemented in the building simulation models to evaluate their effect on energy consumption and indoor comfort.

Building Energy Simulations

The building simulations are performed over a period of one year, resulting in energy consumptions and GTO (Weighted Overheating Hours) index values, which are presented for both aspects in comparison to the simulated current situation (I.0.0).

Figure 4 presents the yearly reduction of energy demands and showing that the greater savings are obtained from the central heating. Significant reduction (up to 535 kWh, 14%) can be achieved without upgrading the HVAC system. However, savings double for set II in scenarios with VAV system reaching 1044 kWh in scenario II.1.1, 27% lower compared to current conditions. Scenarios II.1.1 and II.0.1 are the most expensive, therefore, the most convenient option seems the implementation of the VAV with occupancy controls.

GTO is a performance index representing the yearly number of hours resulting in an unpleasant indoor climate. The whole set of simulations is performed to meet the BREEAM temperature comfort requirement of 150 overheating hours, see **Figure 5**. Scenarios II.1.0 and II.1.0 shows the highest reduction of GTO hours compared to I.0.0 confirming as best solution the VAV with occupancy controls.

Discussion and Conclusions

This research is about obtaining effective reductions in energy consumption and while improving comfort of hospital buildings. The case study, VUmc Policlinic, has shown that despite the great efforts to fulfil energy requirements, the current performances are still inadequate. Moreover, realizing effective reductions are quite a challenge due to strict budgets, life expectation of buildings and their influence on hospital's incomes. Expertise in hospital building processes, life-cycle and maintenance are essential to increase energy performance when the primary process, healing, is extraordinarily leading more than in any other markets and buildings.

A three-step methodology was used to identify possibilities to reach towards nZEB requirements for hospitals. This approach consisted of three steps: (1) in-depth analysis of case study, (2) development of an nZEB-design approach and (3) energy simulations. The in-depth analysis revealed that little attention is directed on energy performance and monitoring activity of buildings.

Application of the proposed nZEB-design method resulted in a top five of energy saving measures. The case study VU Medical Center (VUmc) Amsterdam was analysed and the energy saving potential of the Policlinic quantified. In conclusion, the approach was found to be adequate and showed important potential for energy reduction in hospitals.■

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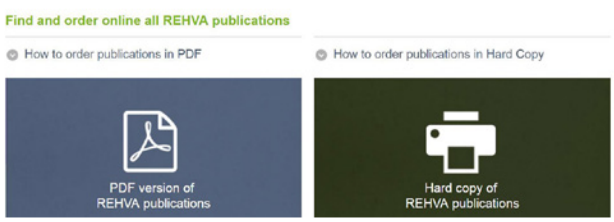

Pareto analysis: a first step towards nZEB Hospitals

ILSE SCHOENMAKERS
Arcadis
ilse.schoenmakers@arcadis.com

WIM ZEILER
Eindhoven University of Technology
The Netherlands
w.zeiler@tue.nl

The energy use of hospitals, especially University Medical Centres, is among the highest of all building types. It is important to reduce it without endangering the primary functions within hospitals. An energy management case study using the Pareto analysis method, in the isolation rooms of Erasmus Medical Center, revealed a large HVAC energy reduction potential.

Keywords: Energy reduction, Pareto analysis, nZEB Hospitals.

Introduction

The world's energy consumption raises concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts. Of this world's energy consumption, nearly 40% is used in the building sector of developed countries [1], with hospitals to be one of the largest consumers. In the Netherlands, the health-care sector consumes 1,64% of the energy consumption, of which 64% is consumed by the 8 University Medical Centres (UMCs) [3]. HVAC systems consume approximately 50% of the total primary energy used in UMC buildings [4]. Operational optimization of these systems is not an easy task since many interrelated building parameters, building user characteristics and building services components influence the operation and performance of these large-scale HVAC systems. The main problems in the optimization process are the difficulties in detecting inefficiencies and intricate relations between the energy consumption and influencing parameters [5]. The majority of the research already performed on energy reduction in UMCs, was aimed on efficient generation of energy, compared to little research on the HVACs energy demand and supply (actual energy consumption), although its energy reduction potential. Awareness of user influences on HVAC systems is an important, but fairly unknown, parameter of the demand [6]. Additionally, research on energy reduction requires engineers to take patient safety, as far as it is provided by the building systems, as major priority [7]. However, preliminary research revealed that UMCs have high potential for energy through reduction in their heating, ventilation and air conditioning (HVAC) demands. To activate this potential, energy management, protocols and a framework are required to support energy reduction.

UMCs in general suffer from a lack of a consistent and homogeneous framework for energy reduction, due to complexity and diversity of their HVAC systems. Systematically approaching the energy reduction potential in UMCs requires a consistent framework. In this research, the ´Pareto analysis´ method is used as a guideline for the development of an energy reduction framework for UMCs. In order to define this framework as a step towards guided HVAC energy reduction in UMCs, the approach was applied in a test case UMC.

Methodology

The Pareto analysis, also known as the 80/20 rule, assumes that: the majority of problems (80%) can be identified by a few major causes (20%), or 80% of the problems can be solved with 20% of the effort. This analysis method is often used in decision-making issues, or in solving complex problems, for example, in the industrial engineering [8]. **Figure 1** illustrates this Pareto analysis, in which the required effort (causes) is plotted against the solutions (problems) [9]. The Pareto analysis identifies the few major causes that result in the majority of energy consumption problems. A Pareto analysis is a useful tool to direct to specific focus points and target the most important aspects that affect the energy consumption. The analysis identifies and rates the influencing parameters, resulting in the most important parameter to focus on first. "It is normally easier to reduce a tall bar by half than to reduce a short bar to zero. Significantly reduce one big problem, and then hop to the next", as cited by [9].

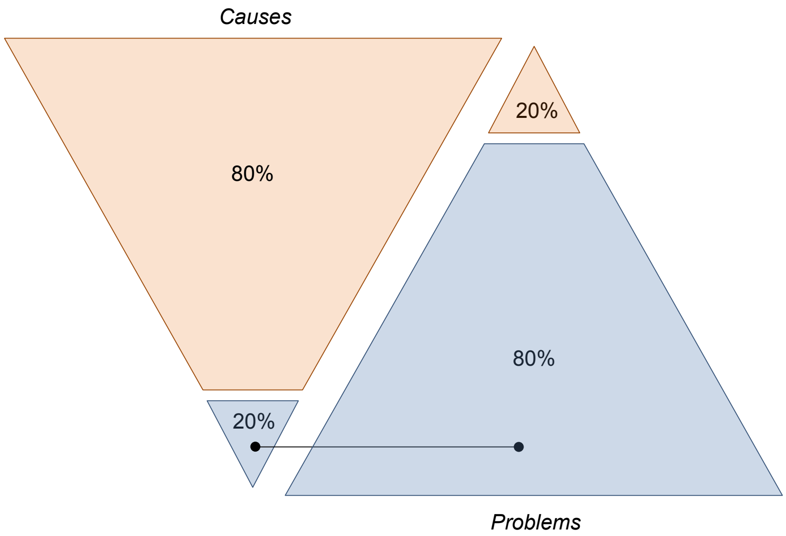

Figure 1. Methodology based on the Pareto-analysis. Majority of problems (80%) can be identified by a few major causes (20%). [9]

If the primary problems are solved, the same technique can be used in a new Pareto analysis, in which again new primary problems can be distinguished (continuous improvement). The Pareto analysis includes six basic steps, as illustrated in **Figure 2**.

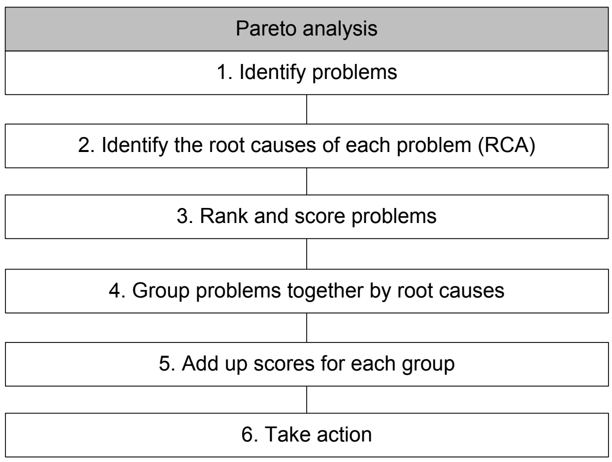

Figure 2. Basic steps of the Pareto analysis. Step 2 includes the Root Cause Analysis (RCA).

Step 1 and 2: Identify problems and root causes of problems (identify)

Main characteristics of energy consumption were indicated using data based on calculations, observations, interviews and reports. The cause-effect of these problems can be identified by a RCA, which defines the nature of the problems. The RCA includes defined basic steps:

1) Collect data: Systematically collect data and notify the problem. Determine for how long this problem has been occurring. Determine the frequency (quantify) and the impact (if the problem will not be solved) of the problem.
2) Define and classify possible causes: Identify how and under what conditions the problems arise, and identify what other problems arise if these identified problems are solved.
3) Define root causes: Define the causes that induce the problems and define their correlation.

Step 3, 4 and 5: Rank, score and group problems (prioritization)

Identified problems are ranked to importance, scored and grouped together. An example of ranking in a financial approach, is the gravity of the problem concentrating on the organizational costs. If the main cause of the organizational costs is customer dissatisfaction (group), the focus is on the number of complains.

Step 6: Take action (corrective actions)

As the problems are identified, an action plan with improvement actions can be formulated in order to solve the problems.

Case study definition for testing the hypothesis (Pareto analysis)

The case study as used for testing the Pareto analysis was Erasmus MC Sophia (EMC). EMC is a compact UMC, includes all healthcare functions, provided in a good cooperation during preliminary research and already has knowledge and experience on this topic. The large scale and complexity of the HVAC systems in EMC was not a manageable situation and needed to be addressed on a smaller scale. The first step for accessing the energy reduction potential in EMC was through differentiation of energy consumption to different healthcare functions in EMC. The outcome of the preliminary research was the energy intensity and the total energy distribution per healthcare function. The energy consumption of EMC is differentiated to functions, see **Figure 3**. Two large energy consuming functions are marked as important functions to focus on: both surgery rooms(SR) and isolation rooms (Isol.r.) consume, overall (GJ) and per square meter (GJ/m²), significantly more energy than other healthcare functions.

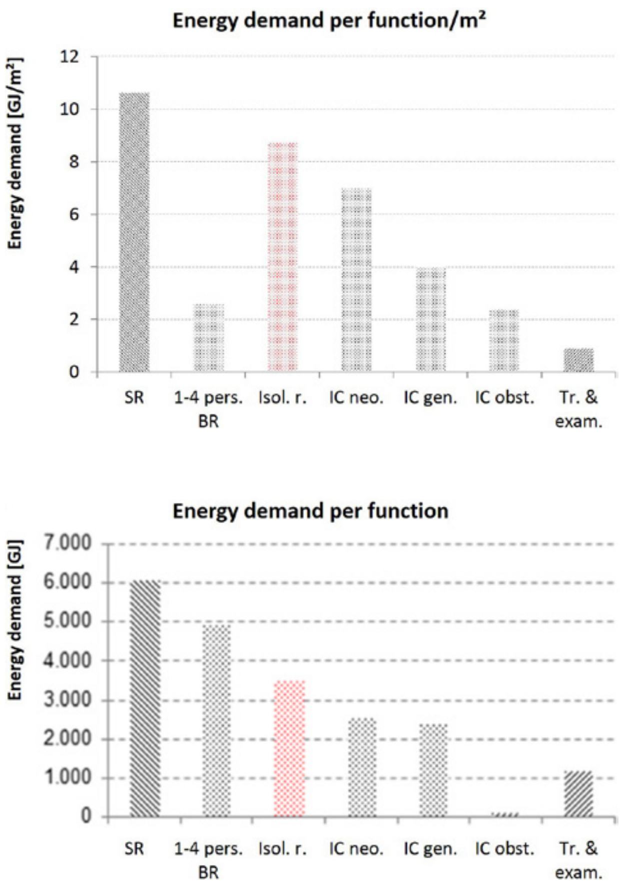

Figure 3. Local heating, cooling and fan energy demand per healthcare function/m² respectively total energy demand per healthcare function [GJ] in EMC. Surgery (SR), bedroom (BR), intensive care (IC), treatment and examination room (Tr. & exam.), assessed using Vabi Elements building simulation.

The research revealed the healthcare function with most potential for energy reduction: isolation rooms.

Step 1 and 2: Identify problems and identify the root causes of each problem

The first step of the Pareto analysis identified the problems (energy consuming parameters) of the large energy consuming HVAC systems in isolation rooms. In this first step, hand calculations and simulations were used. The root causes of the problems were analysed using a Root Cause Analysis (RCA), a well-known method used in the second step of the Pareto analysis.

Figure 4 illustrates a Pareto diagram applied on the energy reduction problem of this research. On the x-axis the problems which causes the energy consumption and on the y-axis the energy consumption. The 80% value line illustrates 80% of the energy consumption, which is assumed to be caused by 20% of the problems. If primary problems are identified, the problems can be solved by defined corrective actions.

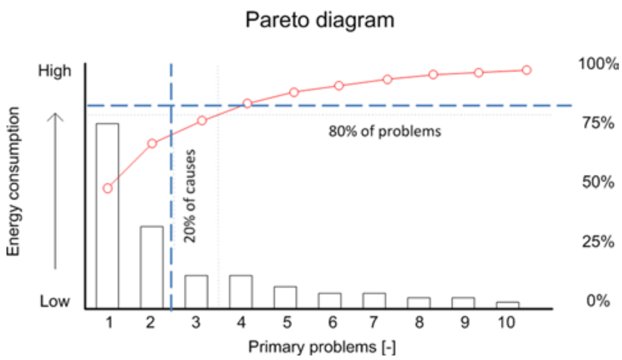

Figure 4. Pareto diagram projected on the energy problem. Primary problems are differentiated and are rated to their energy consumption. The dotted line indicates the 80/20 rule: 80% of the energy consumption can be solved with 20% of the influencing parameters.

Step 3, 4 and 5: Rank, score, group problems

The energy influencing parameters were grouped into five prospective (use influences, setpoints, building, system operation and external influences). The prospective including the parameters were scored and rated using a probability-impact analysis. A high probability and large impact means a high energy reduction potential. The outcome of this analysis were KPIs (user presence and occupancy, room temperature and air changes per hour (ACH)), which represented the focus of the research on corrective actions.

Corrective actions

The corrective actions are part of step 6 of the Pareto analysis. An action plan described improvement actions on the KPIs (user presence and occupancy, temperature and ACH) that were determined and formulated. Corrective actions resulted in a useful solution of energy reduction. Alignment of the actual system operation to the users' energy demand, potentially leads to energy reduction. In order to determine the magnitude of this energy reduction potential, a building simulation model was used. The quantified user influences and their related system operation as specified in the corrective actions of the previous step, were used as input for the building simulation model and defined the theoretical energy demand. The outcome of this simulation was compared to the energy consumption of the actual HVAC operation. Input of the actual HVAC operation was obtained from field measurements

Conclusions

The Pareto analysis is a useful systematic approach for determining energy reduction potential in UMCs. This hypothesis was tested using the case study as described. The rooms of the case study building were differentiated by functions which had the largest energy consumption (based on energy intensity and total area) and these were selected to be analysed. The Pareto analysis was found to be a useful approach for determining energy reduction potential in UMCs. ■

Acknowledgment

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





MIKE VAN OSTA
MSc, Eindhoven University of Technology
Royal HaskoningDHV
The Netherlands

ASIT MISHRA
Dr., Eindhoven University of Technology
The Netherlands

MARCEL LOOMANS
Dr. ir., Eindhoven University of Technology
The Netherlands

HELIANTHE KORT
Prof., Dr., Eindhoven University of Technology
The Netherlands

WIM MAASSEN
Eindhoven University of Technology
The Netherlands
wim.maassen@rhdhv.com

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 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.

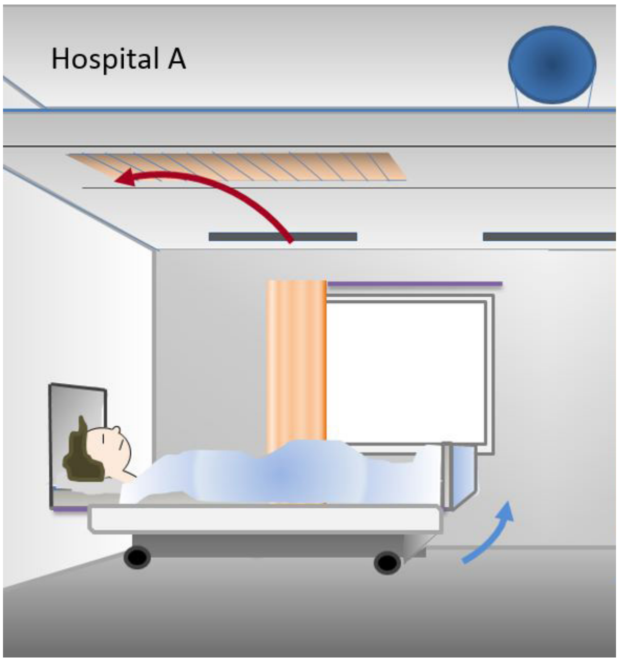
Table 1. nZEB demand healthcare facilities in the Netherlands (Blok, 2015).

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

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



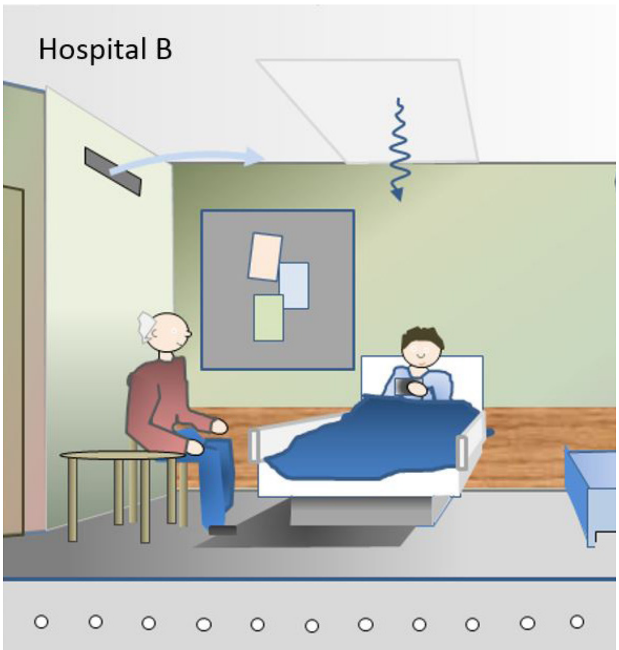


Figure 1. Hospital A: all air system; Hospital B: concrete core activation, conditioned air and openable windows.

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

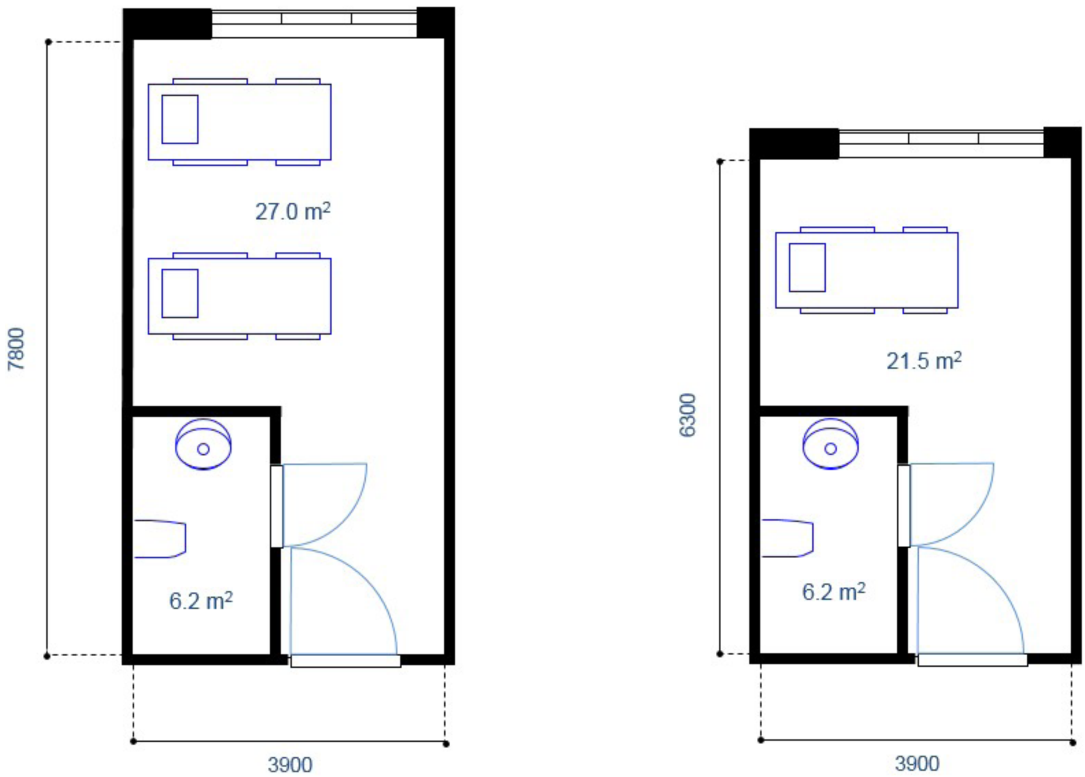


Figure 3. Floorplan of a two-bedded room and single bedded room used for the simulations.

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).

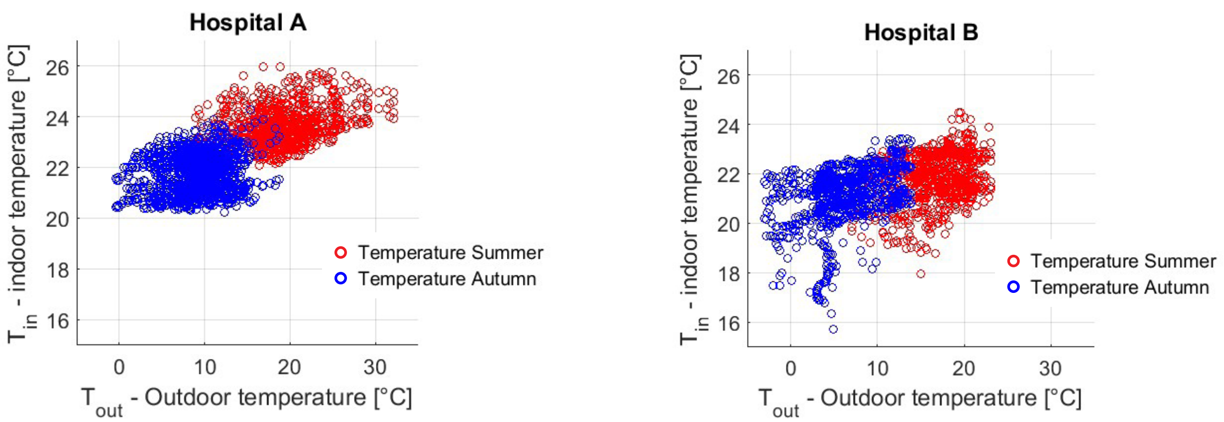


Figure 4. Comparison between indoor and outdoor temperature for hospital A (a) and hospital B (b) based on mean hourly data of all measured rooms.

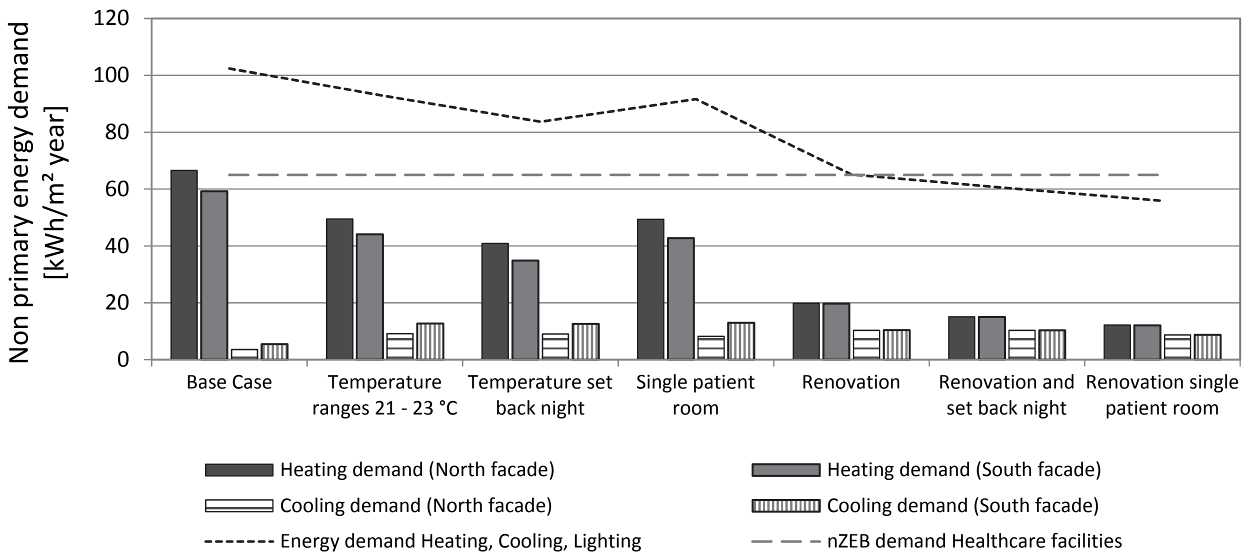


Figure 5. Heating and cooling demand per square meter for different scenarios with heating and cooling set-point of 23–25°C for the base case and 21–23°C for the other scenarios. For the scenarios with temperature set back, heating set point is 18°C during the night (9:00 p.m. – 6:00 a.m.).

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.

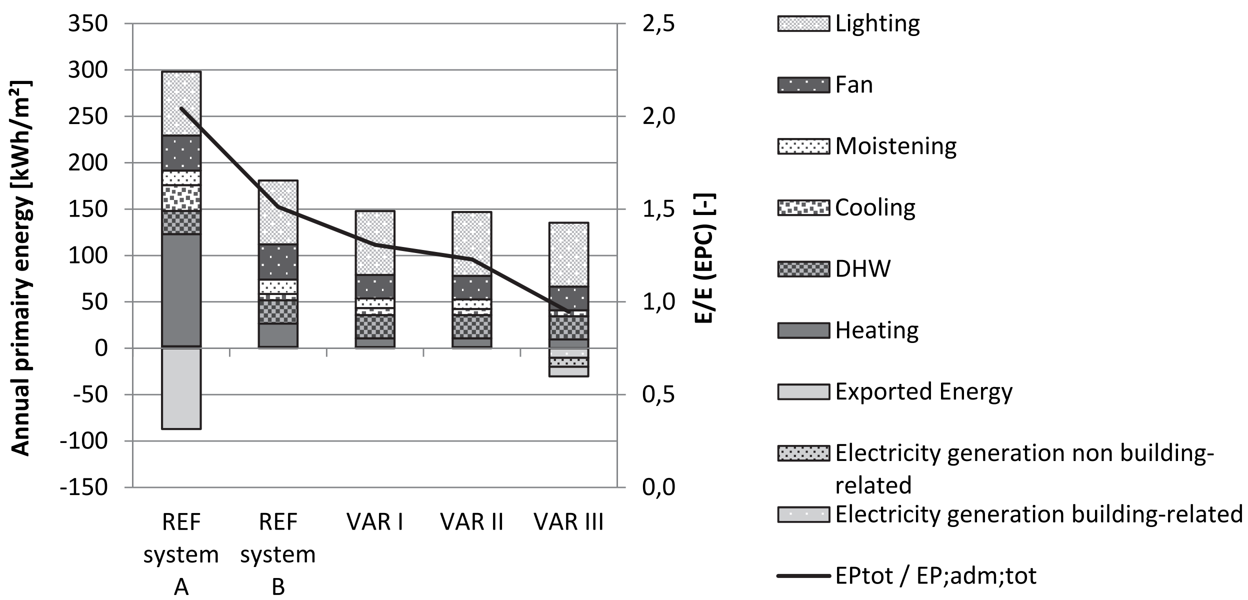


Figure 6. Annual primary energy consumption and EPC rating.

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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Targeting Nearly-Zero Exergy Hospital Buildings (nZEXHB): a new performance metric and a case study

BIROL KILKIS
Prof. Dr., Fellow ASHRAE
Baskent University, Energy Eng.
Program Chair and TTMD President
Ankara, Turkey
birolkilkis@hotmail.com

Hospitals are the most energy-intensive buildings [1, 2]. Yet, for true decarbonization in the EU countries, all future buildings, including hospitals, must be exergy-rational in addition to be energy efficient, because CO_2 emissions are linearly proportional to both conditions [3]. In this context, a new definition, namely nZEXHB and its fundamental theory with a rating model, is introduced and explained with a short case study using the Rational Exergy Management Model (REMM). EU Decarbonization instruments are also re-visited from the exergy point of view.

Keywords: near-zero buildings, exergy-rational hospitals, Rational Exergy Management Model, decarbonization, nearly-zero-exergy hospital building (nZEXHB)

Exergy or Energy?

> "We pay for the quantity of energy but we only use its exergy (Quality of energy)"
>
> – 2004, Peter Novak, ASHRAE TC 7.4

This sad fact is exemplified in **Figure 1**, which shows the energy flow of a ground-source heat pump used in a hospital building. The electric power input to GSHP is utilized to supply heat with a given First-Law *COP* at given operating conditions. But the input side and the supply side have different exergy levels.

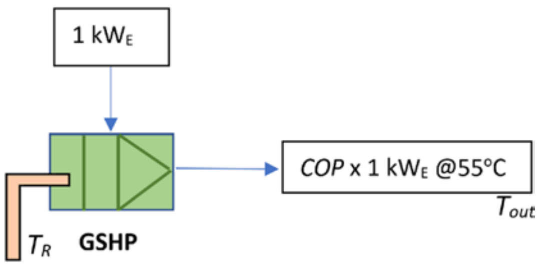

Figure 1. Exergy input and output for GSHP.

The First-Law of Thermodynamics cannot distinguish this difference. From an exergy point of view, the *COP* of the GSHP needs to be at least equal to 7.28 if the input and output exergies must be even. By considering the ideal Carnot Cycle (Temperature Factor) of the heat supplied by the GSHP at 55°C, and taking the unit exergy of electric power to be unity:

$$COP_{min} = \frac{1}{\left(1 - \frac{283\text{K}}{(55+273)\text{K}}\right)} = 7.28 \qquad (1)$$

nZEXHB Building

In the quest of reaching the goals of the recent Paris Agreement for reducing CO_2 emissions, net-zero energy buildings (NZEB) and net positive-energy (NPEB) buildings are becoming common [5]. Following the foot-steps of the above argument shown in **Figure 1**, although general definitions for NZEB have been published, there are other issues to be resolved [6]. A major issue that has not been addressed yet in the building and energy sector is the fact that, with the increasing share of renewable energy resources and systems in the built environment at different exergy levels, their exergy differences and the need for exergy balance between the supply (resource) and the demand points (built environment, such as buildings) need to be identified as well as their importance in optimum and net-positive solutions have to be acknowledged [6]. Almost all of the literature is concerned with the First-Law of Thermodynamics, which is not sufficient to address these problems. Therefore, the Second-Law needs to be incorporated in all related analyses, design, and operation phases. Current practice is primarily focused on the exchange of electrical energy only, which has a unit exergy of almost 1 so that exergy exchange of electricity is almost identical to its energy exchange, except quality of the currents, for example PV generated and thermal power plant generated. In contrary, Thermal energy at different states and temperatures mean a wide variation of the thermal energy quality (exergy). Exergy differences between the supply and demand points yield irreversible exergy destructions and, thus, avoidable but important amounts of CO_2 emissions. Today, Denmark is the only EU country that factors-in the thermal energy exchange. In order to better assess the environmental performance of buildings, in particular, hospitals a new definition has been proposed to ASHRAE TC 1.6 Terminology:

nZEXHB: Nearly-zero Exergy Hospital Building is an individual building or compound connected in a district, which on an annual average basis satisfies at least 70% of its total exergy of heat and power [7].

Such a hospital building faces the challenge of a quadrilemma among Environment, Energy, Exergy, Economy, and Safety and Health, which is shown in **Figure 2**. While nZEXHB satisfies the 80% Law, it must also optimally satisfy all four elements of this quadrilemma without much sacrifice. This is possible on an exergy platform.

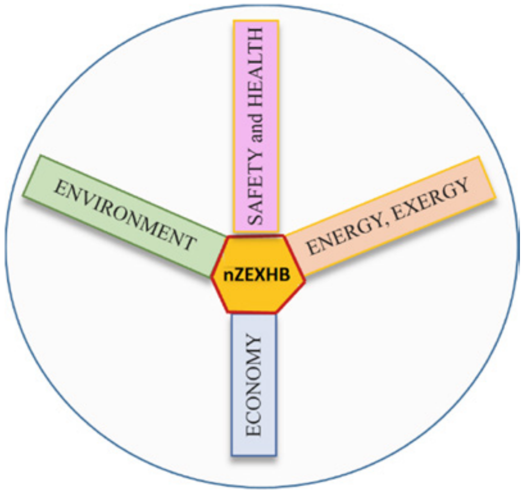

Figure 2. Quadrilemma of nZEXHB.

Rational Exergy Management Model

The so-called exergy platform may be established by using the Rational Exergy Management Model (REMM) [3]. This Model defines a rational exergy management efficiency, namely ψ_R. It checks the balance between the supply and demand exergy, thus the amount of exergy destroyed. It depends on where the major exergy destruction occurs: upstream or downstream of the exergy flow in a process:

$$\psi_R = \frac{\varepsilon_{dem}}{\varepsilon_{sup}} \quad \text{\{If exergy is destroyed upstream\}} \qquad (2)$$

$$\psi_R = 1 - \frac{\varepsilon_{des}}{\varepsilon_{sup}} \quad \text{\{Exergy destroyed downstream\}} \qquad (3)$$

Here, ε is the unit exergy defined in terms of the ideal Carnot Cycle:

$$\varepsilon = \left(1 - \frac{T_{ref}}{T}\right) \qquad (4)$$

T_{ref} is the environment reference temperature. Many hospitals use GSHP and therefore it may be taken to be the average ground temperature like 283 K. T is the application (or source) temperature. For non-thermal sources like solar insolation (electro- magnetic) and wind energy (mechanical), a virtual, Carnot Cycle-based source temperature is calculated [7]. For example, for solar energy with an insolation, I:

$$T_s = \frac{T_{ref}}{1 - 6.96\times10^{-4}\times I} \quad (5)$$

Finally,

$$E_x = \varepsilon \times Q \qquad \{Q\text{: Energy, } E_x\text{: Exergy}\} \quad (6)$$

Exergy-Based Evaluation Model

In this model, four renewable sources of input exergy are identified, namely biogas (BG), Ground Heat (G), Building integrated PV ($BIPV$), and Waste heat (W). A small amount of wind energy is embedded to BIPV slot, because on-site wind turbines may generate uncomfortable noise to patients and medical personnel and even may generate enough electro-magnetic field to affect medical instruments. BIPV is chosen because, façade mounted BIPV emf effect may be reduced by water circulation behind them, which at the same time generates hot water in summer months, while cooling the PV cells for a steady efficiency. The outline of the model is shown in **Figure 3**. In this Figure, c is the CHP capacity chosen with respect to the peak power load and X is the portion of the power output of CHP to the GSHP.

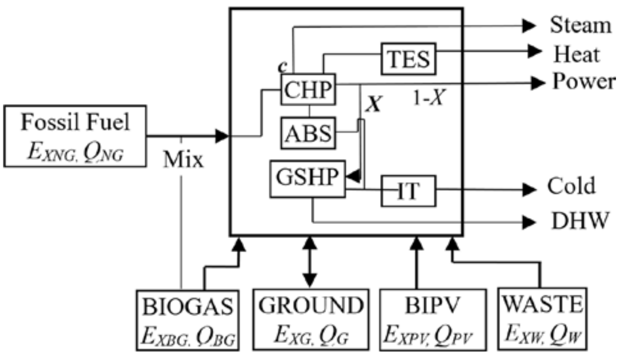

Figure 3. Optimization base model for nZEXHB.

By choosing the c close to one means the CHP plant will be redundant for several hours per year. In contrary, if c is chosen too low, then the fossil fuel portion of the mix will increase such that nZEXHB criteria will not be satisfied. By varying the portion of the power generated by the CHP system, X given to the GSHP system effects the objective function, because it indirectly changes the design c value.

The annual objective function OF_a for nZEXHB is a function of the above renewable sources and the fossil fuel mix (NG).

$$OF_a = \frac{OF_W \times HDH + OF_S \times CDH}{(HDH + CDH)} > 0.70 \quad (7)$$

Here, HDH and CDH are the heating and cooling degree hours, respectively. Equation 8 apply for both winter and summer conditions but the results will be different.

$$OF_W = OF_s = \frac{E_{XBG} + E_{XG} + E_{XPV} + E_{XW}}{E_{XNG} + E_{XBG} + E_{XG} + E_{XPV} + E_{XW}} \quad (8)$$

The following constraints apply due to physical and environmental limitations:

$$E_{XG} \leq E_{Xgmax} \quad (9)$$

$$E_{XPV} \leq E_{XPV} \quad (10)$$

$$E_{XBG} \leq E_{XBG} \quad (11)$$

Case Study

A concept study was carried out in order to investigate the potentials and means of retrofitting the Turgut Özal hospital in the city of Malatya in Turkey.

Figure 4. 900-Bed Turgut Özal Hospital.

The hospital used to be heated by steam boilers running on natural gas and cooled by electric (grid) chillers. The operating costs soared up to 20% almost and a retrofit project was requested. Obviously the OF_a was zero and ψ_R was around 0.18. A complete survey revealed potential exergy intakes from on-site biogas from plumbing wastes, solar PV, ground heat (pump), and waste heat. **Table 1** gives the potential Exergy inputs identified for the terminal buildings without major retrofitting. PV modules on the roofs are quite limited both due to roof area and more importantly due to FAA (Federal Aviation Administration) restrictions to avoid glare and electromagnetic interference with avionics of the planes landing and taking off from a nearby airport. Instead, building integrated PVTC modules are envisioned on suitable vertical building walls. A PCTC module is a combination of PV and TEG modules on each site of the wall and part of the electrical energy activated-TEG modules either for sensible radiant panel cooling or heating by a simple switch of the DC current polarity. **Figure 5** shows the so called the solar brick wall. On site wind turbines are not envisioned due to sound pollution.

Once the *c* and *X* values were optimized independently from economical points of view [8], the fuel mix was optimized along with Equations 8-a and 8-b by varying the natural gas to biogas mix ratio, *m*. The variation is shown in **Figure 6**. Here, OF_a reaches to a peak of about 0.76 when *m* is 6.

At this optimum point, OF_a thus satisfies the 0.7 condition, which means that the hospital may reach nZEXHB status. OF_a in fact has a close relationship with ψ_R too. The overall value was calculated for the design for various arrangements and its impact on OF_a was investigated. Results are shown in **Figure 6**.

According to **Figure 7**, the retrofit is successful both in satisfying the $OF_a > 0.7$ condition and the $\psi_R > 0.7$ condition. This result shows that by satisfying the ψ_R condition, OF_a condition may also be satisfied, because they are both related to exergy rationality.

Table 1. Model inputs [7] (See Equation 6 for E_x).

Exergy Intake	Q, MW_h (thermal)		T, K	ε, W/W	E_x, MW (Thermal except PV systems)	
	Low Case	High Case			Low Case	High Case
Natural Gas, *NG*	3.42	1.93	2200	0.87[b]	2.97	1.68
Biogas, *BG*	1.14	2.63	2200	0.87	0.99	2.28
NG + BG	4.56	4.56			3.96	3.96
Ground Heat, *G*	0.876	2.00	293	0.034	0.030	0.068
Solar, *PV* (All derivatives)	na		na	1	3.55 (electric)	
Waste, *W*	1.5		293	0.034	0.051	

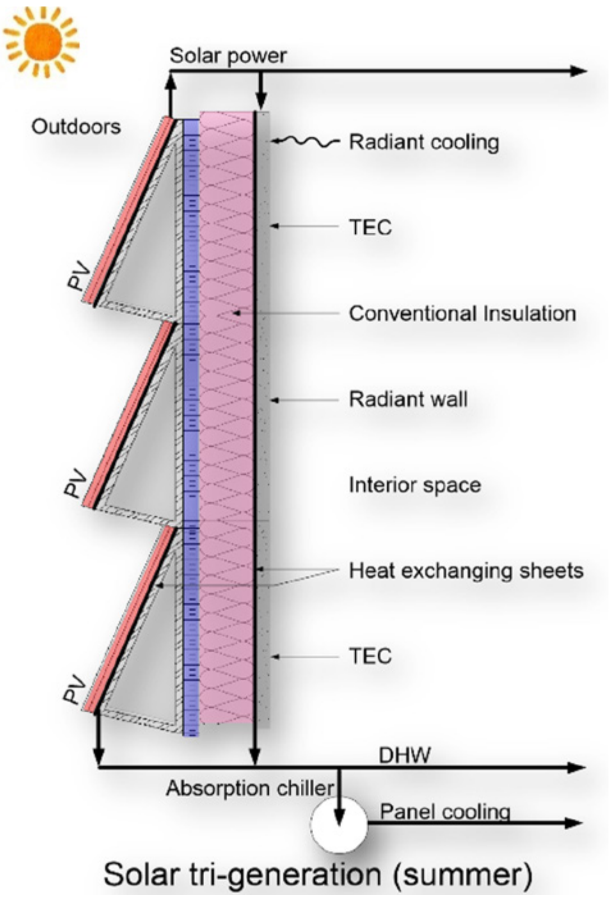

Figure 5. Solar Brick Wall layout.

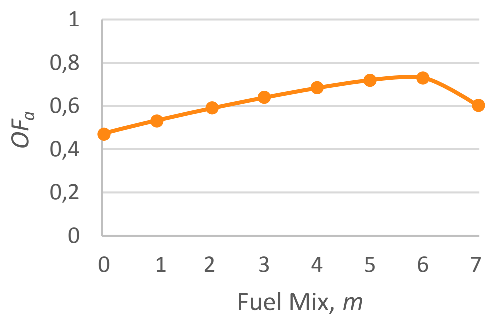

Figure 6. Variation of OF_a with fuel mix, m. [8].

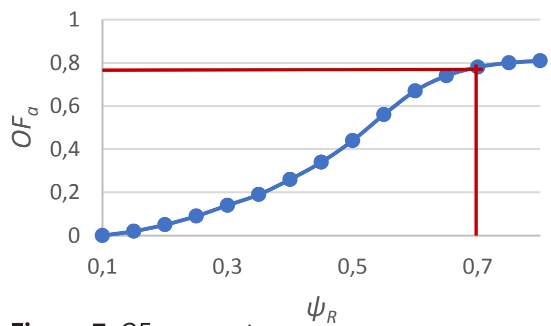

Figure 7. OF_a versus ψ_R.

These results were achieved by optimizing the electromechanical system. **Figure 8** shows the system design for Winter operation. In summer absorption chillers utilize the excess heat of the CHP unit and GSHP delivers cold.

Contributions to Decarbonization Efforts of the EU: A Revisit

EU is striving to decarbonize the member countries by using the First Law only. On the other hand, EU is trying to electrify the heating and cooling sector by using heat pumps. In this paper, it has been shown in **Figure 2** that this is not rational at all, unless heat pump industry reaches an average COP of about 8. Such irrational moves are due to the limitations of the First-Law, which deals with only the quantity of energy but not the quality of energy. The main barrier is the unfamiliarity of the law makers with the Second-Law of Thermodynamics.

In a recent report of TTMD [6], we have shown that all EU directives and guides may be simply upgraded to the second-law by only introducing the variable ψ_R. A summary is given in **Table 2**.

Table 2. A summary of conversion from First-Law to Second Law of EU Directives.

EU Term	First Law	Second Law	Operation
Coefficient of Performance	*COP*	COP_{EX}	Multiply *COP* by ψ_R.
Primary Energy Ratio	*PER* $(PEF)^{-1}$	*PEXR*	Multiply *PER* by ψ_R.
Primary Energy Factor	*PEF*	*PEFX*	Divide *PEF* by ψ_R. Apply to electrical and thermal energy separately.
Primary Energy Savings Ratio: Cogeneration	*PES*	PES_{EX}	Scale *PES* equation with $(1.8/(2-\psi_R))$
Tonne of oil equivalent	*Mtoe*	*Mtoex*	Multiply Mtoe by ψ_R.

$$\overline{\psi}_R = \frac{\sum_{i=1}^{u}\sum_{j=1}^{v} \psi_{Ri-j} E_{xi-j} / \eta_{i-j}}{\sum_{i=1}^{u}\sum_{j=1}^{v} E_{xi-j} / \eta_{i-j}} \tag{12}$$

Here, $\eta_{i\text{-}j}$ is the First-Law efficiency between the system nodes *i* and *j*. For example, about the heat output from the CHP unit (*i*) to a demand point (*j*) the local ψ_R value for each *i-j* connection is calculated from Equations 2 or 3. For all networks of exergy flow in the $u \times v$ nodal matrix gives the overall ψ_R value (Equation 12).

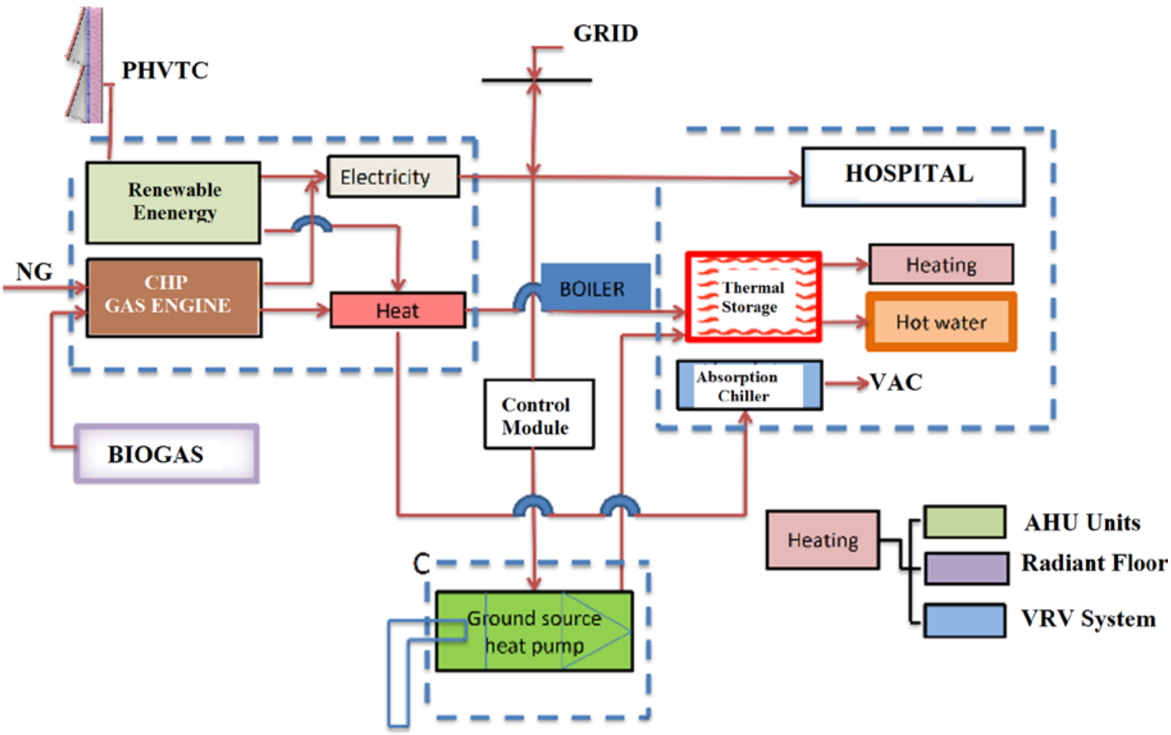

Figure 8. Electro-Mechanical System of nZEXHB.

Part of the nZEXHB requirement is that ψ_R should be at least 0.7 for a green terminal status.

Once the overall ψ_R value is determined, the compound CO_2 emissions may be calculated from

$$\sum CO_2 = \left[\frac{c_l}{\eta_l} + \frac{c_m}{\eta_m \eta_T}(1-\psi_R)\right] Q_H + \frac{c_m}{\eta_m \eta_T} E \qquad (13)$$

Here, c_l is the CO_2 content of the fuel mix of the CHP unit, η_l is its thermal efficiency. c_m is the average CO_2 content of the thermal power plants feeding the grid. η_m and η_T are the power generation and transmission efficiencies, respectively.

Discussion

From the exergy point of view, one needs a common base by converting exergy to cost or vice versa too. In this respect, the cost of exergy destruction per unit supply exergy may be embedded into cost equations, like life cycle cost analysis optimizations [6].

$$\Delta C_{EX} = c \frac{\sum \varepsilon_{des}}{\varepsilon_s} \qquad (14)$$

Here, c is the cost of average unit exergy in Euros. Average unit exergy is calculated according to EU-mix of thermal and power loads. For power, unit exergy is 1 W/W and for thermal loads at an average temperature of 333 K is 0.15 W/W.

This paper shows the need to transform to the Second-Law of Thermodynamics, if EU wishes sincerely to pursue decarbonization further with all fairness to all stake-holders. Such a move will also become a role model for all other countries of the World. In quantified terms, the task is not of a paramount magnitude. Instead, **Table 1** shows that a single key term, namely ψ_R shall transform all directives and rules in a simple fashion with a new mind-set and perspective towards the exploitation, generation, transformation, and utilization of our limited energy resources for a truly sustainable future that we all envision. The second-Law transformation does not need rocket-science, like many thinks. It is a simple change of the mind-set:

We should use:

- The right quality of energy, at the right application;
- At the right order, at the right time and location. ■

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How U.S. hospitals can realize net-zero energy

HEATHER BURPEE
University of Washington
Integrated Design Lab
burpeeh@uw.edu

Hospitals can reduce energy use with the aim of achieving net-zero energy (NZE). Insights from hospitals that are on the path to NZE and other buildings that have realized this goal help identify barriers and help identify next steps for the healthcare sector to design-toward and achieve NZE.

Keywords: Hospital, Healthcare, Energy Efficiency, Net Zero Energy

Abstract

In the United States hospitals use nearly 4% of national energy, emit over 8% of U.S. commercial building greenhouse gas emissions, and exceed $9 billion in annual energy costs. Recognizing buildings' impacts on atmospheric health as well as their connection to community health and economic viability, more hospitals are evaluating their energy impacts. Concurrent efforts are being made to improve codes, strengthen standards, and accelerate deeper energy savings across the building sector. This paper will explore how hospitals can reduce energy use with the aim of achieving net-zero energy (NZE). First, it will contextualize hospital energy use in the U.S., discussing common design practice, and define the scope and scale of NZE for commercial building projects. It will then highlight programs such as Targeting 100! and case study examples of forward-thinking hospitals that are leaders in deep energy savings and are on the path toward NZE. It will also explore an example of a non-hospital building that has achieved NZE, providing insights into achieving this goal in practice. Insights from hospitals that are on the path to NZE and other building types that have realized this goal help identify barriers unique to NZE and hospitals and help identify next steps for the healthcare sector to design-toward and achieve NZE.

Average energy use in U.S. hospitals

Hospitals in the United States (U.S.) use nearly 8% of all national energy (1), emitting an equivalent amount of greenhouse gasses, and exceed $9 billion in annual energy costs (2). In 2016 the private and public healthcare markets combined spent $464 billion nationally on new construction (3). Most of this construction occurs at code minimum energy standards, missing large opportunities for energy savings. With such large infrastructural investments, a focus on energy and environment could bolster positive environmental and economic impacts. Concerted efforts are being made to improve codes, strengthen standards, and accelerate deeper energy savings across the building sector. Hospitals can reduce energy use with the aim of achieving net-zero energy (NZE), though it would be a heavy lift requiring a shift in typical hospital design.

Understanding how typical hospitals use energy is pivotal to informing NZE design. On average, U.S. hospitals consume 231 kBtu/ft^2-yr (729 kWh/m^2-yr), ranging from 110 kBtu/ft^2-yr (347 kWh/m^2-yr) to 450 kBtu/ft^2-yr (1420 kWh/m^2-yr). For comparison, typical office buildings use 78 kBtu/ft^2-yr (246 kWh/m^2-yr) on average (4), and international examples use about 50% less energy than typical U.S. hospitals.

Data shown in **Figure 1** highlights the U.S. national average for hospital energy use as it compares to several specific examples of hospitals in Norway and Denmark (5). These data are corroborated in an older study compiled by the Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), which shows the U.S. as one of the largest energy users for healthcare, second only to Canada (6).

Defining Net Zero Energy (NZE)

In 2015, the U.S. Department of Energy published A Common Definition for Zero Energy Buildings, providing common definitions for Net Zero Energy buildings (7). Their definition for a "Zero Energy Building", which this paper refers to as a "Net Zero Energy" building, is "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy." To simplify this concept, many teams use a site-based only definition that does not consider the energy source. The New Buildings Institute has simplified this definition to only include site energy implications, stating "Zero net energy (ZNE) buildings are ultra-efficient new construction and deep energy retrofit projects that consume only as much energy as they produce from clean, renewable resources (8)." This paper applies this definition.

Net Zero Energy "ready" refers to a building with an energy profile that can realistically be accommodated by a clean, renewable energy source, which may be purchased after construction of the building. For example, the building may be built and operate reliably with a low energy profile and later, when funds are available, a photovoltaic array is installed, which produces as much energy as the building consumes on a net-annual basis.

Approaches for significantly reducing energy in hospitals

Programs such as Targeting 100! (9), ASHRAE's 50% Advance Energy Design Guide for Large Hospitals (AEDG) (10) provide a roadmap for significant energy reductions in hospitals, presenting a path toward 60%

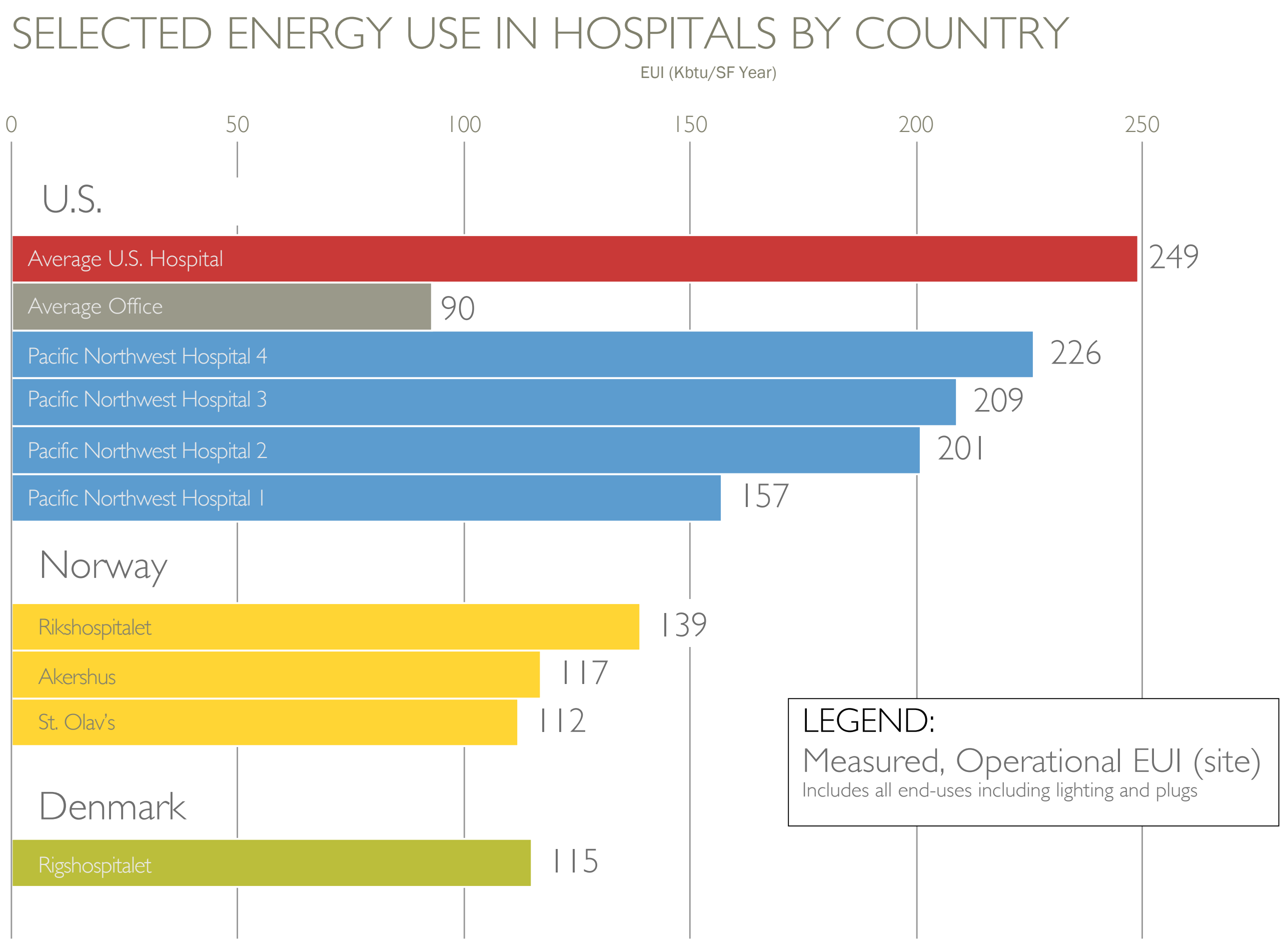

Figure 1. Hospital energy use in the U.S. vs. Norway and Denmark (100 Kbtu/SF-yr = 315 kWh/m²-yr).

energy savings at little-to-no additional capital cost. These roadmaps outline what is achievable utilizing current codes and standards, and represent a starting point for NZE or NZE-ready hospital design. Insights from recently built hospitals also showcase that lower energy hospitals are possible. For example, the Swedish Issaquah Hospital in the U.S. Pacific Northwest. operates below 120 KBtu/SF-yr (380 kWh/m²-yr), and the Peace Island Medical Center operates under 100 KBtu/SF-yr (315 kWh/m²-yr). International examples show that there is consistent achievement of similar or better results (11).

The major points for Targeting 100!, the AEDG, and recent built examples include:

1. Hospitals are large energy consumers for somewhat surprising reasons: Minimum requirements for ventilation mean that a large portion of the energy consumed in a hospital is being used to transport and condition ventilation air. Re-heat energy is the single largest energy consumer, representing 40-50% of the total energy consumed in a typical facility. Hospitals' internal requirements dictate that air be very cool in some hospital areas; spaces needing the coolest air (such as surgery suites) determine the air temperature traveling through an entire zone. All spaces needing warmer air (e.g. offices, exam rooms, patient rooms) require air to be re-heated at the delivery point. Additionally, hospitals are densely occupied, operate 24 hours per day, seven days a week, and house a lot of energy consuming equipment.
2. To reach low energy targets, designs should:
    a. **Prioritize Load Reduction through Architectural Systems**. Energy reductions start by aggressively reducing external climate dependent loads and activity dependent internal loads. A simultaneous focus on peak loads and whole building annual energy loads is important for solving the energy and cost equation. Smaller peak loads mean smaller plant equipment which translates to lower capital cost investments; lower overall load profiles provide flexibility in ventilation system choice and mean significantly reduced annual energy use profiles for heating and cooling, and thereby, annualized energy savings. Highly coordinated architectural and building mechanical systems are required to meet large load reduction goals. For example, exterior shading on the envelope significantly reduces solar heat gain enabling a de-coupled approach to building heating, cooling, and ventilation systems. De-coupling heating and cooling from ventilation of rooms enables much lower whole building load profiles and significantly reduced peak loads.
    b. **Re-Heat Energy Reduction through Building Mechanical Systems**. Strategies for reducing or eliminating re-heat include de-coupling space tempering and ventilation for most spaces; fluid rather than air-transport of heat and cooling for peak conditions; and the final distribution of heating and cooling to each space via a bundle of de-coupled systems such as radiant heating and cooling panels. These systems require a limited load profile and thus, require prioritizing load reduction strategies. Optimized heat recovery from space heat and large internal equipment sources also reduces the overall energy demand as does including advanced HVAC and lighting controls: turn off what is not in use.
    c. **Efficient Plant-Level Equipment**. Provide the ability to capture heat in the most efficient way. Utilize advanced heat recovery at the central plant and implement heat pumping, or enhanced heat recovery chillers paired with highly efficient boilers.

Implication for on-site energy production

Targeting 100!, the AEDG for Large Hospitals, and recent built examples show that achieving an Energy Use index (EUI) of 100 KBtu/SF-yr is possible alongside current codes and standards. Even though these examples utilize significantly less energy than their typical counterparts, they still use too much energy to achieve NZE by simply adding renewables. The total energy use for a 250,000 SF hospital operating at 100 KBtu/SF-yr would require a 6850 kW photovoltaic array, measuring nearly 500,000 SF (in Seattle, WA, U.S.), or a slightly smaller, 4500 kW, 300,000 SF of PV array (in sunnier Los Angeles, U.S.) to produce enough energy to offset the total energy demand in an average year (12). The site area size and cost of PV equipment is not realistic to achieve NZE. If these examples reduced their energy demand to 50 KBtu/SF-yr (158 kWh/m²-yr), that implies a much smaller array, 3400 kW (Seattle) or 2250 kW (Los Angeles), using just under 250,000 SF and 160,000 SF respectively (13). An even lower EUI, more efficient array, or sunnier climate would imply an even smaller and more affordable array to achieve NZE. These calculations highlight that in order to approach NZE, or become NZE ready, a hospital must reduce its energy footprint significantly beyond what has been achieved to date in the U.S.

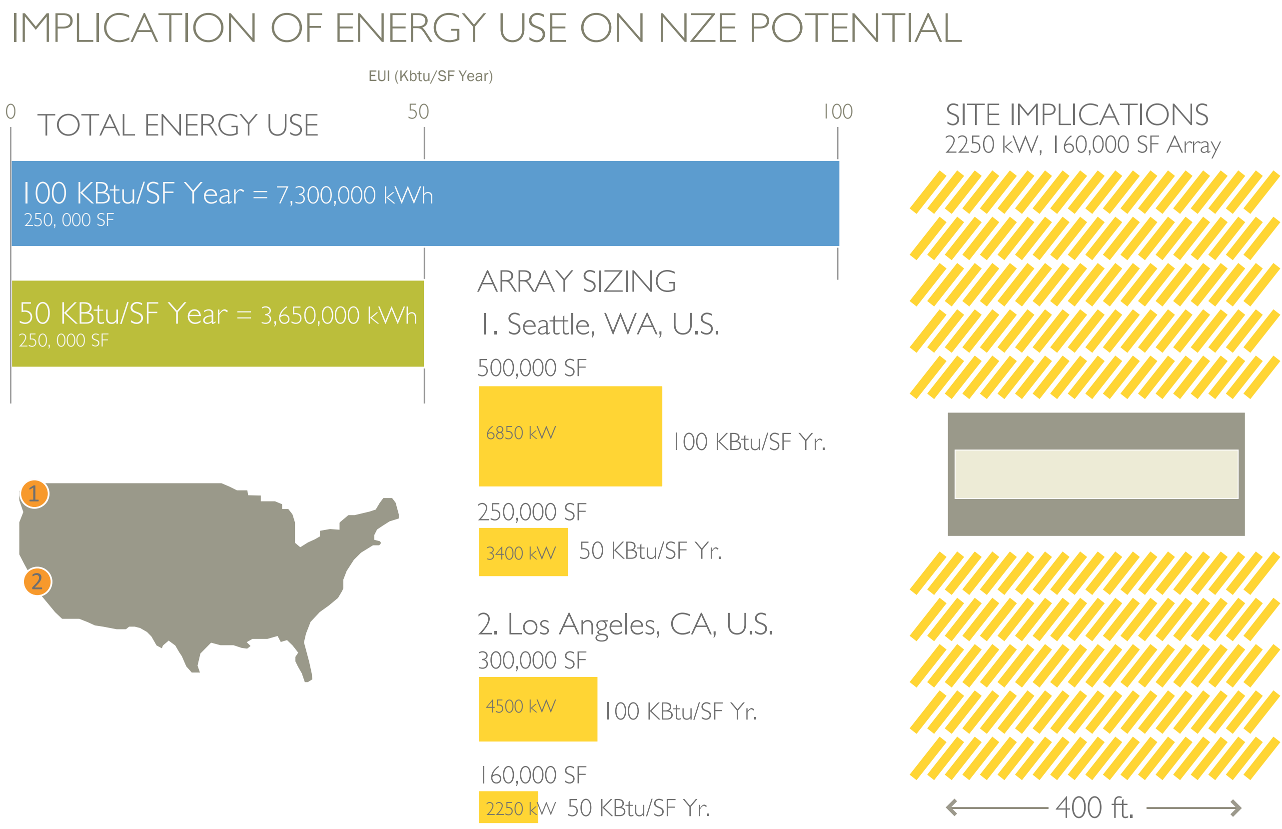

Figure 2. Implication of energy use on net-zero ready potential including relative PV array sizing and relative coverage of site area (100 Kbtu/SF-yr = 315 kWh/m²-yr).

What is needed to achieve NZE

Roadmaps and built examples show how to significantly reduce energy in hospitals usually through the natural gas systems, implying a fuel switch from predominantly gas-fired plants to all-electric plants. This presents opportunity to move closer toward NZE and carbon neutrality through strategies that achieve deeper electricity savings. Major opportunities that have not been fully addressed in healthcare are miscellaneous equipment loads (MELs) and plug loads. MELs include fan power energy both at the plant level and in distributed systems. Plug loads capture all energy connected equipment including computers, TVs, imaging equipment, and rolling devices such as IVs, beds, etc. As has been done with the hospital building as a whole, a coordinated research effort is needed to first understand the energy profiles of this equipment, then reduce energy demand where there is the most opportunity. This will likely start with choosing the most energy efficient devices, then turning off equipment not in use from full-power mode through more sophisticated controls. Re-designing devices to include energy efficiency as an important criterion will help move this area forward without negatively impacting the quality of patient experience or patient care. Efforts such as Energy Star for commercial and residential equipment show a similar path for commercial and residential equipment, and can effectively rate equipment and achieve energy savings. Energy Star has initiated partnerships that will lead to ratings for some large healthcare equipment, such as MRI machines. Once Energy Star equipment is available, a reliable energy attribute can become a specification criterion for designers involved in acquiring new healthcare equipment. Beyond MELs and plugs, careful analysis and research is needed to determine the necessity of codes and standards that impact energy-using systems in hospitals. Specifically, a concerted effort to understand effective and necessary air-change rates throughout hospitals will help re-define minimums, potentially significantly decreasing energy demands, while not compromising (or potentially improving) quality.

Learning from other NZE buildings

Current NZE buildings provide insight into how hospitals can achieve similar energy targets. The Bullitt Center in Seattle, WA U.S. is one example of a 50,000 SF commercial office building that has operated at NZE since 2013. In fact, this building has produced more energy than it consumed (making it Net Positive Energy) in its first three years of operation (14). Insights from this building include: 1. First reduce loads through the envelope, 2. Use water-based heat pumping systems for heating and cooling, 3. Provide minimum ventilation for fresh air using 100% Out Side Air (OSA) with high-efficiency heat recovery, 4. Utilize the outdoor environment as much as possible for natural ventilation and passive cooling, 5. Install very low lighting power and using comprehensive control systems to turn off lights when not needed, 5. Implement sophisticated building controls that guide users in energy-using systems, 6. Gain comprehensive understanding and control of plug loads, 7. Measure and verify energy use patterns at a granular level to understand what is working and where improvements can be made, 8. Since plug-loads and patterns of use become a bigger part of the energy picture, partner with building occupants to participate in energy efficiency strategies and utilization, and 9. Partner with utilities to ensure a transaction structure that is sustainable and economically viable for public and private entities as more buildings approach NZE.

Hospitals are often more complex and sophisticated than typical commercial buildings. However, there is a path toward energy and carbon neutrality that is achievable. A comprehensive re-visioning of how a typical hospital is designed and operated must be part of the solution for meeting and achieving aggressive energy targets that are outlined by city, state, and governmental leaders. ■

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The hope and possibility of net-zero hospitals in the US regulatory context

TRAVIS R. ENGLISH
PE; Director of Engineering;
Kaiser Permanente; Oakland, CA, USA

US hospital energy consumption is high, relative to other US commercial facilities. Net-zero hospital seem a far goal. Much of the energy in US hospitals goes to HVAC systems. US hospital HVAC design is regulated by a set of prescribed air changes per hour for most spaces. This design paradigm could be updated and revised, incorporating learnings from best-practices in indoor air quality, comfort design, and energy conservation. New design ideas and code reform hold promise to move US hospital design towards the net-zero design ideal.

Keywords: health care, ventilation, energy

US hospital energy consumption and net-zero potential

US benchmarking studies use the metric Energy Use Index (EUI), in units of kBtu/ft²-yr (kWh/m²yr). Commercial net-zero buildings, or net-zero capable buildings often target a range of 20–45 kBtu/ft²-yr (60–90 kWh/m²yr). Such a building's annual consumption can typically be offset by an on-site energy plant (e.g. photovoltaic panels).

Compared to other commercial sites, hospital sites are often large and include amenities and support facilities. A normally-developed hospital site, where 10–25% of the property could be devoted to photovoltaic panels, would need to consume between 40 and 110 kBtu/ft²-yr (120–350 kWh/m²yr) for an annual net-zero balance. We have proposed an average target of 60 kBtu/ft²-yr (190 kWh/m²yr) for the consumption of net-zero hospitals.

The average energy consumption of US hospitals, from the 2013 national survey data, is 230 kBtu/sf-yr (725 kWh/m²yr), nearly four times the target. In contrast, the average commercial building energy consumption is 90 kBtu/ft²-yr (290 kWh/m²yr). The high energy consumption shows the need for technological development. At closer investigation, HVAC is the most important and meaningful opportunity. 60% to 75% of the typical US hospital's energy goes to ventilation, heating, and cooling. See **Figure 1**. Therefore, the primary focus to reduce US hospital energy should be that of reducing HVAC energy.

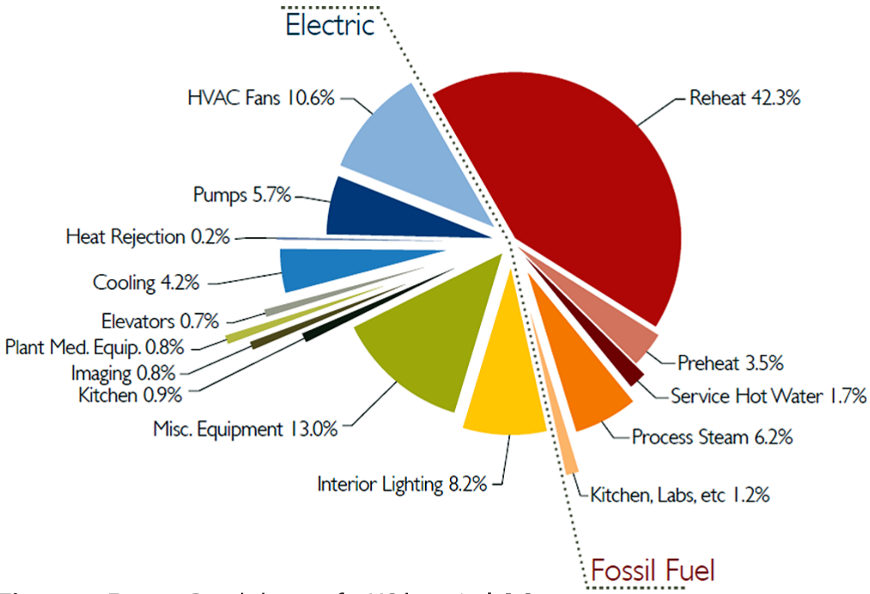

Figure 1. Energy Breakdown of a US hospital. [1]

To meaningfully reduce health care sector energy, technologies must favor existing applications. Turnover of US hospitals is slow. Due to the capital intensity of new development, hospitals have long facility lives. Remodel and renovation are quite common. New construction is a small fraction of the overall stock.

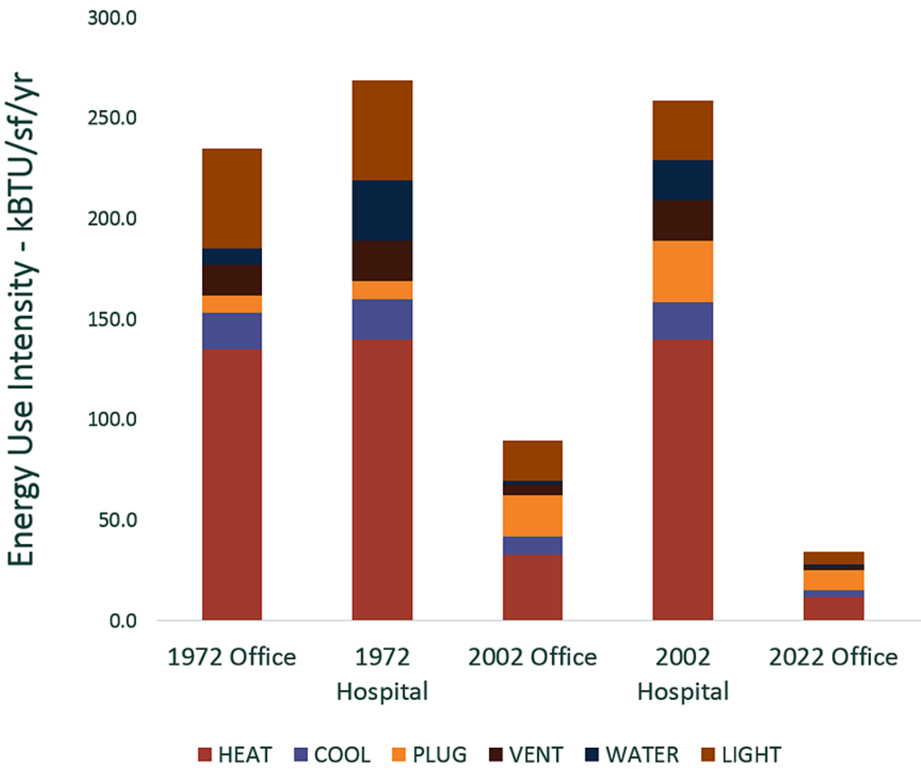

Figure 2. Historical Reduction in US Commercial Building and Hospital Energy.

While significant energy reductions may seem a daunting challenge, there is reason to believe much can be accomplished quickly. From 1976 to 2002, successive and progressive US energy codes have yielded a radical reduction in commercial building energy. Total energy reduced nearly 60%. HVAC energy reduced nearly 70%. Heating reduced nearly 75%. Much of the savings has been in HVAC. In particular, heating and reheat energy has vastly reduced. See **Figure 2**. Health care facilities, whose HVAC systems were granted exceptions from energy codes, have been largely unaffected. Today, for reasons discussed below, many health care spaces are over-ventilated much of the time, causing excess heating and cooling energy use. This energy may be opportunity for reduction.

The Air Change per Hour (ACH) US Code Paradigm

Hospital HVAC systems in the US are designed differently than other buildings. This is true for most spaces, not just critical spaces like operating and isolation rooms, which have specialty requirements in most countries. In the US, spaces that occur in both hospitals and other commercial buildings have unique requirements in hospitals. In other words, the HVAC design standards used for hospital restrooms, corridors, and linen storage spaces are completely discreet from the HVAC design standards used for hotels' restrooms, corridors, and linen storage spaces. On the whole, hospitals require significantly more air than counterpart commercial buildings at the turndown or minimum conditions.

Best practices in ventilation for indoor air quality are well-established in commercial buildings, with a body of scientific and engineering literature dating from the 1970s on attainment of indoor air quality. Indoor Air Quality (IAQ) is the "air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants" [2]. Air quality standards, stated as acceptable limits of contaminants, are developed by multiple sources including the ACGIH [3], OSHA [4] , NIOSH [5], and EPA [6]. The well-respected US ASHRAE Standard 62.1 - Ventilation for Acceptable Indoor Air Quality [7], provides a model code for commercial buildings in the US, but does not contain guidance specific to hospitals.

Best practices for comfort design are also well-established, with a body of scientific and engineering literature. Thermal comfort design in the US is represented in ASHRAE Standard 55 [8], which includes the well-known PPD/PMV (percent of people dissatisfied / percent mean vote) comfort model and survey protocol.

Building standards for hospitals in the U.S. rely on a different, legacy ventilation methodology requiring "air changes per hour" (ACH). Because of this reliance on the older ventilation practices, hospitals over-ventilate many spaces, much of the time. This contributes to relatively large amount of fan, cooling, and heating energy.

The legacy of US HVAC guidelines

US hospital HVAC standards come from an earlier era. As part of the 1946 *Hospital Survey and Construction Act*, "General Standards" were added to the US Federal Register in 1947. The title and authorship of these standards has changed over the years. The US Public Health Service (PHS) published "General Standards" until 1974, then "Minimum Requirements for Construction and Equipment for Hospital and Medical Facilities". In 1984, the American Institute of Architects (AIA), began publishing "Guidelines for Construction and Equipment of Hospital and Medical Facilities" in 1987. In 1998, the AIA turned them over to the Facilities Guideline Institute (FGI) who now published the "Guidelines for Design and Construction of Hospital and Health Care Facilities" [9].

The early versions of these standards contained ventilation requirements in narrative form. Beginning in 1968, ventilation requirements were compiled into a table of ACH rates. In the early 2000's, the table was removed from the FGI "Guidelines", and published as ASHRAE Standard 170.

Unfortunately, much of the thinking behind the ACH rates is lost to history. Entries are not cited to scientific or engineering literature. In 2015, a research paper collected as many historical entries as could be found, and published a table of ACH requirements for key spaces from 1959 to 2013. See **Table 1**. In another effort to discover origins, ASHRAE and FGI have co-sponsored a research project entitled "CO-RP 3 Evidence Based Research Project: Literature Review

Table 1. Selected Air Change Rates Across the Years, Outdoor ACH/Total ACH (Abridged. Source [10])

	1959	1962	1964	1966	1968	1971	1974	1978	1982	1987	1991	1993	1997	2001	2006	2008	2013
	Source: ASHRAE Guidebooks, compiled in "Ventilation Designs" [11].											Source: FGI archives (FGI, 2013).				Source: ASHRAE 170	
Operating Room	8-12	**15**	15	15	**25/5**	25/5	25/5	25/5	25/5	25/5	25/5	**15/3**	15/3	15/3	15/3	**20/4**	20/4
Recovery		**4**	4	4	**15/6**	15/6	15/6	**6/2**	6/2	6/2	6/2	6/2	6/2	6/2	6/2	6/2	6/2
Nursery	**8-12**	**12**	12	12	**15/5**	15/5	15/5	**12/5**	12/5	12/5	12/5	**6/2**	6/2	6/2	6/2	6/2	6/2
Patient Room	**1.5**	1.5	**2**	**4/2**	4/2	4/2	**2/2**	2/2	2/2	**4/2**		**2/1**	**2/2**	**6/2**	6/2	6/2	**4/2**
Toilet Room						**10**	10	10	10	10	10	10	10	10	10	10	10
Intensive Care					**6/6**	6/6	**6/2**	6/2	6/2	6/2		6/2	6/2	6/2	6/2	6/2	6/2
Isolation Room		**4**	4	**6**	**12/12**	12/12	12/12	**6/2**	6/2	6/2	6/2	**6/1**	**12/2**	12/2	12/2	12/2	12/2
Patient Corridor						**4/4**	4/4	4/4	**4/2**	4/2	4/2	2	2	2	2	2	2
X-Ray D&T		**6**	6	**10**	**6/6**	6/6	6/6	**6/2**	6/2	6/2	6/2	6	6	6	6	**6/2**	6/2
Autopsy		**10**	10	**15**	**15/6**	15/6	15/6	**12/2**	12/2	12/2	12/2	12	12	12	12	12/2	12/2
Exam Room		**4**	4	4	**12/6**	12/6	12/6	**6/2**	6/2	6/2	6/2	6	6	6	6	6/2	6/2
Med Room								**4/2**	4/2	4/2	4/2	4	4	4	4	4/2	4/2
Treatment	**4**	4	4	**12/6**	12/6	12/6	**6/2**	6/2	6/2	6/2		6	6	6	6	6/2	6/2

for ASHRAE Standard 170-2013" the purpose of which is to uncover or discover available evidence supporting the requirements in the US standard. As of this writing, the research is in progress. The researchers have identified over 500 studies and papers, and are attempting to extract what evidence can be found to support the over 850 unique requirements in the US standard.

The US health care HVAC standard story is analogous to a software developer having lost the source code to an application. Without source code, an application can still be used, copied, and installed on new workstations. It can continue to gain users. However, it can't be updated. Bugs can't be fixed. Features can't be added. Similarly, the US health care HVAC guide, with ACH rate requirements of uncertain origins, is still used. Authors add new spaces simply by copying entries from spaces already in the guide. However, existing entries are difficult to update. Problems are difficult to fix. New technologies are difficult to add.

Popular perceptions of US engineers

Ask many US engineers why the ACH rates are used or maintained, a common answer will be related to control or prevention of infections. We performed a survey of US engineers in 2013 that found many US engineers believe the HVAC guide requirements are related to infection control [12].

Naturally, there are spaces in hospitals where the HVAC practices are related to the clinical outcomes and infection control. In operating rooms, clean air is used to mitigate surgical site infection risk from airborne particles [13]. In protective environments, for transplant recipients or severe immune compromised, clean air is used to mitigate "opportunistic infections" from airborne particles [14]. Other clean spaces include pharmacy compounding and sterile packing. Facilities also have designated airborne isolation spaces, both short term and long term. When airborne disease cases arrive at facilities, they are isolated to a room which is exhausted, and held under negative pressure [15].

However, popular perception among engineers extends beyond these spaces. Some engineers believe air rates factor in typical inpatient infections, such as catheter infections or bloodstream infections. That this idea lacks scientific evidence seems to dampen its popularity only little.

The present and path forward

The path to next-generation, performance-based design and operating standards will be long and difficult. However, progress has begun; code groups are working on solutions. One group convened in early 2015 to coordinate across clinical standards and clarify operating protocols. Another independent group worked through 2015 and 2016, to investigate alternate health care HVAC design methods. A risk-based, less prescriptive approach has been proposed and is in development. A task group has done a preliminary investigation into allowances for natural ventilation, and is moving forward in development. A recent focus on outpatient facilities may result in recognition of alternate methods already in use in the outpatient portfolio. Smaller teams are also sharing knowledge and best practices among domestic standards.

Architects and engineers take creative approaches to forge ahead. They often stretch to the limits of standards, or slightly beyond. Chilled beams, natural ventilation, and displacement ventilators are deployed in US acute care projects. Facilities operators have adapted systems into more performance and risk based operational paradigms. A pilot project in development is investigating performance-based ventilation in an inpatient tower based on continuous indoor air monitoring. Outpatient projects are designing for very low design energy use, 40–50 kBtu/ft²-yr (120–190 kW/m²yr).

There have been a few US examples of net-zero, near net-zero, or attempted net-zero hospital designs. The trend will continue. Some of the examples to date are a bit opportunistic. They've invested in renewables, but they haven't been able to deeply reduce consumption.

Evolving to a new US HVAC toolkit, based on indoor air quality and comfort tool, will open the door to lower consumption, more net-zero hospitals, a greener health care building sector. ■

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Getting to zero – Managing the impacts of waste

WALT VERNON
Principal, CEO
Mazzetti, San Francisco, California

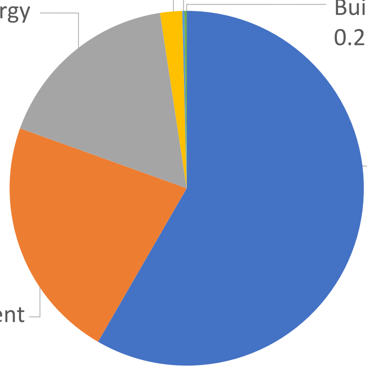


Figure 1. The ecological footprint of the National Health Service in England and Wales, by component, in 2001.

Why waste is an essential element of net-zero analysis

The concept of net-zero buildings usually focuses on the energy that flows into the building in some metered form – electricity, diesel fuel, natural gas – but the reality is that the emissions footprint of a building as a locus of human activity goes much beyond. Indeed, failing to effectively recognize and manage the emissions resulting from the stream of physical objects into and out of the building leaves much opportunity for climate mitigation on the table.

For many years, climate emission calculations have included emissions from "Scope 1", "Scope 2" and "Scope 3" activities[1]. These categories extend the focus from direct on-site energy emissions (Scope 1); to generation of energy off site (Scope 2); to indirect emissions that are the consequence of the activities of the company, but occur at sources owned or controlled by another company. In the healthcare world, the UK's National Health Service first tried to catalog these broader impacts for the entire sector in that country in 2001.[2] That initial analysis showed that the building produces only about 20% of the total energy/emissions impact of a building, with by far the largest impact from products consumed and wasted (**Figure 1**).

The work of the UK was extended by the International Federation of Hospital Engineers in its first ever projection of global greenhouse gas emissions for the global health sector.[3] This analysis determined that the global health sector currently accounts for approximately 2.6% of all emissions (Scope 1,2, and 3).

So, while it is clearly important for designers of the health sector to focus on the reduction of direct building energy consumption, a truer focus of net zero must also include the management of the healthcare material flow through that building. Yet, other than efforts to manage the waste stream to less costly and more compliant flows, we have historically not had much in the way of tools to help us manage these emission impacts at all. But, that is now changed.

Two new tools, one from the US EPA and one from a private consulting firm, provide the first attempts to extend the analysis of emissions footprint to the waste stream. For a serious focus on "net zero" energy buildings, these impacts must become part of the equation.

1 See, e.g. World Resources Council for Sustainable Development and World Resources Institute, The Greenhouse Gas Protocol, A Corporate Accounting and Reporting Standard, Revised, (file:///Users/waltervernon/Desktop/ghg-protocol-revised.pdf)

2 See, e.g., Best Foot Forward Ltd., Material Health, A mass balance and ecological footprint analysis of the NHS in England and Wales, April, 2004.

3 Troy Savage and Walt Vernon, "Greenhouse gas: global healthcare inventory," IFHE Digest, July 4, 2017, pp. 41. (http://ifhe.info/library/greenhouse-gas-global-healthcare-inventory)

The US EPA recently launched WARM, the Waste Reduction Model.[4] This tool has many beneficial features, including the presumption of scientific validity and impartiality. However, for the practitioner aiming at net zero for healthcare buildings, it falls short. The EPA tool, in particular, does not include certain critical categories of waste (infectious, pathological, and pharmaceutical) specific to the healthcare enterprise. Moreover, it ignores new technologies for waste conversion that are non-combustion. Finally, it focuses only on CO_2, and not the myriad of other climate-changing airborne emissions from the healthcare waste stream. Another tool has recently emerged that fills these critical gaps.

The hazards created by healthcare waste are complex, and its management much more so. It varies in type and quantity, risk profile, public perception, regulatory complexity, and available management methods. Laws and regulations across the globe require certain types of waste be treated in specific ways to render it into less-hazardous materials. These treatment options can be expensive, resource consumptive, and environmentally damaging; in fact, every method of waste management creates consequences for the natural world[5]. Most problematic is the treatment of infectious, pathological and pharmaceutical wastes. These wastes are a small portion of the total volume of waste coming out of a hospital, but they pose special complications. Pathological and infectious wastes obviously carry with them the risk of disease transmission. Health threats such as Ebola underscore the hazardous nature of these waste streams. Pharmaceutical wastes are chemicals that pose exposure risks to humans and wildlife. Many countries require these parts of the healthcare waste stream to be incinerated. With no real alternative, the WHO agrees[6] that, in the short run, incineration is a preferable strategy, though aspiring to better methods that produce no or few dioxins and furans in the future. Many parts of the world have no regulation, or at least, no effective regulation of medical waste disposal. Even where regulation exists, needed infrastructure to implement it may be seriously lacking, leaving a local facility with few options.

4 Available at https://www.epa.gov/warm.

5 See, e.g. Francesco Cherubini, Silvia Bargigli, and Sergio Ulgiati, "Life cycle Assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration," Energy 34 (2009), 2116 – 2123.

6 "Safe management of wastes from health-care activities", World Health Organization, 2nd edition, 2012.

EPA Waste Emission Reduction Techniques

Warm includes traditional waste reduction techniques, including source reduction, recycling, anaerobic digestion, composting, combustion, and landfilling, with a high degree of granularity. Indeed, this very granularity, while apparently improving the accuracy of its results, also makes data gathering and input daunting.

Waste to Energy Emission Reduction Techniques

The Healthcare Waste Calculator of IFHE introduces healthcare specific waste streams, simplifies to a degree the data gathering required, and introduces new waste management techniques specifically applicable to healthcare needs.[7]

Autoclaving, the most widely used non-incineration form of treatment system, sterilizes medical waste using steam and high pressure. These systems are limited to the treatment of pathogens (live infectious agents) and do little to render chemicals non-hazardous. Further, autoclaving does not render waste unrecognizable and in the U.S., many states required that before waste is landfilled, it must be unrecognizable, adding the need to shred treated waste. Autoclaving was used in many base scenario-planning cases.

Pyrolysis is an oxygen-free thermal treatment process that processes waste at temperatures between 750°F and 1500°F in the absence of air.[8] The lack of oxygenation is a critical difference between pyrolysis and combustion. The fuel used to initiate the "baking" of the waste can be natural gas, propane, or the gas generated by the pyrolysis process itself. This process first uses a pyrolytic chamber that reduces the waste to ashes and gases, and uses a "post-combustion" chamber to burn the produced gases at very high temperatures. This resulting synthetic gaseous (syngas) product of this and other conversion technologies is often referred to as syngas, and consists of hydrogen, carbon monoxide, and methane. Both off- and on-site facilities, as well as small- and large-scale pyrolytic systems are available. Today, pyrolysis is the most likely technology to be used for healthcare applications because of unit sizing more appropriate to in-house or smaller uses, and because, while still costly, it is relatively less than other CTs like gasification or plasma arc, briefly included below for edification.

7 See Walt Vernon, "The Complexities of waste management," IFHE Journal, January 1, 2016, p.53, (http://ifhe.info/library/the-complexities-of-waste-management).

8 California Integrated Waste Management Board. 2007. New and Emerging Conversion Technologies: Repot to the Legislature.

Gasification is a process in which organic waste is partially oxidized to form chemical reactions to produce carbon dioxide, carbon monoxide, and methane gases that create extreme high temperatures in the gasifier. The syngas that is generated from the three primary gases can be utilized for industrial and commercial process and products, including photographic film, coal, and petroleum, while the solid residue (slag), made non-hazardous by cooling, can be used for a variety of manufacturing products. Some versions of this technology use the gas to fuel the process, and extract heat energy from the system for use as an energy source.

Plasma Arc is another form of CT that uses extremely high temperatures, and is also very expensive. It may be a good solution for the chemical or ammunitions industry, is it probably overkill for on-site healthcare solutions.

Waste-to-energy (WTE) systems can be integrated into these CT systems rather easily, and because these systems can generate a large amount of syngas, the opportunity to generate energy is used in both the economic and environmental countermeasures. CT systems are applicable for waste treatment for infectious, pathological, sharps, and (if applicable) MSW.[9] However, RMW must be pre-treated and MSW must be shredded prior to the CT process, which is yet another complicating factor.

So where do we go from here? The volume and toxicity of waste is not getting any smaller. Existing systems are aging. New technologies are available. Health facilities need a plan. But in order to develop a plan, they need data on the health impacts of transporting waste long distances, on the real emissions of one technology over another, on the benefits, and impacts, of waste-to-energy compared to the impacts of energy from other sources. Is it more environmentally and health friendly to recycle waste that is transported hundreds of miles, and perhaps shipped overseas, or used in a local WTE/CT unit? The healthcare sector could greatly benefit from asking these tough questions so that, together, we might be able to make evidenced-based informed on the benefits and impacts of one technology over the other.

9 Los Angeles County Department of Public Works. 2007. Los Angeles County Conversion Technology Evaluation Report, Phase II report.

10 http://www.mazzetti.com/wastecare-calculator-help-revolutionize-medical-waste-management/

WasteCare Calculator [10]

The International Federation of Hospital Engineering recently published an article on a new Waste Treatment Calculator as a means for comparison and assessment of the different treatment scenarios specific to healthcare organizations. Not only is the tool specific to healthcare, but also it expands the consideration to all gaseous emissions, as well as including various waste to energy waste management processes. The Calculator compiles performance data, transportation considerations, and environmental emission factors from different types of waste treatment options presented in **Table 1**. The calculator references various emissions factors from landfilling, transportation (e.g., distance, fuels consumed, truck type), mass and energy balances, etc. wherever they are used so that can be changed when new data is available, or if there is simply a disagreement factor used.

Table 1. Waste treatment options.

Waste Management Technique	Considered by EPA Tool?	Considered by IFHE Tool?
Source Reduction	Yes	Yes
Recycling	Yes	Yes
Anaerobic digesting	Yes	
Composting	Yes	
Combustiont	Yes	Yes
Landfilling	Yes	Yes
Autoclave		Yes

The intent of the calculator is to be a free, globally-relevant, transparent, highly scientifically rigorous, and open-source tool for the measurement of waste management scenarios. The website clearly describes data sources and invites public input to improve the tool's accuracy.

The calculator user needs to understand and compile all of the information on what is happening today to create the Base scenario. This includes information relating to waste generation types and weights, where and how the waste if being managed. Then to further understand the assumptions of the scenarios to be analyzed, like the on-site and off-site, CT treatment systems need to be compared via CT systems and information and assumptions, summarized in **Figure 2**.

Analyzing WTE systems adds a certain complexity, but a necessary one that addresses the impacts of energy produced, and displaced. Material input specifications included waste, water, and oxygen consumption. Material output specifications included syngas, water, and solid residue generation; recoverable residue generation (if applicable). Energy input specifications include energy from internal waste processing; natural gas and electricity consumption, and output includes net electricity export; internal plant "parasitic" consumption; energy losses from system. And of course, emissions from all sources, and of all types (including mercury, dioxins, and furans).

Calculator assessment example

To determine the validity of the Calculator, treatment scenarios were formulated that reflected real-world scenarios. The Base Model assumed that waste is treated using typically available treatment methods and actual distances for a 100-bed hospital in Southern California. **Table 2** summarizes the general assumptions for the scenarios. A critical assumption was that the total waste management operation included a progressive waste minimization and recycling program to minimize the total amount of waste of any kind that requires treatment, creating a recycling rate of 40%, while the other 60% of the waste requires treatment.

Per the Calculator requirements and assumptions, the total amount of waste in each scenario remains constant. It was assumed that 60% of the total waste quantity would require treatment and include 1) Dangerous Waste (DW: pathological and pharmaceutical waste that is required to be incinerated by regulations), 2) Regulated Medical Waste (RMW), and 3) MSW. All the analyzed scenarios are shown in **Table 3** with their specified assumptions that were included when analyzed within the Calculator. In the Base Model, the three waste streams are treated in different locations using different technologies. In the scenarios using CT's, the

Table 2. Assessment scenarios.

Item	Assumptions
Waste Generation	Total Generation Rate: 1.15 Tons/Day DW (5% of Total) RMW (10% of Total) MSW (45% of Total)
Hospital Size and Location	100 beds in Southern California
Treatment Facility Locations	Incineration: Chambers, TX Off-Site Treatment (CT & Autoclave): Vernon, CA Landfill: Lancaster, CA
Cost Considerations	Electricity, Water, Wastewater, Diesel Fuel, Labor, Landfill Disposal, Hauling, Off-Site Treatment
Hauling Schedule	Based on EPA Requirements 3 days for all types of untreated waste 90 days for residuals from on-site CT treatment

Table 3. Assessment scenarios.

Scenario Name	Waste Commingled?	Treatment System	System Location	Waste Disposed in Landfill
Base Model	NO	Incineration for DW Autoclave for RMW Landfill for MSW	All Off-Site	MSW Residuals from Treatment
Pyrolysis	YES	Pyrolysis – Small	On-Site	Residuals from Treatment

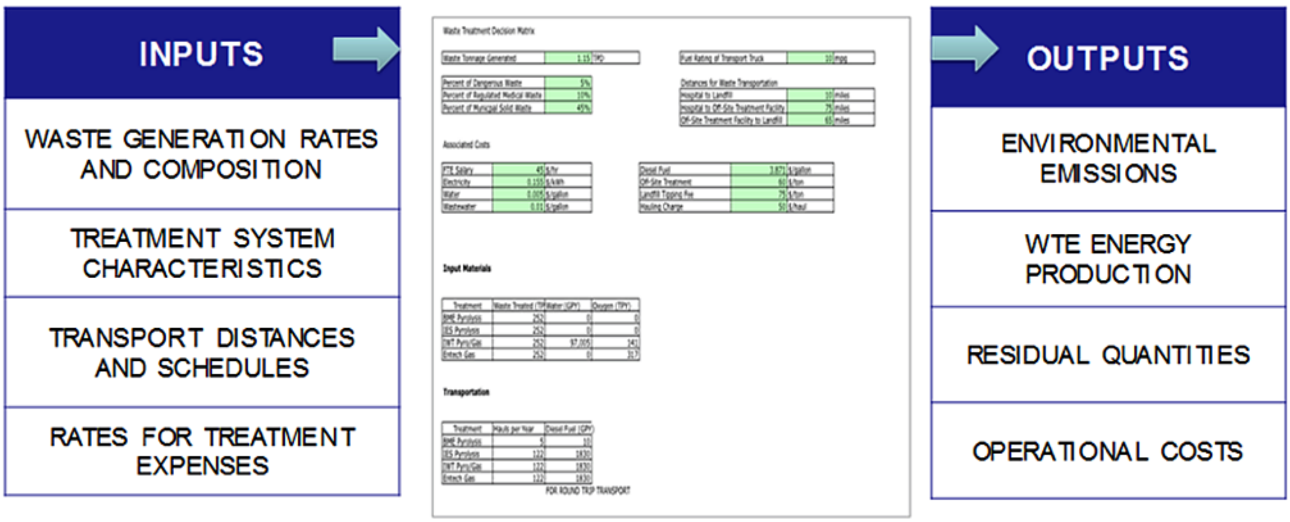


Figure 2. Inputs and Outputs of the Waste Treatment Calculator.

waste is "commingled" (only in the sense that they are going to the same location, but stored and managed according to regulations).

One important waste management question that was considered is if it is better to landfill MSW or include it in the total waste sent to the CT system, even though it is not required to be treated. For the specified scenarios, emissions were found to be greater for landfilling MSW than through a treatment system; a factor of four was reported for carbon dioxide emissions and a factor of two was reported for dioxin emissions for landfilling versus treatment. It was also beneficial to include MSW for adequate moisture content preservation during treatment and to reduce expenses.

Conclusion

This article probably raises more questions than it answers. But the healthcare sector needs solutions to address a waste dilemma that is not going away. Are conversion technologies really just incinerators in disguise? What are the emissions from a life-cycle analysis? For a hospital that is committed to human health and environmental protection (aren't we all?) and thinks they are making the right decision to ship waste to faraway places instead of treating waste closer to home, is that really the "right" decision? The IFHE invites the global community to review the WasteCare Calculator so we can all benefit from a viable, reliable decision making open-source tool. ■

REHVA Displacement Ventilation GUIDEBOOK

Displacement ventilation is primarily a means of obtaining good air quality in occupied spaces that have a cooling demand. It has proved to be a good solution for spaces where large supply air flows are required.

Some advantages of displacement ventilation:

- Less cooling needed for a given temperature in the occupied space;
- Longer periods with free cooling;
- Potential to have better air quality in the occupied spaces;
- The system performance is stable with all cooling load conditions.

Displacement ventilation has been originally developed in Scandinavian countries over 30 years ago and now it is also a well-known technology in different countries and climates. Historically, displacement ventilation was first used for industrial applications but nowadays it is also widely used in commercial premises.

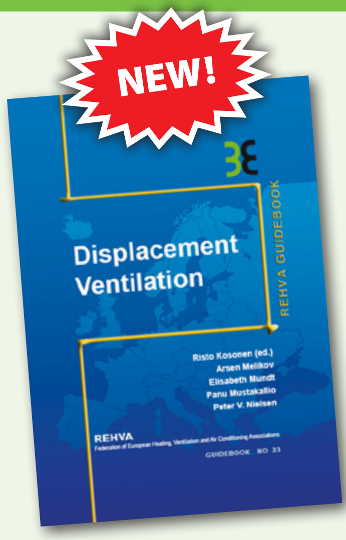
However, displacement ventilation has not been used in spaces where it could give added values. For that there are two main reasons: firstly, there is still lack of knowledge of the suitable applications of displacement ventilation and secondly, consulters do not know how to design the system.

REHVA published 2002 the first version of displacement ventilation guide. The aim of this revised Guidebook is to give the state-of-the art knowledge of the technology. The idea of this guidebook is to simplify and improve the practical design procedure.

This guide discusses methods of total volume ventilation by mixing ventilation and displacement ventilation and the guide book gives insight of the performance of the displacement ventilation. It also takes into account different items, which are correlated, to well-known key words: free convection flow; stratification of height and concentration distribution; temperature distribution and velocity distribution in the occupied zone and occupant comfort.

The guide book discusses two principal methods which can be used when the supply air flow rate of displacement ventilation system is calculated:

1) temperature based design, where the design criterion is the air temperature in the occupied zone of the room and



REHVA Guidebook No. 23 is now available!

2) air quality based design where the design criterion is the air quality in the occupied zone. Some practical examples of the air flow rate calculations are presented.

The air flow diffusers are the critical factor: most draught problems reported in rooms with displacement ventilation are due to high velocity in the zone adjacent to the diffuser. This guide explains the principle for the selection of diffuser.

This guide also shows practical case studies in some typical applications and the latest research findings to create good micro climate close to persons is discussed.

These and some other aspects are discussed in this book. Authors believe you will find this guide useful and interesting when you design or develop new ventilation solutions.

REHVA - Federation of European Heating, Ventilation and Air Conditioning Associations
40 Rue Washington, 1050 Brussels – Belgium | Tel 32 2 5141171 | Fax 32 2 5129062 | www.rehva.eu | info@rehva.eu

Towards net-zero hospitals in the UK

FRANK MILLS
BSc(Hons) FCIBSE MIMechE MASHRAE MIE
Frank Mills Consulting Limited, Leyland, UK, PR26 6RP

This paper reports progress toward the target of Net Zero Energy Hospitals in the UK. The UK has set ambitious targets for reducing carbon emissions and for reducing energy usage generally to move away from the use of fossil fuels and toward non-fossil or renewable' energy sources. This involves amongst other things, moving toward net zero hospitals.

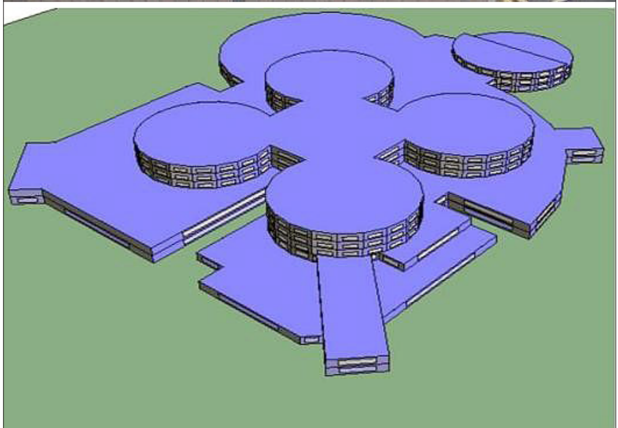
Keywords: Net zero Energy, hospital ventilation, district energy, natural ventilation.

The UK wants to achieve a 'decarbonised' electricity grid. Applying this policy to UK Hospitals, both new and existing, poses a challenge because they are amongst the highest energy consuming buildings and the trend is toward MORE rather than less energy as healthcare uses more medical equipment.

Agenda for change

Climate Change, depletion of fossil fuel reserves and rising energy costs are impacting directly on the UK and have led to the conclusion that the future will be 'zero carbon'. Continued reliance of fossil fuels is also impacting upon health and well-being and is being an economic risk.

Queens Hospital, Romford



- Energy reduced from
  101 (previous hospital)- to 60 GJ/100m³/annum
- Over 50% naturally ventilated
- Daylighting with Lighting controls
- Control of glare and summer heat gains
- Heat recovery

In healthcare, the UK NHS has introduced policies for 'Sustainable Healthcare' buildings [1] and through its HTM publications (Hospital Technical Memorandums) [2] is setting new ambitious targets.

These are also in-tune with wider UK policies such as the Climate Change Act [3]and more recent city plans such as the London Plan [4] and the Manchester Climate Action Plan [5].

Future hospital energy usage

The indicators show that hospitals will need to use more energy rather than less. The population is growing – and living longer, getting older. Healthcare is also developing its scope, finding new cures, providing more and better services. Many of these new services require sophisticated medical equipment and reliable energy supplies.

The UK's energy policy can be summarised as follows

- All new buildings including hospitals should be 'Zero Carbon' from 2019.

- All existing buildings including hospitals should progress toward zero carbon as part of the commitment to reduce by 80% overall by 2050.

Action so far

Whilst there have been several exemplary projects constructed, the UK is failing to meet some of its early stage commitments. For example, the Target to build all new schools as zero carbon from 2016 onwards has not been achieved. The 'Road to Zero Carbon' report published by the Zero Carbon Task Force of the UK department for children, schools, and families, in 2010, set out strategies for achieving zero carbon schools and showed that this is a relatively easy target since schools are occupied for limited periods, during daytime hours and have limited overall energy usage. However, there are no actual zero carbon schools completed. Instead, the Building Regulations Part L target for zero carbon has been revised to 'near zero'.

The conclusions now are that the political ambitions are not being realised in practice. In healthcare, this situation is further compounded by the priorities toward the patient experience, rising demands and pressure on hospital budgets. Whilst energy reductions should lead to improved budgets the investment needed to fund energy savings is being spent on NHS Staff costs, new medical equipment – and even higher energy costs, as tariffs rise.

Hospital Boards find themselves postponing energy improvements to respond to public and political demands for more and better treatments.

The UK NHS took part in the Energy4Health research project [7] which was carried out in support of the EU Demand Side Action Plan. The aim was to develop a roadmap to influence the demand for innovative energy solutions in the healthcare sector. The vision for this initiative was to: -

1. Make the European Healthcare sector the global leader in energy efficiency and community renewable energy systems.
2. Achieving 'many' carbon and cost neutral hospitals
3. Reducing the average cost of energy to less than 1% of the healthcare budget.
4. Moving toward a target carbon footprint less than 20% of 1990 levels (in-line with the 80% reduction target in the UK Climate Change Act).

The NHS found many difficulties in establishing a realistic roadmap and noted the following: -

a) Energy benchmark data poor or not available
b) Lack of investment finance, with a general intent to direct as much funding as possible to 'front-line' services. The financial benefits of lower energy use can never be realised
c) Skills shortage in Energy Saving.

Energy4Health road map issue:

Issue identified	UK Hospitals - NZE
Energy Benchmark Data	ERIC system requires overhaul
Finance and Investment	NHS priority is patient care
Energy Knowledge and Skills	Reliance on meeting basic standards – Building Regulations
Health Impacts of Energy Choices	Lack of awareness
Strategic Direction and Incentives	NHS HTM 07 and other codes regarded as 'guidance'.
Risk Aversion to Innovative Solutions	Traditional – Business as Usual, is the norm. PFI contractor lead prefers tried and tested solutions.

UK hospitals use too much energy

The UK Energy database, commonly known as the ERIC system uses annual returns from Hospitals to provide an overview of UK Hospital energy usage. The data is configured to show usage in bands from the highest to lowest and can be used as a type of league table. However, there are usually reasons for high energy use – location, old uninsulated Victorian buildings, high equipment load, intensive usage and so forth.

What is perhaps more concerning, is a comparison of UK data with North America.

Average UK performance is 68.6 GJ/100m³/annum, the US is 45 GJ/100M³/annum.

This is a surprising fact considering that the UK has a mild, temperate climate compared to the extreme summers and winters of the US.

Table of UK hospital energy usage comparisons:

CRITERION	UK HOSPITALS
US average 45 GJ/100M³/annum	UK average 688 GJ/100M³/annum
UK Mandatory target for existing buildings is 65 GJ/100M³/annum	Only 65% of existing UK Hospitals meet the mandatory target.
UK Mandatory target for new build is 55 GJ/100M³/annum	Only 45% of new build UK Hospitals meet the mandatory target.
40 GJ/100M³/annum	Only 17% of UK Hospitals meet target
Notes: Data from NHS HTM 07	

Barriers to net zero – Fresh Air Ventilation

The UK healthcare industry still prefers full fresh air systems and there are very few recirculation systems. This is a long standing, traditional approach based on the belief that Hospital air was being contaminated by dust, dirt, particles carrying bacterial colonies, medical gases, - nitrous oxide and others – and air borne infections. Fresh air was considered 'clean', whilst extracted air was considered dirty, polluted and contagious.

The NHS Ventilation Code HTM2025 required full fresh air. However, in 2007 it was replaced by HTM03 which introduced 'Recirculation Systems' into its list of ventilation options, but appeared to limit its use to HEPA filtered clean rooms and other specialist applications. Since its introduction in 2007, HTM03 has provided designers with the option to recirculate but in practice the full fresh air option has been followed.

Natural ventilation

UK Hospitals have long favoured natural ventilation and design solutions dating back to the works carried out by Brunel in response to Florence Nightingale's appeal for better ventilation of Wards. In the publication by Robert Boyle [8], there are drawn examples of Hospital Wards and Operating Theatres using effective natural ventilation. Modern UK Hospitals still use natural ventilation. The Queen's Hospital Romford completed in 2006 has approximately 50% of its areas naturally ventilated. However, uncontrolled Natural Ventilation can use a great deal of energy and therefore the new Advanced Natural Ventilation, ANV, approach should be used. Recent research carried out by Cambridge University on behalf of UK Department of Health shows how ANV can be a significant strategy toward NZ. However, for existing Hospitals which rely on manual control of windows, it wastes heat energy.

UV air disinfection

Ultra violet light is now an established method of reducing air borne infection rates by dealing with environmental colon y spores carried in air ducts. However, despite research funded by the Dept. of Health and trial installations such as the Basingstoke and North Hampshire case [9] controlled study which showed that energy reductions could be as much as 80%, UV has had very little usage in the UK. Hospital microbiologists still view it sceptically and prefer, wherever practically possible, to use full fresh air and HEPA filtration.

Investment priorities

UK Hospitals face many pressures for funds and the priorities appear to be to focus onto the current 'front line' services, to keep the existing infrastructure operational and whenever possible improve, extend or add new, better clinical facilities. Reducing energy usage is certainly an aspiration and would in fact contribute to Hospital finances by cutting costs. However, it becomes a 'nice to have' as soon as Hospitals feel the pressures to achieve more in terms of medical performance.

There is also concern amongst Hospital Estates Staff who have the responsibility of keeping their Hospitals working - no matter what - that introducing new equipment, new strategies or even just changing existing settings will jeopardise the primary task of keeping everything in working order. This fear was evident at two recent projects where the following was noted: -

- Cancer Centre Ventilation Systems must operate 24/7 despite actual usage of 12/6. Fears that air handling plant would fail to start next day has led to a decision to operate 24/7 albeit with some energy saving by reducing fan motor speeds overnight using inverters.
- A project to replace distributed packaged chillers with a central chiller plant using three heat pump chillers incorporating heat recovery was carried out successfully and provides resilient control plant with additional capacity. The local, isolated units have been removed and a new comprehensive distribution network for cooling installed. However, the heat recovery circuit which was designed to preheat the incoming cold feed to the HWS (Hot Water System) has not been installed due to fears that it might create technical problems and could even introduce Legionella problems into the HWS circuits.

Of course, there are many successful examples of ventilation equipment that is switched off at night and on again next morning, and hot water systems that are preheated using recovered or waste heat, but in healthcare there appears to be a preference to stick to tried and tested solutions, no matter how energy intensive.

What chance NZ Hospital in the UK

The current situation appears desperate. UK Hospitals use far too much energy, in fact significantly more than other countries. Those responsible for the day to day operation of Hospitals are focused onto maintaining the status quo – 'keeping the lights on'. Those responsible for future planning and strategies are focused onto patient care, achieving performance targets based on numbers of medical procedures, patient throughput and minimising budget overspend. Energy is not a priority and may not even be on their agenda. Net Zero is certainly not. It is not really mentioned within the NHS Energy code. HTM 07 published in 2015, although it does mention the need to reduce carbon emissions.

Hospitals and communities

Hospitals are constructed to serve communities and are strategically located in places which are safe, secure, unlikely to be affected by flooding or other extreme weather events, close to transport networks and, of course, population centres.

Whilst Hospitals strive to provide 'healthcare' to people it is usually a reactive service. People are treated for illnesses and follow medical pathways to recovery. There are of course services such as maternity which are not 'illnesses' but are nevertheless reacting to a requirement for mothers and babies.

There has been a move toward proactive healthcare in which Hospitals could give advice, direction and even services around health and well-being, fitness, strength and even dietary and mental well-being. There is a strong case for doing so since it directly reduces the demand on its reactive services – people are less sick – and indirectly supports productivity and economic growth through a fitter, healthier more productive workforce.

Hospitals could extend this wider community intervention and make financial gains, by sharing its energy systems with its local community. In some ways, this would mean operating an energy business alongside its health functions, but this is already the case. All Hospitals must have resilient, reliable and affordable energy systems. They must be able to operate even if the local power supplies fail. What Hospitals do not do is share this with others – because they do not consider it to be 'their business'. It is a distraction. However, it should be their business because: -

- Supplying district heat to neighbours would allow larger electricity generation which is an increasing demand as more and more electrical medical equipment is installed.
- There is an income gain through sale of waste heat.
- Extra generation could be installed to improve stand-by cover. Basically, Hospitals move away from using expensive, never used stand-by generators to revenue earning, always running combined heat and power plant.
- Providing affordable heat (at a profit) to local communities supports health and well-being through winter months, reducing the usual 'winter rush for beds' as people struggling to heat their homes contract colds, flu and pneumonia.
- Reducing pollution from power plants by improved efficiencies. A recent paper from the Energy in Buildings and Communities Programme, EBC, May 2017, entitled 'Towards Net Zero Energy Resilient Public Communities, set out the case for community based energy systems as a route to Nett Zero Energy. In fact, community energy systems, also known as district energy systems, are not a new idea. They are commonly used around the world, especially in Scandinavian countries where they are the norm. In fact, cities like Aalborg are 100% served by district energy.
- Surprisingly it is not the case in the UK where there are only a few, local schemes. Media City UK constructed in 2010 is the most successful recent example. However, it is small scale at 2MWe, compared to Scandinavian examples. In contrast to other countries, the UK has no heat recovery from any of its national grid power plants and consequently operates an electrical grid at an average efficiency around 35 to 40%, wasting most of the input energy as heat to atmosphere.

  The UK is aware that this is a major contributor to global warming but is stuck with an established power grid with power stations releasing 3000 MW or more each, usually located a long way from communities who could use the heat, and a public dislike of the road closures which would be needed to install pipe networks.

There is a long-term solution and it involves starting small, locally and growing outward TOWARD the power stations. Hospitals provide the key to this approach as they could, and should, be at the centre of the local networks.

The low energy hospital studies

During the 1980's the UK carried out research into the next generation of healthcare building in a series of research studies and two new build hospitals – St. Mary's, Isle of Wight and Ashington, Northumberland. The research used the 'standard nucleus hospital' as its model and carried out detailed analyses using dynamic energy simulation models. They showed that energy reductions over 50% were possible and cost effective.

The two sample hospitals have been monitored post occupancy and feedback provided to assist NHS strategies.

More recently, the Dept. of Health has funded research led by Cambridge University into low energy cooling and ventilation using natural ventilation [10].

This research also showed that significant reductions in energy usage can be made if Low Energy Ventilation is employed. The project focussed onto Natural Ventilation which is still a preferred solution in the UK where possible and practical, but identified a looming problem due to Climate Change because rising summertime temperatures will cause overheating for long periods and jeopardise patient health and well-being.

The study also identified HVAC as the major energy consumer in healthcare and noted areas for improvement, in existing as well as new build.

Guidance, strategies and policies

The UK benefits from a strong technical base developed by NHS Estates in the past and from innovative research studies such as the Low Energy Hospital.

NHS Estates have a comprehensive energy reporting system and through a range of energy studies and the monitoring and reporting data from hospitals in use, have developed their EnCode information, which is essentially a Hospital energy code. EnCode has been incorporated into HTM 07-02, EnCo2de 2015– Making Energy Work in Healthcare – Environment and Sustainability [11], published in March 2015 in two parts: -

- Part A. Policy and Management
- Part B: Procurement and Energy Considerations for New and Existing Building Facilities.

These documents provide guidance and strategies for energy efficient Hospitals and in Part B, Section 3.3.3 states that the UK has set the target of zero carbon new build by 2019, creating a legal requirement for new Hospitals constructed in 2019 and beyond to be net zero carbon.

This target is implanted through the UK Building Regulations, Part L, which was last updated in 2016. The 2019 update is awaited but expected to set the Target CO_2 emission rate, TER, as zero. The UK construction industry must deliver Hospitals to meet the target. ■

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Airflow dynamics of a patient room

KISHOR KHANKARI
Ph.D., Fellow ASHRAE
President, AnSight LLC
Ann Arbor, MI
kishork@ansight.com

This present study attempts to evaluate the impact of supply and return locations on the airflow patterns and temperature distribution along with the resulting thermal comfort of occupants, and probable flow path of airborne pathogens in a typical patient room using Computational Fluid Dynamics (CFD) simulations.

Keywords: Patient room, healthcare, CFD, airflow, airborne particulates, HVAC

Air is the primary carrier of heat, moisture, contaminants and airborne contaminants in health care facilities such as patient rooms, isolation rooms and operating rooms. Therefore, the flow path of supply air plays an important role in determining the air velocities, air temperatures, concentration of contaminants and flow path of airborne pathogens in these spaces. These factors in turn determine the thermal comfort of occupants, indoor air quality, distribution of surface contamination, and potential for transmission of airborne pathogens in a room.

The airflow patterns, temperature distribution and concentration of contaminants including the flow path of airborne pathogens in a patient room can depend on several inter-related factors. These include the location and type of supply diffusers, supply air flow rates (air change rates) and associated diffuser throws, supply air temperature, size and locations of room return, bathroom exhaust flow rates, locations and strengths of various heat sources in a room, arrangement of furniture and other obstructions to airflow and importantly relative location of a patient in the room. In addition, orientation of the room can determine the solar sensible heat loads in the room. Several studies indicate that the design of a ventilation system and the resulting airflow patterns play a more important role in controlling the flow path of contaminants than just the supply airflow rate or air changes per hour (ACH) alone (Licina et. al. 2015, Pantelic and Tham 2013; Memarzadeh and Xu 2012). A study of airflow patterns and resulting potential exposure of the healthcare worker to airborne pathogens in a patient room and in an isolation room indicates airborne aerosols released from the patient can flow towards the healthcare worker during the movement of the air from the supply diffuser to the room exhaust (Ghia et al., 2012). In another study, interactions of exhalation flows of the cough particles with the ventilation flow in a hospital suite indicated that low exhausts outperform other exhaust locations in terms of particle removal and particles remaining around the bed (Memarzadeh 2011).

Virtual patient room

A three-dimensional steady state CFD model of a patient room is developed for this analysis. The virtual patient room in **Figure 1** shows the location of the patient, healthcare provider, seating area, door to the corridor, door to the bathroom, supply and return air locations for the various cases analyzed in this study. The room has about 200 sq. ft. (18.9 m²) floor area and 9 feet (2.74 m) ceiling height with a drop ceiling in part of the room. It contains several pieces of heat generating equipment including a monitor, infusion pump, a television, and a computer. The total sensible heat load due to this equipment was assumed to be 2.2 Btu/h per sq. ft. (6.84 W/m²). The sensible heat load due to two occupants (patient and healthcare person) was assumed 2.5 Btu/h per sq. ft. (7.8 W/m²) whereas the sensible heat load due to the lighting was assumed to be 2.3 Btu/h per sq. ft. (7.3 W/m²). The room has a south-facing window with a solar heat gain of 9 Btu/h per sq. ft. (28.4 W/m²). All other exterior walls of the room are assumed to be adiabatic. Thus, the total sensible heat load in the room is assumed to be 16 Btu/h per sq. ft. (50 W/m²). These analyses were carried out for partial load conditions which are more prevailing than the peak design load conditions.

The air is supplied through three, single-slot (1 inch, 25 mm wide) linear diffusers each 4 feet (1.2 m) long. The total supply airflow rate and the supply air temperature were specified at 227 CFM (107 l/s, 6 ACH) and 58F

(14.4 °C), respectively. The two linear diffusers placed on the drop ceiling are facing the window and designed to supply 70 CFM (33 l/s) each directly towards the window whereas the linear diffuser over the patient is designed to supply 87 CFM (41 l/s). All linear diffusers are assumed to supply the air at an angle of 15 degrees to the ceiling which is selected arbitrarily. The room was assumed to operate under negative pressure. The return flow rate from the room was designed for 177 CFM (112 l/s) whereas the bathroom exhaust flow rate was designed 60 CFM (28 l/s). Thus, the total return flow rate was assumed to be 237 CFM (112 l/s) with a deficit of 10 CFM (4.7 l/s) which was supplied through the leakage under the main door from the corridor.

Thermal comfort of occupants was analyzed by employing Predicted Mean Vote (PMV) index as described in ASHRAE Fundamentals Handbook (ASHRAE, 2013). This index was computed assuming CLO values of 0.5 and the metabolic heat production rate (MET) of 1.2 representing the healthcare providers and other occupants. The probable flow paths of airborne pathogens are analyzed by tracking the airflow path streamlines released from the patient's face.

This analysis focuses upon low-momentum pathogen releases (i.e. does not focus on high momentum releases such as full-volume coughing) and assumes most of the airborne pathogens released from the patient's face would follow the flow path of the air, neglecting any settling and deposition of these particles on the surfaces. This assumption is consistent for small particles as described by Memarzadeh and Jiang (2000). A total of 4 cases analyzed for various locations of supply and return diffusers are described below and in **Figure 1**.

- Base Case: Ceiling supply diffuser over patient's head and ceiling return near the entry door. This is a typical HVAC configuration for a patient room.
- Case 1: Ceiling supply diffuser over the patient's head moved over TV (away from the patient) and ceiling return kept near the entry door.
- Case 2: Ceiling supply diffuser over TV (away from the patient) and the ceiling return replaced by the low wall return placed behind the patient's head.
- Case 3: Ceiling supply diffuser over patient's head and the ceiling return near the door replaced by a large ceiling return over the patient's head.

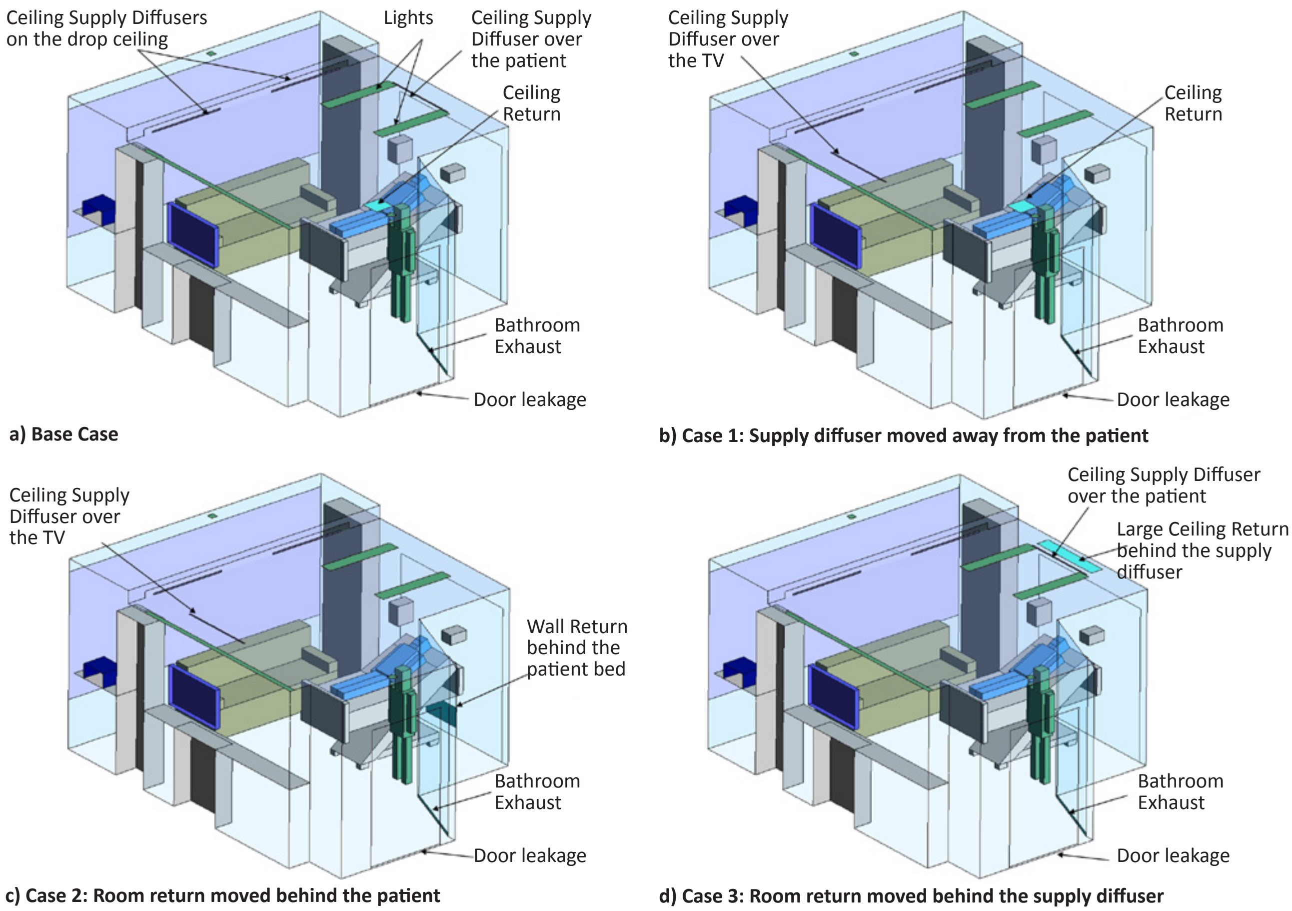

Figure 1. Schematic diagram of CFD models for the analysis of a patient room showing various HVAC configurations.

Analysis and insights

Base Case: Typical HVAC Configuration

Computational results for each case are presented in the form of color contour plots showing temperature distribution, PMV distribution, vector plot showing the airflow distribution, and streamline plots showing probable path of airborne particles released from the patient's face. In the base case analysis, both the supply diffusers and the return grille are located at the ceiling with the linear supply diffuser placed directly above the patient's head (**Figure 1a**). The air exiting from the diffuser forms a strong recirculating pattern above the patient. Linear diffusers, which are also referred as "mixing diffusers", are known for their induction characteristics. The exiting air jet from the linear supply diffuser creates strong entrainment (induction) flow over the patient and behind the bed (**Figure 2a**). As a result, the air flows upward over the patient and gets entrained back into the supply air stream. The airflow patterns shown in all of these cases are at one specific plane which passes through the center of the patient's body. However, the three-dimensional airflow patterns (not shown) resulting from various arrangements of the supply and return diffusers in the room are quite complex, which in turn affects the airflow patterns in the plane which are shown in these figures.

The resulting air temperature distribution shows slightly higher air temperature near the patient's head, behind the bed, compared to the temperatures near the opposite wall (**Figure 2b**). This is partly due to the flow of the return (entrained) air passing through this region. **Figure 2c** shows the resulting distribution of the PMV, the thermal comfort index. As shown in this figure at the

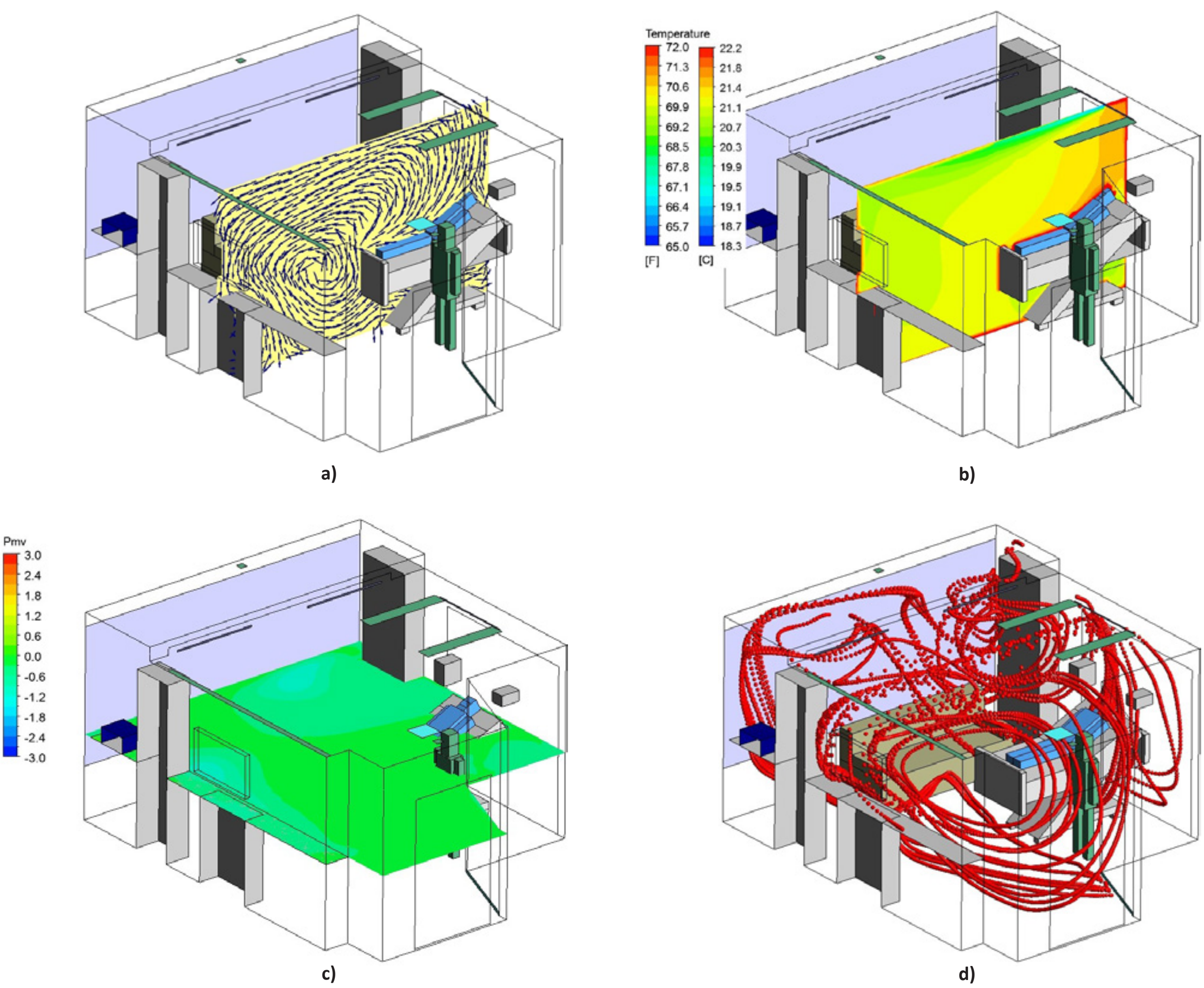

Figure 2. Results for the base case analysis showing a) airflow patterns, b) temperature distribution, c) PMV distribution at 4 feet (1.2 m) height, and d) resulting flow pathlines indicating probable trajectory of airborne particles released from the patient's face. This HVAC configuration entrains airborne particles back into the supply air stream which eventually spreads into the entire room.

4 feet (1.2 m) height from the floor, occupant thermal comfort is almost at neutral level (PMV close to 0.0) indicating an acceptable thermal environment. The strong induction airflows cause the airborne particles released from the patient's face to move upward towards the supply diffuser and entrain back into the supply air stream which eventually can spread into the room. This illustrates that mixing airflows, which otherwise might be desirable for obtaining the uniform air temperature in the space, can adversely affect the goal of contamination control. This particular HVAC configuration introduces the airborne pathogens back into the supply air stream.

Case 1: Supply Diffuser Away from the Patient

In an attempt to avoid the strong air recirculation and entrainment airflows directly over the patient's face, the supply air diffuser was moved away from the patient and placed closer to the opposite wall over the TV (**Figure 1b**). Like previous case both the supply diffusers and the return grilles are now located at the ceiling. As shown in **Figure 3a**, moving supply diffuser away from the patient reversed the airflow pattern. In this case the entrainment (induction) flow region moved near the TV. The supply air after exiting the diffuser falls near the patient's head and flows downward over

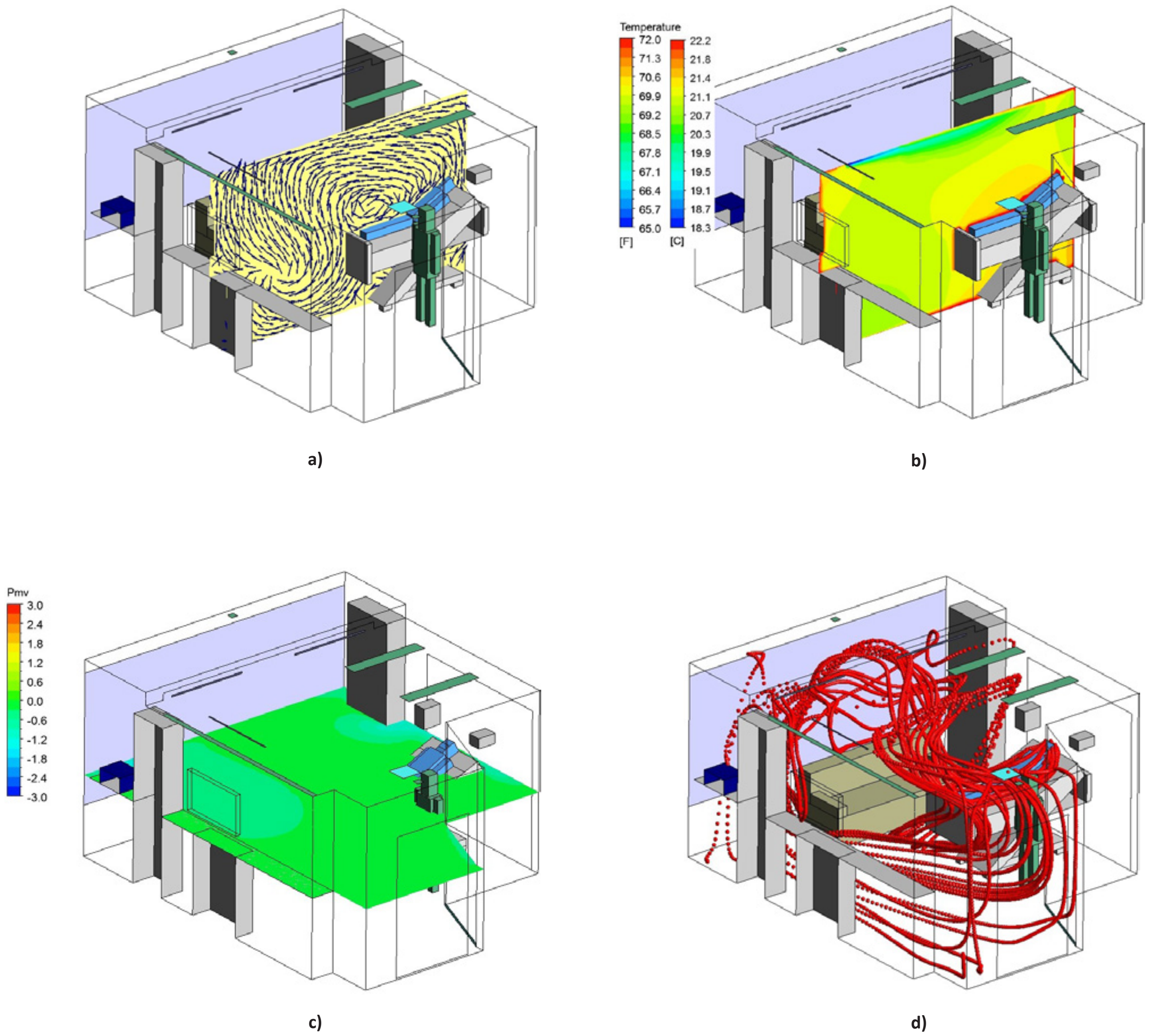

Figure 3. Results for Case1: supply diffuser moved away from the patient showing a) airflow patterns, b) temperature distribution, c) PMV distribution at 4 feet (1.2 m) height, and d) resulting flow pathlines indicating probable trajectory of airborne particles released from the patient's face. Moving the supply diffuser away from the patient reversed the flow path of airborne particles which still get entrained into the supply air stream from the diffuser.

the patient. Such a relocation of the diffuser slightly lowered the temperature near the patient's head and still maintained thermally comfortable conditions at 4 feet (1.2 m) height from the floor as indicated in **Figure 3b and 3c**, respectively. However, the flow pathlines released from the patient's face indicate that airborne particles now move downward instead of upward from the patient's face and then move upward back towards the supply diffuser. Similar to the previous case, the airborne pathogens can still get entrained back into the supply air stream and can eventually spread into the entire room. Although relocation of the supply diffuser helped in reversing the flow path of airborne particles near the patient's head, it could not avoid the entrainment and the mixing with the supply air stream.

Case 2: Return behind the Patient

In the next analysis (Case 2) as shown **Figure 1c** the location of the return grille is moved from the ceiling to the wall behind the patient at 0.5 feet (0.15 m) above the floor. The location of the supply diffusers still remained near the ceiling as in the previous case (Case 1). It was anticipated that such modification would cause the return air to move over the patient and down to the return and probably could avoid the spreading of airborne pathogens into the room. However, as shown in **Figure 4**, the airflow patterns, the temperature distribution, the resulting thermal comfort, and the resulting flow pathlines are very similar to the previous analysis. It indicates the airborne particles released from the patient's face can still spread into the entire room before returning

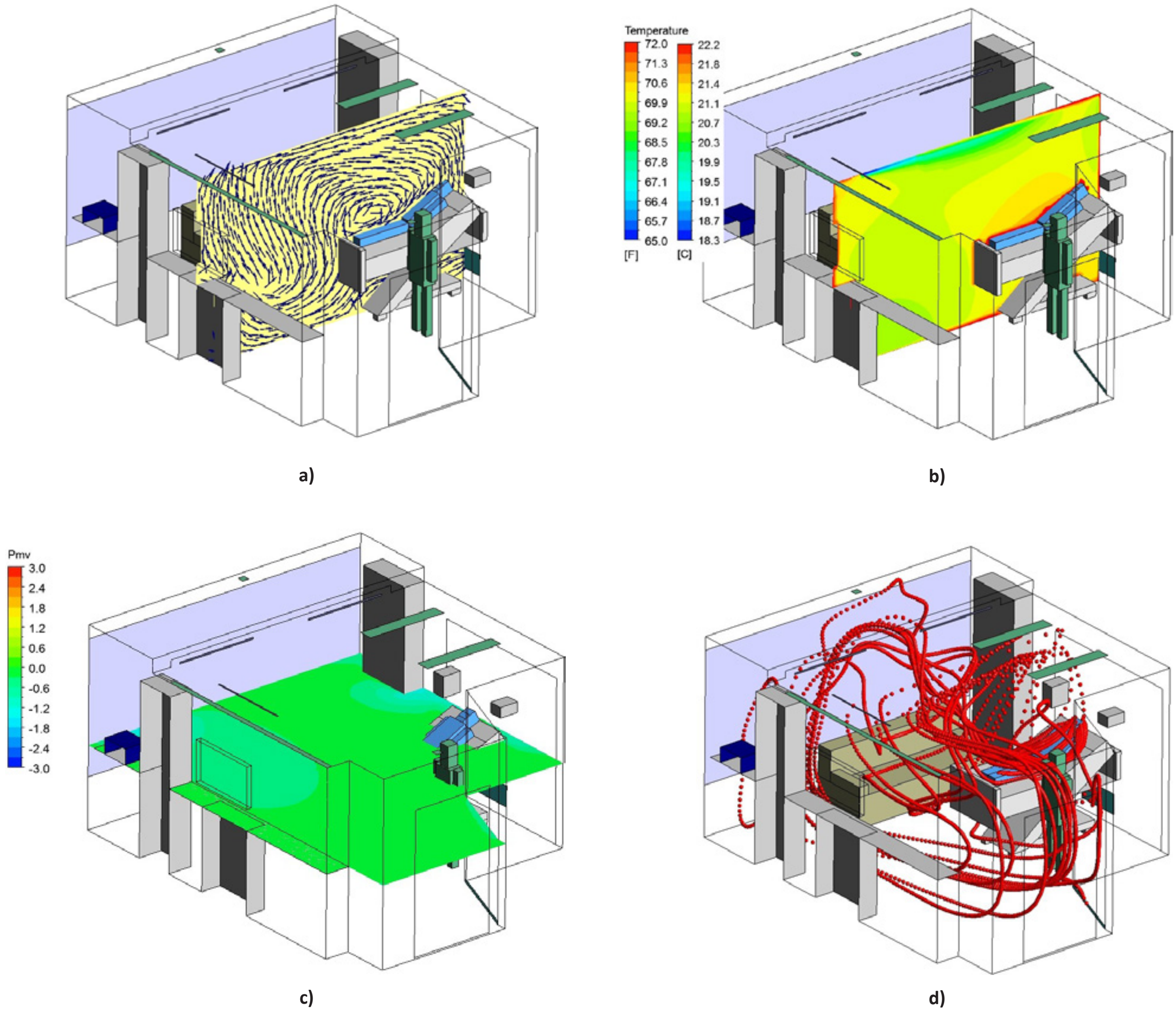

Figure 4. Results for Case 2: room return moved behind the patient bed showing a) airflow patterns, b) temperature distribution, c) PMV distribution at 4 feet (1.2 m) height, and d) resulting flow pathlines indicating probable trajectory of airborne particles released from the patient's face. Placing the return low on the wall behind the patient does not provide ready exit for airborne particles. High momentum of the supply air prevents the airborne particles from flowing downward directly towards the low wall return.

through the low wall return. High momentum (caused by the high air change rates) of the air exiting from the linear supply diffuser prevents the airborne particles from flowing downward directly towards the low wall return. Thus the new location of the room return has little effect on the airflow distribution in the room.

Case 3: Return behind the Supply Diffuser

Ideally the supply air after exiting the diffusers should pass over the patient and return back to the return grille through a single pass without entraining back into the supply air stream which could avoid mixing with the room air. In the current analysis, the ceiling return is placed right behind the ceiling linear diffuser (with the discharge angle facing forward away from the ceiling return). This allows the entrainment airflow induced by the supply air discharge to work collaboratively with the ceiling return, allowing the return air to readily exit out of the room (**Figure 5a**). It should be noted that the size of the return grille is also increased in this arrangement to facilitate easy passage of the return air.

Also as shown in **Figure 5b and 5c** such modification does not significantly change the temperature distribution and resulting thermal comfort of occupants. However, it significantly modified the probable flow path of airborne particles as indicated by the flow pathlines released from the patient's face (**Figure 5d**). It clearly shows such a configuration can potentially provide a single pass flow over the patient and can

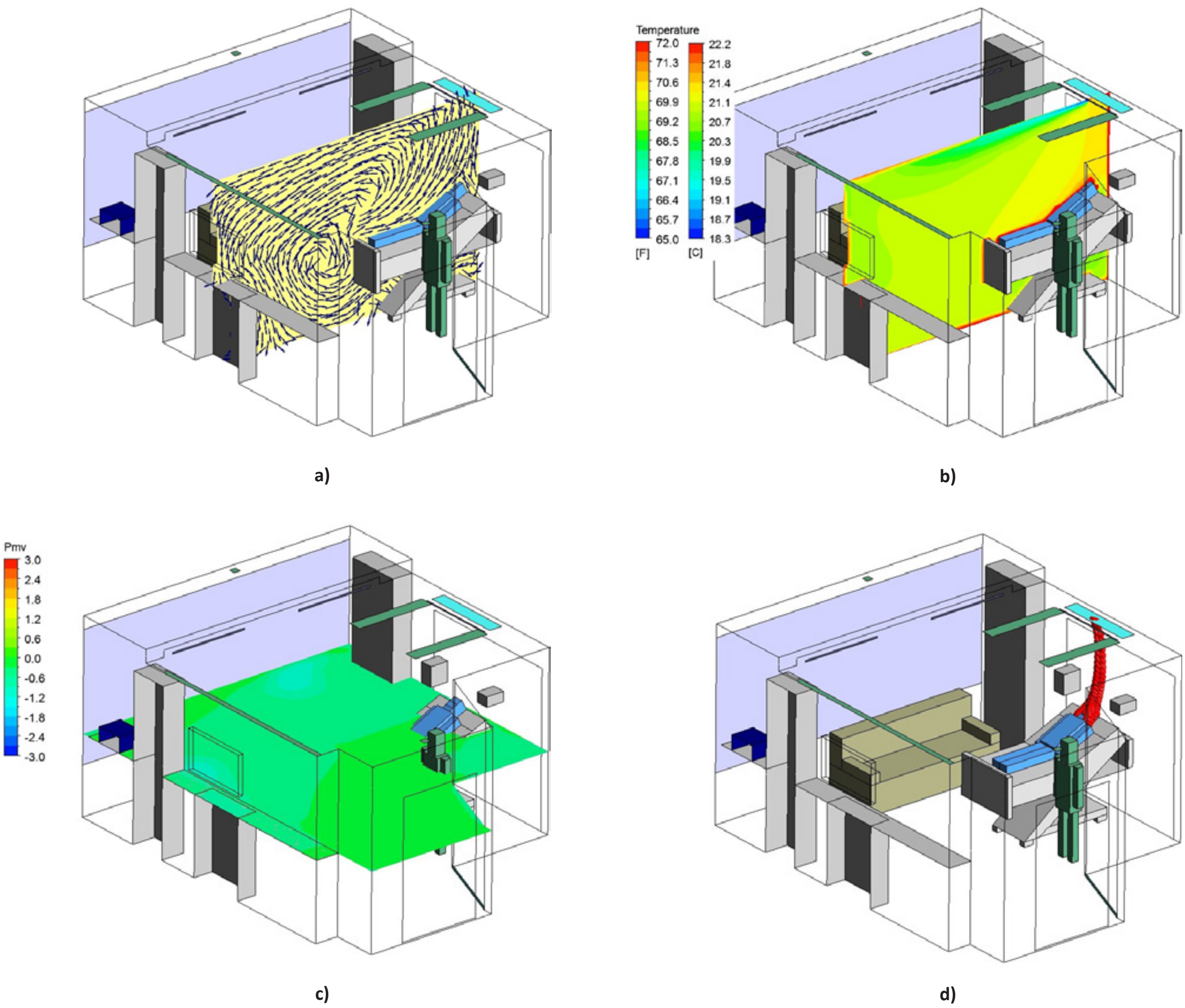

Figure 5. Results for Case 3: room return moved to the ceiling and behind the supply diffuser showing a) airflow patterns, b) temperature distribution, c) PMV distribution at 4 feet (1.2 m) height, and d) resulting trajectory of airborne particles released from the patient's face. Placement of a return grille right behind the linear supply diffuser over the patient's head can potentially provide ready flow path to airborne particles to exit out of the room without significant recirculation and entrainment back into the supply stream.

reduce the probability of entrainment of the airborne particles back into the supply stream. While a part of the return air may get entrained into the supply air stream, most of the airborne pathogens would follow a direct path into the return grille without any obstructions and recirculation. This arrangement can further reduce the possibility for deposition of airborne pathogens on the exposed surfaces in a patient room.

Summary

CFD models are developed to evaluate the impact of various HVAC design configurations on the airflow patterns, temperature distribution, and resulting thermal comfort of occupants, and on the probable flow path of airborne particles released from the patient's face. These analyses indicate the linear diffusers combined with high supply air flow rates (high air change rates) can cause strong recirculation and entrainment (induction) flows in the room. Depending on the location of the return grille, the airborne particles released from the patient's face can get entrained back into the supply air stream and can eventually spread into the entire room. However, this study indicates placement of a return grille right behind the linear supply diffuser over the patient's head can potentially provide a ready flow path to airborne particles to exit out of the room without significant recirculation and entrainment back into the supply air stream.

It should also be noted that a combination of locations and type of supply diffusers, locations of the room return and supply airflow rates can affect the airflow patterns in the patient room which are quite complex and specific to a particular design configuration. Therefore, it is difficult to reach any general conclusions about the optimized design configuration and placement of supply diffusers and return grilles in a patient room. This study demonstrates that the supply air flow paths, induced air flow paths, and exhaust grille placement can work collaboratively to establish protective and effective contaminant control. Thus, a careful evaluation of the HVAC configuration can help in gaining the insight and optimizing the flow path of air to obtain the desired combination of occupant thermal comfort and the best possible hygienic conditions in the patient rooms. ■

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REHVA Annual Meeting 2018

The next Annual Meeting that will be held in Brussels, Belgium from **Saturday 21 April 2018 to Monday 23 April 2018**.

The schedule will be the following:

- **Saturday 21 April 2018**: the Committee meetings and a Member Associations roundtable discussion followed by the REHVA Welcome Cocktail;
- **Sunday 22 April 2018**: the REHVA General Assembly in the afternoon followed by the ATIC Anniversary Dinner and REHVA Professional Awards;
- **Monday 23 April 2018**: the REHVA/ATIC Conference with in parallel the part 2 of the Technical and Research Committee in the morning in which our Supporters are invited, while, in the afternoon, the Supporters Committee meeting.

The website of our annual meeting will be opened soon!

REHVA Annual Meeting 2018
Brussels, 21-23 April
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Predicting energy savings for energy performance contracting

– the impact of the energy performance gap

DAVE BAAS
Royal HaskoningDHV
The Netherlands
dave.baas@rhdhv.com

RIK MAAIJEN
Royal HaskoningDHV
The Netherlands
rik.maaijen@rhdhv.com

WIM MAASSEN
Eindhoven University of Technology
The Netherlands
wim.maassen@rhdhv.com

WIM ZEILER
Eindhoven University of Technology
The Netherlands
w.zeiler@tue.nl

The building industry faces a significant mismatch between predicted- and measured energy consumption of buildings, known as the energy performance gap. This study assesses the magnitude of the performance gap and the impact it has on the profitability of business cases for investments in energy conservation and energy performance contracting.

Keywords: energy performance contracting; energy prediction; EPC; performance gap; risk assessment.

Introduction

Over the past decades, the building industry has come aware of a recurring mismatch between predicted- and in-use energy consumption of buildings, often referred to as the 'energy performance gap'. Evidence on the magnitude of the gap is adding up fast, suggesting buildings tend to use 1.5 to 2.5 times more energy than predicted in their design [1,2]. This mismatch in energy performance also holds for hospital buildings, using even 2 to 3 times more energy than predicted in their design. Causes for the performance gap are arising in all different stages of the building process, from poor assumptions and model inadequacy in the design stage to deviant occupant behaviour in the operational stage [3]. The gap due to poor assumptions in the design stage, however, can generally not be redressed or reduced after building completion. This makes improving predictions even more important in reducing the energy performance gap.

Investments in energy conservation measures and nZEB building design are key drivers to realise a low-carbon building stock. Energy Performance Contracting (EPC) has shown to be a successful tool to accelerate energy conservation, achieving significant energy savings in the building stock of most European countries [4]. EPC can be a powerful approach in reducing the performance gap, but the gap is also attributed as a significant barrier for large scale implementation of EPC. This study investigates the consequences that the gap in energy performance has for investments in energy conservation and conducting energy performance contracts.

Risk assessment

A risk assessment is employed to identify and quantify the risk profile of EPC-projects for the Energy Service Company (ESCO). By conducting a building performance evaluation, this study evaluates the industry's current ability of predicting building energy performance and the impact this can have for performance contracting.

Performance based projects typically involve an increase in project risks, when compared to fixed-fee projects. This increase in risks is experienced as one of the major barriers for further development of the EPC-industry [4]. Risk management is, therefore, one of the core elements in performance based contracting. The main starting point for a typical risk management framework is the process of identification, analysis and evaluation of the risks, often called 'risk assessment'. To evaluate how urgent the risks on energy performance are, a risk assessment is made for EPC-projects. The risk assessment is based on the RISMAN method [5], a common risk management framework in the Dutch industry. First, a risk breakdown structure is employed to identify the general risks involved in EPC. The risks are identified and structured based on the main actor (ESCO, customer or external) and their type (e.g. economical, technical etc.). Then, the risks are quantified by calculating the risk score for each individual risk. The risk score is defined as the product of the probability and impact of an event ($risk\ score = P \times I$), in here the probability and impact are defined as respectively the likelihood of occurrence and the impact of the risk when it occurs. RISMAN further defines the impact as the sum of several individual impacts, for this study, impacts on money, time and quality were considered. Each risk can then be assessed as: $risk\ score = P \times (Imoney + Itime + Iquality)$. After quantifying the risks, they can be ranked based on their risk score, which helps one to decide which risks should be given highest priority.

Building performance evaluation

For the building performance evaluation, five projects of the engineering consultancy Royal HaskoningDHV are taken as case study. All five projects are focusing on a single building, of which the main characteristics can be found in **Table 1**. These buildings are evaluated based on their annual thermal energy demand, comparing monitoring data with the predictions from the design. Due to a limited availability of data, the buildings could not be evaluated on energy consumption for e.g. energy generation or plugloads. Depending on the availability per case, 3 to 10 years of monitoring data is used for the comparison. Weather fluctuations are taken into account by degree-day normalization.

Table 1. Main characteristics of the case buildings.

	Project year	Project type	Function	Gross floor area [m^2]
Building A	2002	New built	Office	17.000
Building B	2004	New built	Office	38.600
Building C	2000	Retrofit	Office	21.500
Building D	2005	New built	Office	74.500
Building E	2004	Retrofit	Office	26.000

Investment appraisal

Investment decision makers generally use appraisal tools as basis for their decisions. The most common approaches for investment appraisal are Net Present Value (NPV) and Internal Rate of Return (IRR). The latter approach, IRR, is a relative measure of worth often employed in real estate and investment performance measurement. In short, the IRR is defined as the percentage of discount rate for which the NPV becomes zero. The higher the IRR of an investment, the more attractive it is for the investor. Often a minimum IRR, the Required Rate of Return (RRR), is defined by investors as the necessary expected rate of return to consider investing. EPC-projects are typically long-term contracts and are based on third party financing, a typical RRR which can be considered for EPC business-cases is 9%.

The business-model for EPC is, to a large extent, based on the predicted rate of energy savings. Given the figures on the performance gap, it is important to know how sensitive the profitability of EPC projects is to the accuracy of energy predictions. Hence, a typical EPC business-case of Royal HaskoningDHV is evaluated. The evaluation is based on the IRR as measure for the profitability and the energy prediction as source of uncertainty.

Results

With the risk breakdown structure, 27 different risks were identified for a typical EPC-project. All 27 project risks were quantified by calculating their risk score. **Figure 1** shows the results of this risk assessment in a pareto diagram. The risks are ranked based on their relative risk score. The cumulative in the diagram shows the risks are widely spread. The risk due to a mismatch in energy performance is ranked as nr. 4, with a risk score of 32% (highlighted in black in **Figure 1**).

To get insight in the distribution of the most important risks, the 6 risks with the highest risk score are summarized in **Table 2**. From these 6 highest risks, 2 risks are related to the building energy demand (risk 4 and 6). Looking at **Table 2**, no particular dominance can be recognized in the type or the main actor of the risks. In other words, EPC-projects are characterized by a widely distributed risk profile, in which one risk is formed by the performance gap.

Figure 2 shows a comparison of the predicted- and measured heating demand for the five office buildings. The boxes in the figure indicate the distribution of annual measurement data for respectively building A to E. **Figure 3** shows a similar comparison, but for the annual building cooling demand. The average annual heating demand shows to be 40% above predicted and the cooling demand 50% above predicted.

Table 2. Top 6 highest project risks for EPC.

Risk nr.	Risk score	Actor	Type	Description
1	40%	Customer	Economical	Bankruptcy of customer
2	36%	ESCO	Economical	Bankruptcy of ESCO partner
3	35%	Customer	Other	Building-/systems demolishing (e.g. by fire)
4	32%	ESCO	Technical	Energy savings are lower than expected
5	32%	Customer	Contractual	Hidden defects from customer
6	32%	Customer	Technical	Change in energy consumption pattern customer

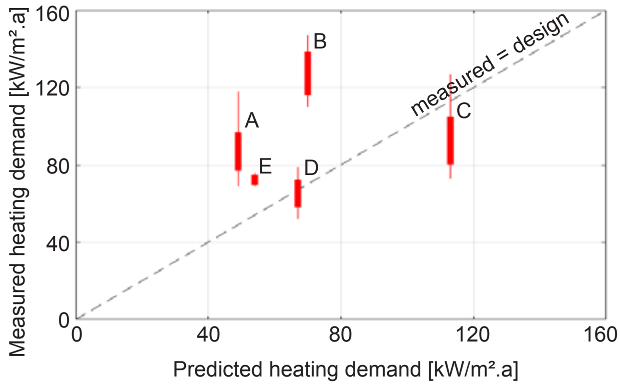

Figure 2. Comparison of predicted- and measured annual heating demand for the case buildings.

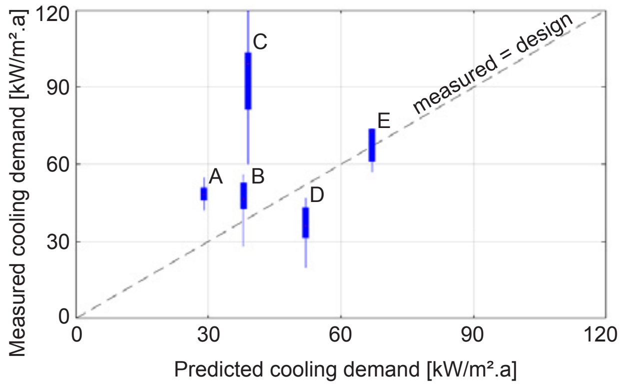

Figure 3. Comparison of predicted- and measured annual cooling demand for the case buildings.

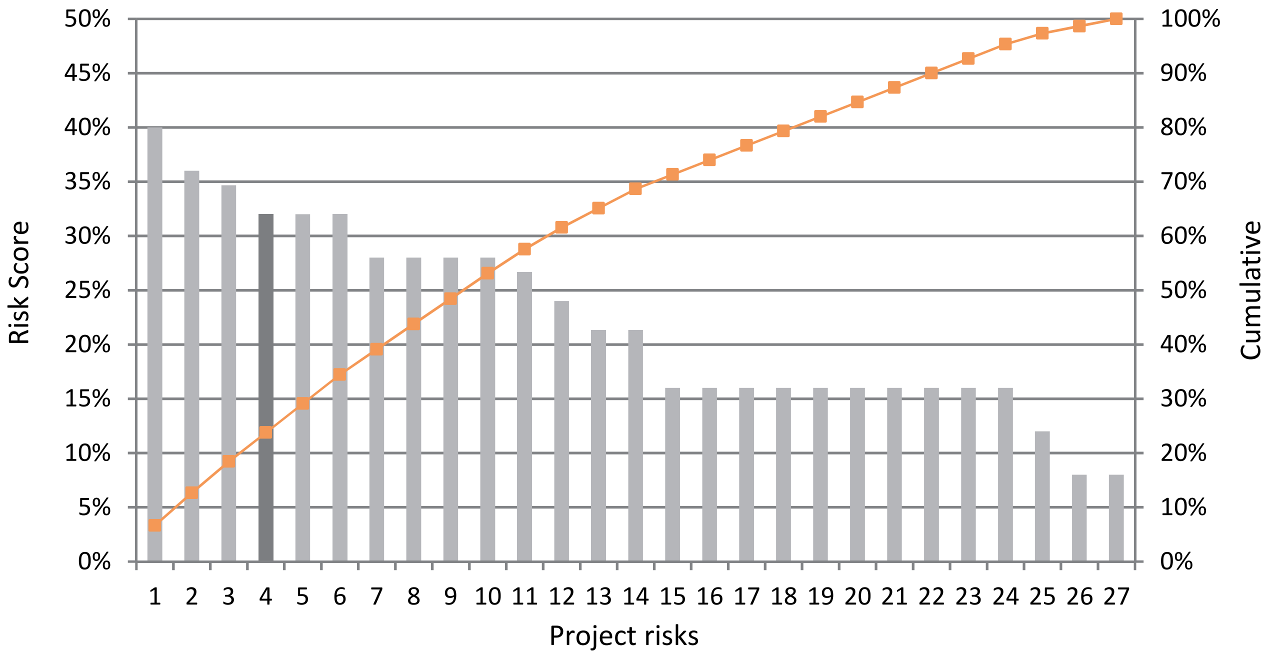

Figure 1. Pareto diagram risk assessment for EPC-projects.

The results on the performance gap suggest that predictions on energy performance get accompanied by significant uncertainty. However, the predicted energy consumption of all case-buildings was given as point estimate, suggesting there is no uncertainty at all. This incomplete representation of energy predictions is illustrated in **Figure 4**, showing the given point estimate with the disregarded uncertainty range.

The performance evaluation shows that the thermal energy demand of office buildings tends to be 1.5 times higher than predicted in its design. This indication for the magnitude of the performance gap is, therefore, used for further analysis on the consequences for EPC. **Figure 5** shows the impact a mismatch of 50% would have on the profitability of a typical EPC-project. When realizing energy savings as expected, an IRR of 13% would be achieved. This is a reasonable result for a typical investment in energy saving measures. However, a deviation of 50% from predicted energy savings will either increase the IRR to 20% or decrease to a marginal 6%. The decrease to 6% would be critical for the ESCO, since it is below the RRR of 9%.

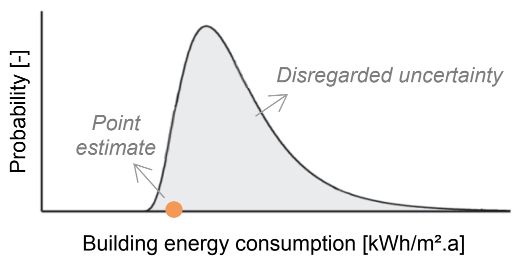

Figure 4. The incomplete representation of energy performance predictions.

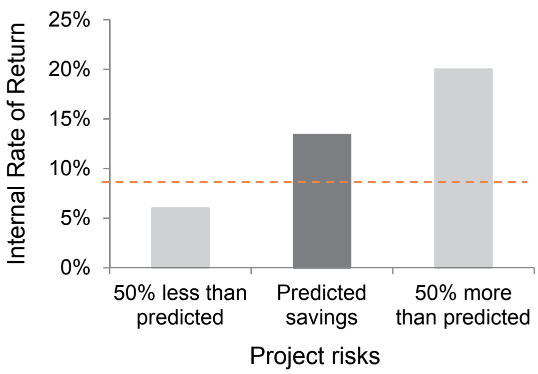

Figure 5. Effect of energy savings on IRR of a typical EPC-project.

Discussion & Conclusion

Evaluation of five case buildings shows that the thermal energy demand of the five buildings tends to be 1.5 times higher than was predicted in their design. These findings are in line with other work on the performance gap, confirming that the performance gap is also present in the Dutch building industry.

Results on the case study show the impact of uncertainty in the energy performance prediction can be significant for EPC-projects, decreasing the internal rate of return from 13 to 6% for a deviation of 50% in energy savings. Integrating the risk on energy performance into current practice risk management for EPC-projects is, thus, required to ensure sound business-cases for all stakeholders.

Reducing the energy performance gap is a very important and major challenge for the building industry, especially in the need to design and deliver (nearly) zero energy buildings. Improving the energy performance predictions is essential in reducing the performance gap, since the part of the gap due to poor assumptions in the design stage can generally not be redressed or reduced by building monitoring or –commissioning.

Based on the findings of the mismatch in thermal energy demand, it can be concluded that energy performance predictions get accompanied by significant uncertainties. Despite these uncertainties, energy predictions are generally given as point-estimates, suggesting there is no uncertainty at all. Quantifying uncertainties in standard practice energy predictions is needed to provide any valuable input for decision making. ■

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Experimental study of the effect of operation lamps on downward airflow distribution in an operating theatre in St. Olavs Hospital in Norway





AMAR AGANOVIC
Norwegian University of Science and Technology (NTNU), Trondheim, Norway
amar.aganovic@ntnu.no

GUANGYU CAO
Norwegian University of Science and Technology (NTNU), Trondheim, Norway
guangyu.cao@ntnu.no

LIV-INGER STENSTAD
Operating room of the Future at St.Olavs Hospital Trondheim, Norway
Liv-Inger.Stenstad@stolav.no

JAN GUNNAR SKOGÅS
Operating room of the Future at St.Olavs Hospital Trondheim, Norway
Jan.Gunnar.Skogas@stolav.no

HANS MARTIN MATHISEN
Norwegian University of Science and Technology (NTNU), Trondheim, Norway
hans.m.mathisen@ntnu.no

The objective of this study was to exam the effect of surgical lamps on the downward airflow distribution from the laminar ceiling diffuser in the operating microenvironment in one operating theatre at St. Olav Hospital in Norway. Measurement results show that both the height of the operating lamps and the angle of the lamps may influence the particle concentration in the operating microenvironment. The measured value of Colony Forming Unit (CFU) was higher when the operating lamps were located at a height of 1.92 m from the floor than at a height of 1.75 m from the floor. The particle concentration (0.3–3.0 micron) increased when the angle of the operating lamps was changed from 45° to horizontal. However, the increase of measured particle concentration did not result in the increase of measured CFU, which may indicate that the CFU may be affected by other factors.

Keywords: Airflow distribution, operating room, operating lamp, particulate matter, Colony Forming Unit, operating microenvironment.

Introduction

The indoor air quality of operating theatres is important for patients and surgical staff in terms of surgical-site infections. Earlier studies shown that among surgical patient's surgical-site infections (SSIs) are the most common hospital-acquired infections accounting for

36% of nosocomial infections [1]. Currently, SSI occurs for approximately 7% of all operations and is the third most frequently reported healthcare-associated infection in Sweden [2]. In Norway, the national average SSI rate was 2.0% which is higher than lower respiratory infection (1.4%), urinary tract infection (1.2%) and septicaemia (0.9%) in 2015 (Helsenorge, 2015).

In fact, the design of the microclimate in operating theatres (OT) is a complex task mainly due to the stability of air temperature, relative humidity, scheme of pressures, mean velocity and air quality [3]. The ultra-clean ventilation systems and laminar air flow ceilings are used in OTs to improve the indoor air quality. (One early study found that the measured bacterial and particle concentrations close to the operating field and at the level of instrument table were 20-fold lower in operating theatres with laminar airflow ceilings than in hospital rooms used for diagnostic or therapeutic procedures without ultra-clean ventilation systems [4].) However, another individual study showed significantly higher severe SSI rates following knee prosthesis and significantly higher SSI rates following hip prosthesis under laminar airflow conditions [5-6].

The objective of this study was to exam the effect of surgical lamps on the downward airflow distribution from laminar airflow ceilings in the operating microenvironment in an operating theatre at St. Olav Hospital in Norway.

Materials/Methods

The operating theatre (OT)

The measurements were conducted in a real OT which is located in St. Olav Hospital in Norway. In the middle of the OT, a laminar airflow ceiling was mounted to provide laminar downward airflow to the operating table (see **Figure 1**). In this study, five people were employed during the measurements to mimic two surgeons, one patient, one assistant and one anaesthetist in simulated operations. Two people simulating surgeons stood beside the operating table with one assistant standing close to the operating table. The simulated anaesthetist sat close to the head of the simulated patient laying on the operating table. Two type of measurement instruments were installed closely to the operating table to measure the number concentration of particulate matter pollutants and colony forming unit (CFU) (see **Figure 2**). The small zone close to the operating site may be defined as operating microenvironment (OMiE) and the rest of the operating zone may be defined as operating macro environment (OMaE). The OMiE is exterior and immediately adjacent to the surface of the operating site, where heat and moisture may be exchanged between body tissues and the indoor airflow [7]. The air quality of OMiE plays an important role of postoperative infection.

Measurement instrument

Two TSI AeroTrak® Handheld Particle Counters Model 9306-v2 were used to measure the particle concentration. The particle counters may measure particles in the range of 0.3 to 10 μm with a flow rate of 0.1 CFM (2.83 L/min). The counting efficiency of this instrument is 50% at 0.3 μm; 100% for particles >0.45 μm (per ISO 21501-4 and JIS). The two AeroTrak counters have been calibrated by the manufacturer before the measurements.

Measurement conditions

The measurements were performed in the OT and all the normal procedures for a real operation were followed, including cleaning, room preparation, sterilization of operating field and equipment and arrangement of surgical staff. **Table 1** shows more detailed information of the 6 cases.

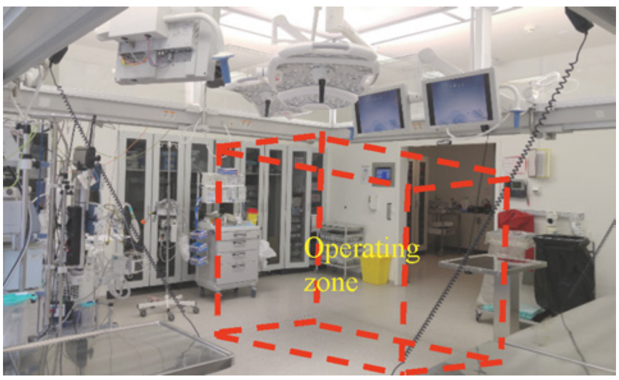

Figure 1. A photo of the operating theatre with all the medical equipment used in real operations.

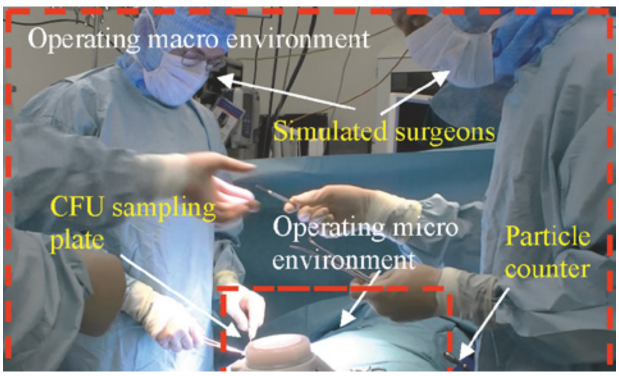

Figure 2. The locations of the measurement instruments for CFU measurement and particle measurement.

Table 1. Measurement conditions.

	Persons inside the operating room		Door opening	Measured parameters	Light position	
	nonsterile	sterile			Angle	Height from the floor
Case 1	4	3	2	PM, bacteria	45°	1.93±0.01 m
Case 2	4	3	3	PM, bacteria	45°	1.75±0.01 m
Case 3	3	3	2	PM, fungus	45°	1.75±0.01 m
Case 4	3	3	0	PM, bacteria	horizontal	1.75±0.01 m
Case 5	3	3	0	PM, fungus	horizontal	1.75±0.01 m
Case 6	3	3	2	PM, bacteria	45°	1.75±0.01 m

a) b)

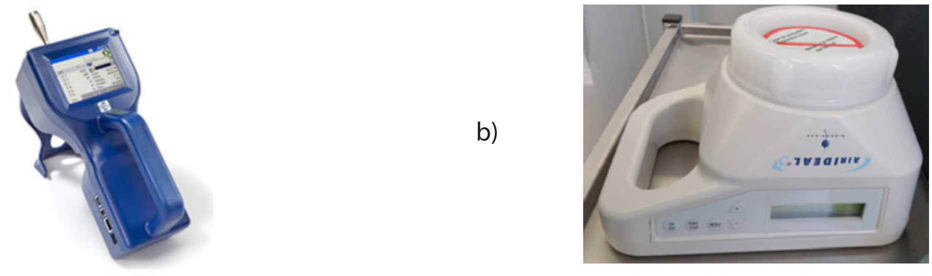

Figure 3. Measurement instruments, a) AEROTRAK™ Handheld Particle Counter Model 9306, b) CFU measurement device.

Results and discussion

Measured fine particle concentration and CFU

Figure 4 shows the measured fine particle concentration (0.3–1.0 micron) and CFU in all cases. The measured particle concentration (0.3–1.0 micron) in Case 1 is lower than other cases. It may indicate that the downward laminar airflow may dominate the operating table area regarding the fine particle control when the

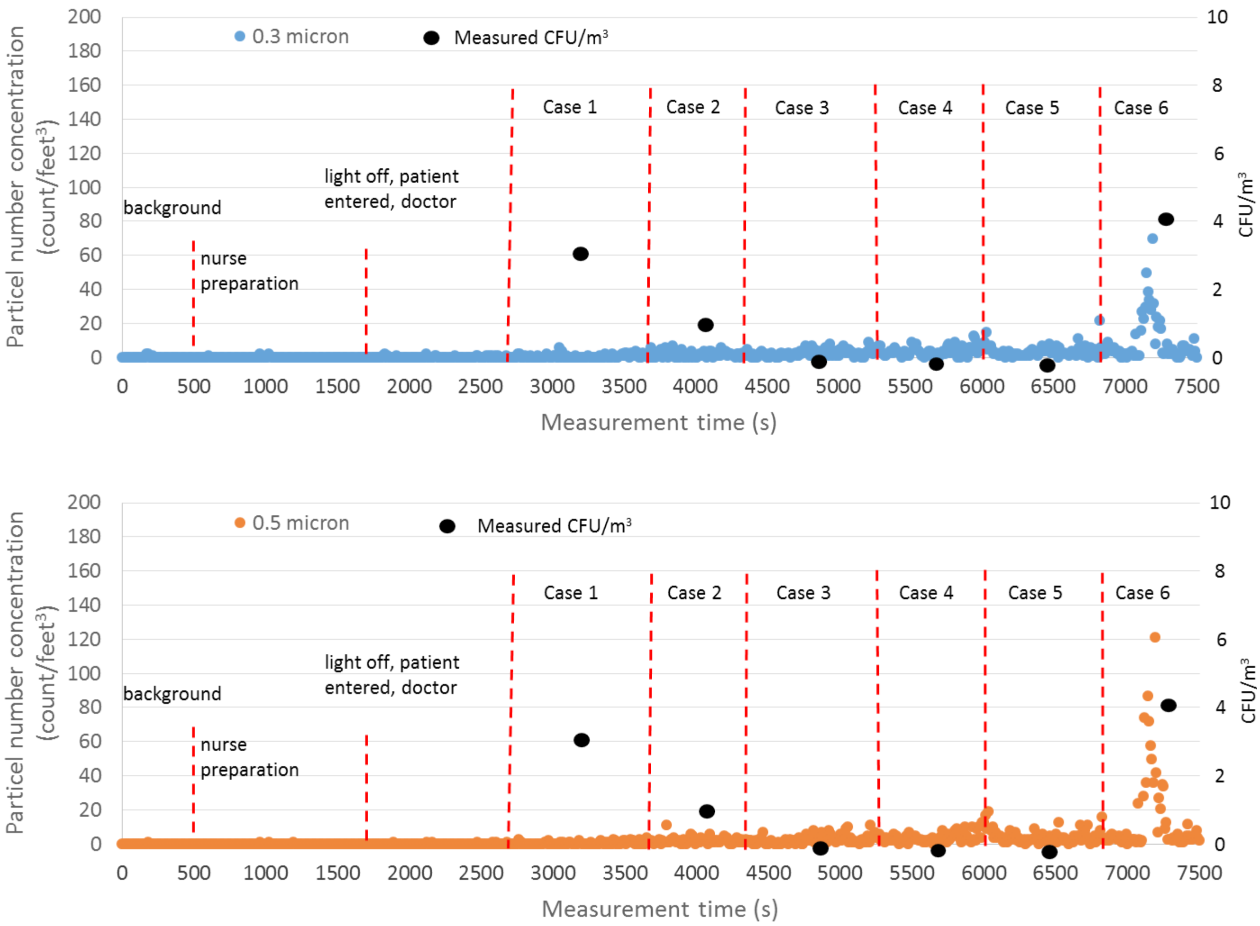

Figure 4. The measured fine particle concentration and CFU, a) 0.3–0.5 micron, b) 0.5–1.0 micron.

lamps were located at the height of 1.92 m. However, the measured value of CFU in Case 1 is higher than the values in case 2–4. In addition, **Figure 1** shows that the installation angle of the operating lamp may not affect the dispersion of airborne fungus in Case 3 and Case 5.

Measured coarse particle concentration and CFU

Figure 5 shows the measured fine particle concentration (1.0–14 micron) and CFU in all cases. It shows the measured particle concentrations (1.0–3.0 micron) in Case 3–5 are higher than other cases. The results

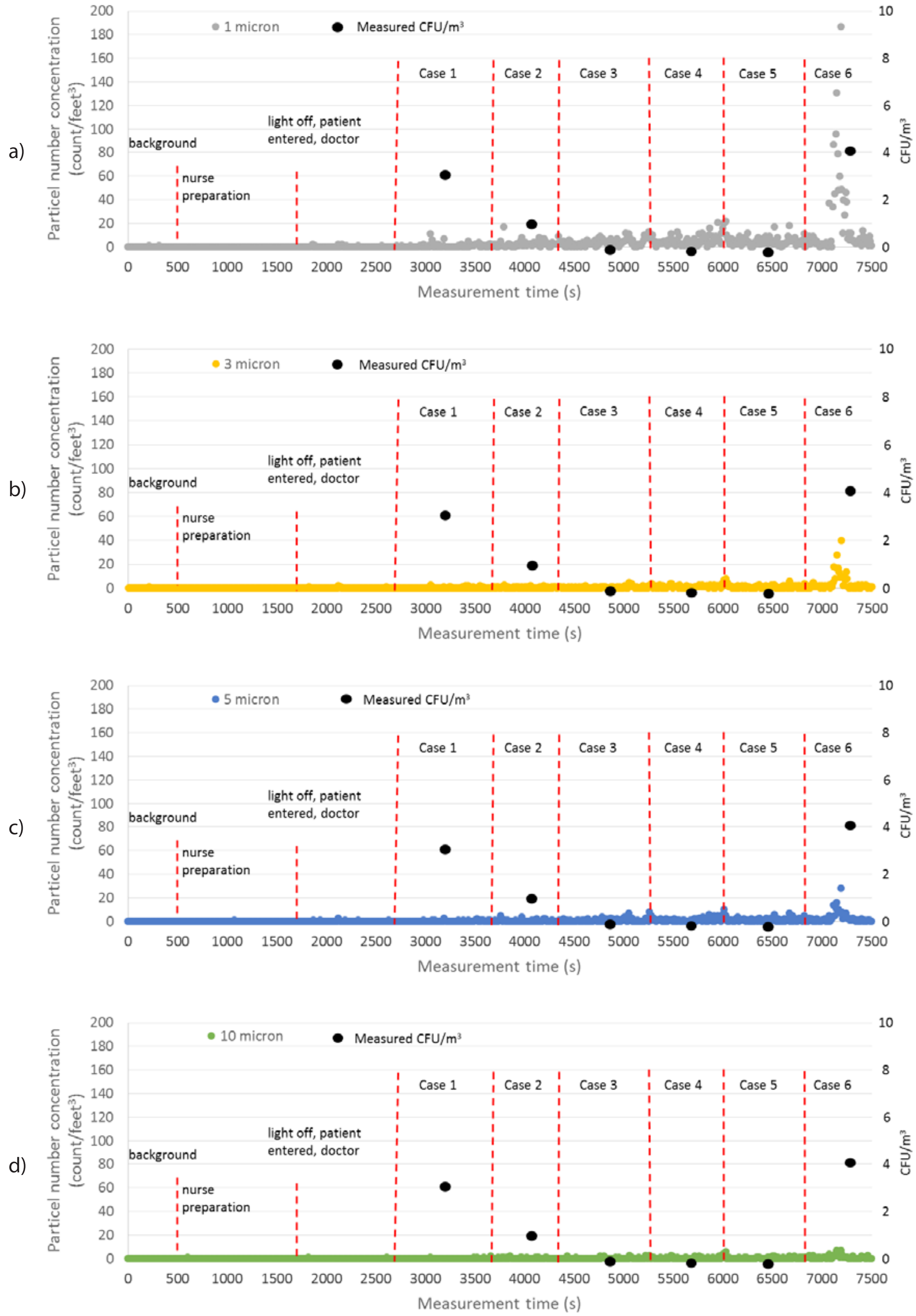

Figure 5. The measured fine particle concentration and CFU, a) 1.0–3.0 micron, b) 3.0–5.0 micron, c) 5.0–10 micron, d) 10–14 micron.

may indicate that the downward laminar airflow may be disturbed by the lamp near the operating table area when the lamps were located at the height of 1.75 m regardless the installation angle. However, the measured CFU is lower in case 3–5 than in other cases. However, the lower CFU may be caused by the reduced number of door opening, which may be the factor that induce more bacteria from outside of OT.

Figure 5a shows that the height of the lamps has different effect on particles with different sizes. When the height of the lamps was 1.92 m from the floor, the particle concentration (1.0–3.0 micron) is higher than other particle sizes: 0.3–1.0 micron and 3–14 micron. On the other hand, the particle concentration (1.0–3.0 micron) is higher in all cases than other particle sizes. This may indicate the increased CFU may be associated with particles with the size of 1.0–3.0 micron. However, this needs to be confirmed by more measurements due to the limited measured cases.

Conclusions

In operating theatres, many factors, including the number of staff, clothing, different airflow schemes, ventilation systems, supply airflow rate and the use of portable ultra-clean airflow unit, may influence the indoor air quality in the operating microenvironment and SSI. Earlier studies have reported that the increased airflow rate and the use of laminar ultra-clean airflow may make contribution to reduce the SSI. However, few studies have reported the influence of surgical lights on the air distribution in the operating microenvironment. This study found that the height of the operating lamps may influence the particle concentration at level of the operating microenvironment. The measured CFU shows nonetheless the opposite trend. The angle of the operating lamps may also affect the particle concentration at level of operating table. The particle concentration (0.3–3.0 micron) increased when the angle of the operating lamps was changed from 45° to horizontal. However, the change of the measured particle concentration did not result in the increase of measured CFU in the operating microenvironment. The limited measurement cases may not find out the correlation between the measured particle concentration and CFU. More field measurements in different cases should be carried out in the operating microenvironment to receive a better understanding of the effect of operating lamps together with other factors on measured particle concentration and CFU close to the operating table. ■

Acknowledgment

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Lower energy consumption requires lower air pressure

GÖRAN HULTMARK
R&D Manager, Lindab A/S - Indoor Climate Solutions
Adjunct Professor – SBi/Aalborg University
email: goran.hultmark@lindab.com

JESPER LAURSEN
Product Manager, Airborne Solutions
Lindab A/S - Indoor Climate Solutions
email: jesper.laursen@lindab.com

The HVAC systems of the future must use less energy – much less. However, most Demand Controlled Ventilation (DCV) systems are currently constructed in such a way that the fan has to produce a higher pressure than is actually needed by the users. Lindab has an interesting solution to this problem.

The output of a fan in a ventilation system can be calculated by a simple formula:

Output (W) = Airflow (m³/s) x Pressure (Pa)

The output over time plus the efficiency gives the fan's energy consumption, and if this is to be reduced, the pressure and/or the airflow must consequently be reduced.

The necessary airflow depends directly on the requirements on air quality and temperature in the ventilated rooms, so therefore the airflow cannot be reduced significantly. The system must supply the airflow required to maintain a good interior climate.

So, if the world's ventilation systems are to use much less energy in future, the air pressure must be reduced as much as possible – but in reality, we are almost doing the opposite.

The problem is the pressure control

Today most Demand Controlled Ventilation (DCV) systems are currently constructed so that the air pressure from the fan gradually declines during its passage through the duct network. This is done with the aid of pressure-adjustment dampers designed to prevent annoying noise for the consumers. However, this type of pressure control creates at least as many problems as it solves.

In the first place because the incorporation of numerous dampers also has the undesired effect that the fan must produce a greater pressure than is actually needed by the users. This extra air pressure is lost in the process of the pressure control.

In other words, a significant part of the fan's energy consumption is due to the system's design – not the user's needs. In addition, stepwise pressure control makes the systems more expensive to buy, install and balance. It is also more difficult to optimise their energy and retrofit the building when required.

The solution to these problems is in principle simple: remove the large number of dampers so that the duct network is completely open and instead reduce the fan's maximum air pressure in the rooms where the air is to be used. In this way, the job can be done with much lower energy consumption.

Until a few years ago, the big challenge was to assure full pressure control over the users heads without generating noise. But there is now a solution, and it is likely to have a major effect on how ventilation systems will be designed in future.

Patented MBBV damper halves energy consumption

In 2012, Lindab Indoor Climate Solutions launched the "Pascal" system, which can reduce the full pressure from the fan in each room as needed, even in large buildings. The system is based on a patented plenum box with a MBBV damper that can silently control the air pressure up to 200 pa precisely behind the diffuser in each room.

"MBBV was a major breakthrough. It meant that we could eliminate all forms of pressure control in the duct network in one fell swoop. Completely open ducts produce far less resistance, and the fan no longer needs to produce a greater pressure than needed. That partly explains why the fan in a Pascal system typically uses 50% less energy than corresponding pressure-controlled ventilation systems. Another advantage is that the system is easy to clean and maintain," says Göran Hultmark, R&D Manager at Lindab Indoor Climate Solutions and associate professor at SBI/ Aalborg University.

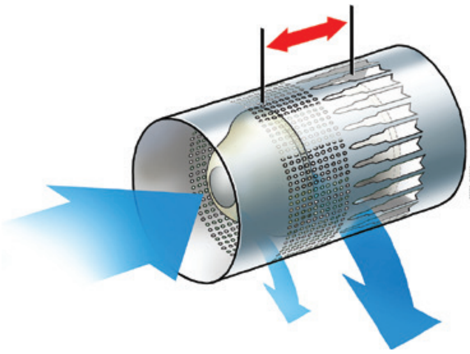
Room with greatest need controls the fan

Each room in a "Pascal" system acts as an autonomous unit. A temperature sensor incorporated in the diffuser or placed on a wall controls how open the MBBV damper is. Separate PIR or CO_2 sensors may also be added as required.

The pressure distribution system is constantly sending data from each room to a system controller about the temperature and the movements of the MBBV damper. The room with the greatest pressure requirement – i.e. where the damper is most fully open – determines the fan's speed. The system controller simultaneously evaluates the status of the other dampers and controls the airflow to assure the maximum energy saving.

"If five people sit in separate offices next to an empty meeting room, the need for cooling and ventilation is quite different than if they were together in the meeting room and their offices were empty. These kinds of changes occur all the time, and the "Pascal" system adapts itself automatically. The main principle is that it's always the most open damper that controls the fan speed. So, there is always just enough pressure in the system to reach the room with the greatest requirement, and the fan's speed and energy consumption are kept as low as possible," says Jesper Laursen, Product Manager at Lindab Indoor Climate Solutions.

In a "Pascal" system, the room whose damper is most fully open controls the fan. The air pressure and energy consumption are consequently always kept to a minimum.



The heart of the "Pascal" system: Lindab's patented MBBV damper allows the system to operate with completely open ducts and full air pressure in each room. An internal cone damper is moved back and forth in a tube perforated by holes of various sizes with the aid of a motor. By coordinating the movements of the cone damper with changes in air pressure, a linear pressure drop is produced that generates almost no noise.

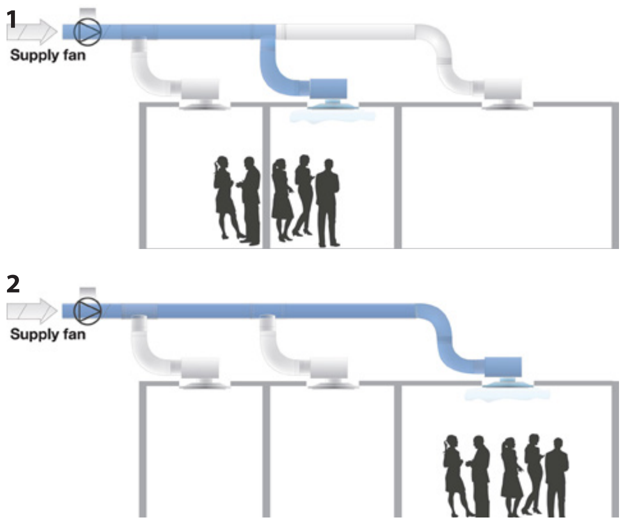
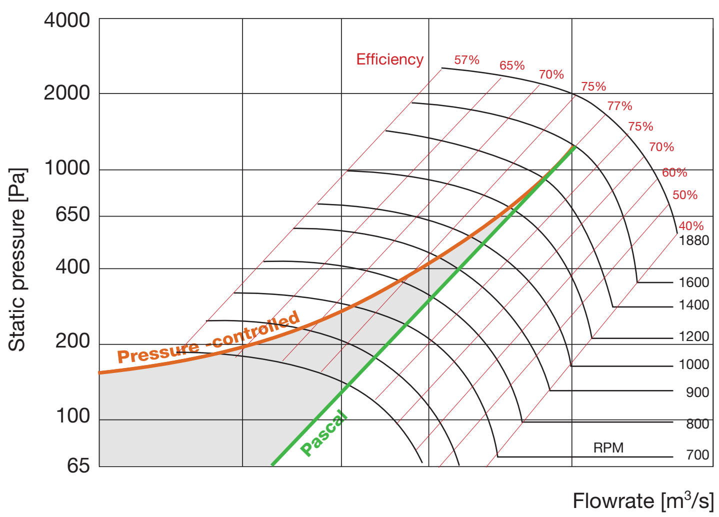


Illustration of two different situations where the number of people in each room determines which room has the greatest need and hence controls the fan.

MBBV is a plenum box with integrated volume flow regulator used for the DCV regulation of air supply diffusers. The MBBV is equipped with a unique linear cone damper technology which makes it possible to adjust in the full operational area 0–100% up to 200 pa with a low sound level. The built-in DCV actuator is delivered pre-programmed with a damper characteristic and makes the VAV adjustment very accurate and reliable in combination with a stable flow measurement over the damper.

In the "Pascal" system MBBV is controlled by a room controller where all settings are to be made after installation. This means that no factory settings or specific room labelling is needed for MBBV.



Lower efficiency loss: As the fan speed drops, the efficiency loss in the fan is less in a "Pascal" system than in a pressure-controlled system. That is because the "Pascal" system's airflow and pressure tend towards zero as the need for cooling drops. In contrast, a pressure-controlled system maintains a constant minimum pressure irrespective whether there is a need for cooling or not. The shaded area thus indicates the energy saving of the "Pascal" system. If the electric motor is also included in the picture, the total efficiency is reduced further at low speeds.

The MBBV must be used in combination with a suitable diffuser that can handle low airflows (LCP, LKP or LCC).

Easier to retrofit

Changes often need to be made to most business properties due to for instance restructuring, growth, moving or redesign as open office space. The use of buildings and rooms can change radically from one day to the next. So, the simpler the ventilation system is, the easier it is to adapt it to new requirements.

"To understand the flexibility of the "Pascal" system, we should recall that each room is an autonomous self-regulating unit. The airflow is controlled with the aid of a temperature sensor incorporated in the diffuser or mounted on a wall. So if an extension is added with several new rooms, this can be done without affecting the rest of the system. Unlike pressure-controlled systems, there is no need to reconfigure the whole system. The modular construction, open ducts and only five different components produce a system which is really simple to plan, maintain and retrofit," says Jesper Laursen.

There are currently some 400 Pascal systems in operation or under construction. The energy saving in fan operation can vary from one building to another, but is in all cases over 50 per cent greater than that of comparable DCV systems with pressure control.

The fans are the next big challenge

Even if an average energy saving of 50% may sound like much, the savings potential of the "Pascal" system is even greater. But to achieve maximum savings, the fans themselves must be optimised.

"Our ability to reduce the airflow and pressure to this extent is still relatively recent. The fans and their electric motors must be further optimised. We need fans that can change from large airflow and high pressure to low airflow and low pressure with no loss of efficiency. Fortunately, that's only a matter of time and technological development," says Göran Hultmark. ■

The 2nd Annual GCC HVAC Summit – Ensuring Sustainability

With immense growth in the number of construction activities in the Middle East, the need for a more energy-efficient Heating, Ventilation and Air-Conditioning (HVAC) systems has increased. This year's summit will have discussions about ensuring sustainable and environment-friendly HVAC systems in the industry leading to sustainable buildings and reduced Carbon footprint.

The 2nd edition of the GCC HVAC Summit, now recognized as the region's largest gathering of global experts and specialists in the HVAC sector, is expected to follow the footsteps of its predecessor to tackle major issues that are being faced.

The event is supported by the Ministry of Energy – United Arab Emirates, Dubai Municipality, Abu Dhabi Quality and Conformity Council, Dubai Carbon Centre of Excellence, Emirates Green Building Council, Clean Energy Business Council, Chartered Institute of Building and Middle East Solar Industry Association.

While the HVAC industry is growing at an exponential pace it is not immune to pitfalls and challenges. This precisely why such a platform for continuous discussion and exchange of information among the stakeholders in the industry is crucial to its further advancement.

The two day conference and exhibition will be held on 14th and 15th of November, 2017 in Dubai. The summit will be attended by more than 180 experts and decision makers belonging to the leading organizations in the industry. These include the Developer, Contractors, Technology Solution providers and Manufacturers, Regulation Bodies and Design and Architectural Consultants.

Know more about the event: www.thehvacsummit.com aeroventic

Aeroventic – International online marketplace for HVAC industry

This article discusses the HVAC industry in light of the dynamic Internet development. Firstly, the very trendy and ubiquitous Internet of Things Phenomenon. Then, new approach to online sales and marketing communication. Last but not least, the global project Aeroventic dedicated exclusively for the HVAC business will be presented.

The Internet Revolution: It is much bigger than you think

One cannot argue the fact that the Internet in the HVAC industry plays a very significant role. This is well illustrated by the Modern Concept of the Internet of Things (IoT) and its impact on smart HVAC controls market. The very term „the Internet of Things" was coined by Kevin Ashton of Procter & Gamble, later MIT's Auto-ID Center, in 1999. To put it simply, the IoT refers to the connection of devices (other than standard computers and smartphones) to the Internet. Experts estimate that the IoT will consist of about 30 billion objects by 2020. IoT has revolutionized the operation of HVAC regulators in an unimaginable way. The Internet of Things drives innovation in HVAC products and manufacturers compete in delivering smart technologies that improve energy efficiency, comfort, remote monitoring, convenience, and ease of use. There is no doubt, the digital revolution continues its course, and will continue it over the next decades.

Taking into account the above, it is worth mentioning that the Internet is also one of the greatest communication tools of all time. However, there is great competition in the market. To do well in the face of strong competition one needs to be aware that planning effective and integrated web communication is a key factor in any marketing and sales strategy. How to gain a competitive advantage in online business?

In order to reach as many customers as possible for products or services, one should invest in multi-channel and integrated information management in the global market. Good website is a great start, but that is not enough. Thematic websites, newspapers, local business listings, social media, thematic forums are a must these days in order to be able to create positive brand image and build engaged brand community.

Let us introduce Aeroventic – International Internet based online solution for the HVAC sector.

For whom?
Aeroventic is dedicated to manufacturers, distributors, installers,designers who want to fully exploit the Internet and end-users seeking reliable information on products and services.

Aeroventic structure
Aeroventic is currently available in 9 countries.

These websites have been prepared in native languages and function independently of each other. Such geographic division enables suppliers to diversify their product offering and adapt their marketing and sales communication to the particular region. Suppliers can present different products or services in different countries depending on their sales targets. In 2018 Aeroventic will be available in additional countries such as: United Arab Emirates, Canada, Italy, Czech Republic, Slovakia, Ukraine, Russia, Croatia and more.

What are the Benefits?
- Possibility to present product portfolio in target country
- Professionally prepared business profile with clearly stated business objectives
- Reaching key audience groups
- Press release sites
- New markets exploration
- Chance to strengthen competitive position
- Traffic from target countries
- Interaction with the target audience via product inquiries
- Staying updated with the industry news
- Social media promotion

Case studies

The promotion in international marketing, which is a specific form of „intercultural meeting" of the company with selected target groups of buyers in other countries, has a distinct characteristic in the form of a different communication system, legal, social and cultural conditions in which we want to operate. We will present 3 companies that take advantage of Aeroventic's potential. Thanks to this we will try to present the wide range of opportunities offered by the platform.

NEUTEC GmbH is the German provider of technically advanced and energy-efficient heating devices. They offer devices with EC motors, created for heating of: restaurants, workshops, warehouses, car washes, shops and so on. The competitive advantage is built by the best quality confirmed by TÜV Rheinland Group and the shortest market delivery time. A multi-level quality control system allows NEUTEC to offer the longest, standard 5-year warranty for devices. NEUTEC has decided to launch its new air heaters sonnEC on the following markets: Germany, Sweden, Denmark, Norway, Finland and the United Kingdom. Therefore, sonnEC air heaters were placed on the following websites: aeroventic.se, aeroventic.dk, aeroventic.fi, aeroventic.co.no, aeroventic.uk where comprehensive information on them can be found by distributors, installers or designers.

See NEUTEC Gmbh at Aeroventic Germany: http://aeroventic.de/firmen/neutec

Temko & Universal is a leading manufacturer in Romania, that offers high performance HVAC ventilation systems. SPIRO, round ducts, as well as rectangular ducts are their key products. Temko & Universal is present at Aeroventic Romania, where they promote its ventilation systems with an emphasis on the innovative smoke and fire protect line that meets the highest fire safety requirements. This is an example of a supplier with a strong market position. Temko uses Aeroventic to build up its image as a professional Romanian manufacturer of cutting edge products.

See Temko & Universal at Aeroventic Romania: http://aeroventic.ro/companii/temko-universal

Manufacturer of patented slot diffusers **AirIdea** that is looking for distributors in countries such as Denmark, Lithuania, Germany and United Kingdom. In this case Aeroventic supports the supplier in establishing new business contacts and reaching their goal.

See AirIdea at Aeroventic Denmark: http://aeroventic.dk/firmaer/klima-oprema-polska

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If you are interested in joining Aeroventic, or wish to get more information, please contact: office@aeroventic.com

Author: Joanna Kosinska
Project manager
e-mail: office@aeroventic.com
phone: +48 733 259 515

MCE – MOSTRA CONVEGNO EXPOCOMFORT

It is full steam ahead for the 2018 edition

First highlights from the exhibition scheduled for 13th -16th March 2018 at Fiera Milano.

Milan – August 25, 2017 – The organisation is moving up into high gear for the 41st edition of MCE –MOSTRA CONVEGNO EXPOCOMFORT – the world's leading biennial exhibition dedicated to residential and industrial installations, air-conditioning and renewable energy, enlivening the halls of Fiera Milano from 13th – 16th March 2018.

mce
mostra convegno
expocomfort
13-16 Marzo / March 2018
Fiera Milano

Technological innovation in terms of products, systems and solutions for comfortable living and strong internationalism, reign once again as the undisputed protagonists of MCE 2018, reaffirming the event leading position in an even more global context. Right now, MCE - MOSTRA CONVEGNO EXPOCOMFORT 2018 has registered over 1,100 direct exhibitors. It has all it took to be a success. Many new companies choosing the show to make their debut, some big names making a comeback and a sharp rise in foreign exhibiting companies. In particular, the display area dedicated to air-conditioning, refrigeration and hardware sectors is almost completely sold out. Excellent performance for sanitary technology, water treatment, heating and renewables too. In total, over 80% of the exhibition spaces have already been pre-booked.

MCE 2018 will once again be an ideal showcase that will take visitors on a journey through the most innovative technologies for energy efficient management of the built environment (commercial, residential, and industrial), from a single flat to a block of flats, from public buildings to industrial plants. A unique opportunity for all players in the global HVAC&R systems market; from manufacturers of high-tech solutions to wholesalers and retailers, designers and installers, to discover novelties and the leading sector trends.

"MCE mirrors and accompanies the evolution of a robust industrial sector that is very attentive to innovation - stated Massimiliano Pierini – Managing Director of Reed Exhibitions Italia – an industry that sees in MCE an ideal platform, generating new contacts and building new business. This motivates us to find out new tools to support our customers: exhibitors and visitors. To this purpose, MCE 2018 has launched a complimentary business matchmaking service, an online platform. This tool will allow exhibitors and pre-registered attendees to create a detailed personal profile, prioritize the categories and products they are interested in, search through recommended contacts, and organise their schedule so they can make the most of their time at the show. We are aiming to offer our participants a bespoke service as well as offer new networking opportunities."

Amongst the new features in store for MCE 2018, some previously announced, as the Country Partner initiative, that sees India as a special guest of this year's edition, one of the most promising and dynamic markets for European and Italian businesses – Indian companies have so far occupied more than 600 square metres of exhibition space. Moreover, the launch of BIE – BIOMASS INNOVATION EXPO that will add value to MCE entrepreneurial network focused on dealing with energy efficiency and other currently in progress.

MCE 2018, as usual, will offer a busy programme of conferences, workshops, cultural and scientific events in collaboration with the main trade associations coordinated by the Scientific Committee of Energy & Strategy Group, Polytechnic University of Milan, chaired by Professor Vittorio Chiesa. Once again, THAT'S SMART will be one of the strengths of MCE 2018, a workshop format combined with an exhibition space located in Hall 2/4, dedicated to building automation, domotics, smart metering, smart grids, renewable electricity, and remote plan management app. A unique event, highlighting the synergy between electricity and installation technology, energy saving technologies and integrated intelligence systems to allow the construction of energy efficient, comfortable, connected, affordable buildings.

All the latest updates on MCE – MOSTRA CONVEGNO EXPOCOMFORT 2018 are available online at www.mcexpocomfort.it, on Facebook.com and Twitter.com MCE's pages.

MCE - Mostra Convegno Expocomfort

Mostra Convegno Expocomfort is the biennial International exhibition dedicated to residential and industrial installations: heating, air-conditioning, refrigeration, hardware, valves, sanitary technology, bathroom, water treatment, tools, renewable energy sources, and services. Established in 1960 as Italy's first trade exhibition, MCE has been a leader in the sector for more than 50 years thanks to its proven ability to follow the evolution across the reference markets, creating opportunities for technical, educational and political exchange and discussion. Mostra Convegno Expocomfort is owned by Reed Exhibitions, the world's leading organiser of exhibitions, trade shows, and conferences, whose current portfolio includes over 500 events in 30 countries with overall attendance figures of more than 7 million participants in 2016. Reed Exhibitions has 38 branches worldwide serving 43 industry sectors. Reed Exhibitions is part of RELX Group plc, the leading provider of professional information and workflow solutions in the business sector.

Press Office: Flaminia Parrini, Reed Exhibitions Italia, tel. +39 02/43517038, flaminia.parrini@reedexpo.it

Lindab Pascal
Creating Balance

Upgraded and simplified DCV system for a perfectly sustainable indoor climate.

Lindab's DCV system Pascal has now become better and even more flexible. Pascal is now available with new integrated web interface that makes it easier to set up and maintain your ventilation system on a day-to-day basis. With direct online access, you can now install and commission your system in a quick and easy way.

In addition, we have upgraded Pascal with a new application for DCV control of chilled beam systems, so Pascal is now fully compatible with our Air- and Waterborne solutions. Just as before, Pascal offers demand and presence-controlled ventilation that in combination with intelligent fan control provides an optimal and sustainable indoor climate with minimal energy consumption.

REHVA has announced a strategic partnership with WorldBuild365,

the B2B platform which helps companies promote their products and services to more than 1.4 million professional buyers worldwide

WorldBuild365 is a B2B industry platform that unites buyers from around the world with global suppliers to the building, architecture, HVAC, design, and décor industries. The platform, part of ITE Group, one of the world's leading exhibition organisers, uses the Group's knowledge of the industry to unite manufacturers, their products, and the professionals who specify and procure them. WorldBuild365 offers a space to keep up-to-date with the building, interiors, design, and décor industry all year round, source products, services and new suppliers, get inspiration, as well as connect with businesses and professionals.

With a targeted audience of more than 1.4 million, WorldBuild365 offers a way for HVAC manufacturers to connect with industry buyers and do business anywhere, anytime. As the platform for the world's largest portfolio of exhibitions for Building, Interiors and HVAC, WorldBuild365 opens the doors for suppliers to its exhibition visitors from all over the world. Suppliers promote their products and services and communicate with the professional audience benefiting from a wide variety of marketing channels.

Valentyna Podgorodetska, Head of WorldBuild365, commented, "We are very pleased to be partnering with such a respected organisation as REHVA. With the Federation's key positioning within the European HVAC Sector, this partnership offers strong support for our business and we will provide a valuable service to the associations and engineers it represents."

WorldBuild365 offers discounts on advertising packages for all REHVA members. To learn more about this opportunity, please email info@worldbuild365.com, or phone +44 207 596 5012.

REHVA Office Responsibilities

NATHALIE WOUTERS – Office and Membership Manager
- Office management, HR
- Membership liaison
- REHVA Student competition
- REHVA Awards
- REHVA Board meetings' secretariat
- REHVA Newsletter, Bulletin publication
- REHVA Annual meetings, General Assembly secretary
- EC, AC secretary
- MoU-s: follow-up and coordination

ANITA DERJANECZ – Managing Director
- REHVA office executive management
- REHVA Legal representative
- Business development
- EU policy and public affairs
- Commissioning certification scheme project
- EU project development and implementation
- ERC, TRC secretary

CHIARA GIRARDI – Publication and Promotion Officer, RJ Editor Assistant
- Publication of REHVA Guidebooks and Journal (as Editor Assistant)
- REHVA website content management
- REHVA promotional services and sales
- Supporters Contact
- REHVA Dictionary and App development
- REHVA presence at events and fairs, events management and promotion of REHVA events
- SC, PMC, COP secretary

GIULIA MARENGHI – Project Assistant
- Administrative support of general office management
- Financial and administrative reporting of EU projects
- EU project implementation – communication activities
- Reception and secretarial support

TIZIANA BUSO – Project Officer
- TRC secretary, support of Task Forces, and technical publications
- EU project implementation
- EU proposal writing
- Supporting REHVA technical seminars
- Commissioning certification scheme project

MULTI V 5

LG Business Solutions

DESIGNED FOR THE **ULTIMATE**

DUAL SENSING CONTROL

MAX ESEER 9.46 with DUAL SENSING CONTROL

that senses and controls both Temperature and Humidity

Smart Load Control (SLC)
SLC controls cooling load by sensing both temperature and humidity to increase energy efficiency up to 15 – 31%.

Comfort Cooling
It maintains operation at mild cooling mode around set temperature without stopping in between for maximized user comfort.

Continuous Heating
It increases heating capacity and indoor comfort via delayed defrost and partial defrost without periodic oil recovery operation.

Smart sensors make energy saving second nature:
Breakthrough Technology Prioritizes Energy Efficiency Without Sacrificing User Comfort

The spread of climate control technology in the latter half of the 20th century helped raise the standard of living across the globe as happiness and productivity soared due to solutions that were able to make any environment more comfortable. However, many do not realize that the effective climate control required to create a comfortable environment involves much more than simply regulating temperature. While many top-of-the-line VRF solutions are designed to keep temperatures under control, efficiently creating the ideal environment also involves tackling humidity head on. After all, even if a VRF is able to maintain a constant temperature, humidity plays a key role in determining relative comfort levels.

This has a number of practical applications, as office productivity and morale suffer if steps are not taken to guarantee employee comfort by reigning in temperature and humidity. The need to combat humidity is felt even more acutely at production facilities since these same productivity concerns apply to costly equipment and machinery as well as employees.

However, most VRFs don't take room humidity into account when calculating airflow output. This can cause users to overuse their air conditioner as they seek to create a comfortable temperature. Similarly, in rooms that have lower levels of humidity, air conditioners may be able to operate at lower levels despite the user tendency to turn up the AC at every opportunity.

These issues are addressed head on by the Dual Sensing Control capabilities of LG's new MULTI V 5. Dual Sensing Control raises user comfort while increasing control, allowing the advanced MULTI V 5 to perform real time climate evaluations down to the smallest detail. Unlike conventional air conditioners which only track temperature, the MULTI V 5 is able to measure the temperature and humidity levels of surrounding outdoor and indoor environments. This comprehensive understanding of its surroundings helps the MULTI V 5 tailor its performance to achieve optimal energy efficiency and indoor comfort levels.

Moreover, efficient systems like Smart Load Control make it possible to control the outdoor unit's discharge refrigerant temperature, increasing energy efficiency by up to 31 percent. This stands in stark contrast to typical VRFs which inefficiently fluctuate in order to maintain a set indoor temperature. The addition of the Comfort Cooling function and Dual Sensing Control gives the MULTI V 5 the ability to maintain operation around a desired temperature, delivering maximum user comfort.

LG's Leading VRF, The MULTI V 5.

Solutions like the MULTI V 5 are demonstrating that superior user comfort can be achieved without sacrificing energy efficiency through the use of advanced sensors and adaptive programming. By doubling the ability of its VRF to interpret environmental factors, LG has created a solution that is able to effectively respond to user demands while reducing energy consumption. This significant boost in efficiency has made the MULTI V 5 a leader in its market, showing how the most forward-thinking technology can be applied to create solutions that benefit users, their pocketbooks and the planet.

Multifunctional Belimo Energy Valve™.
Transparent energy monitoring with the Belimo Cloud.

The Belimo Energy Valve™ combines many functions in a single installation-friendly unit. Building owners, facility managers, contractors and system integrators will not fail to recognise the advantages of this intelligent technology such as:

- Quick and certain dimensioning as well as simple commissioning
- Energy-saving through automatic, permanent hydronic balancing
- Correct volume of water despite differential-pressure changes and partial loads
- Efficient operation ensured through the Delta-T management

With the integration of the Belimo Energy Valve™ into the Belimo Cloud the users create their own account to have full transparency about the energy consumption in the cooling/heating application.

We set standards. www.belimo.eu

BELIMO CLOUD

BELIMO®

Transparent energy monitoring of multifunctional valves with the Belimo Cloud

The Belimo Energy Valve™, which consists of a 2-way characterised control valve, volumetric flow meter, temperature sensors and an actuator with integrated logic combines many functions in a single installation-friendly unit. This intelligent technology brings new advantages: Quick and certain dimensioning as well as simple commissioning. Energy-saving through automatic, permanent hydronic balancing and correct volume of water despite differential-pressure changes and partial loads. With the integration of the Belimo Energy Valve™ into the Belimo Cloud users create their own account to have full transparency about the energy consumption in the cooling/heating application – anytime and from everywhere and whenever they want.

One optimised complete solution – easier energy control than ever before

The new Belimo Energy Valve™ is an Internet of Things (IoT) device – a smart connected pressure-independent valve that measures and manages coil energy consumption by utilising an embedded flow meter, along with supply and return water temperature sensors. The Belimo Energy Valve™ also has power control and Delta-T manager logics built-in that monitor coil performance and optimise the heat transfer of the coil by maintaining the Delta-T.

The Belimo Energy Valve™ combines several useful functions in one valve unit. Such as the connection to BACnet, MP-Bus and Modbus with the same valve. Besides this multi-bus connection, it is possible to save and reload settings from one valve configuration and load them into another valve allowing for fast and accurate setup. Another highlight is the new designed user interface with an intuitive installation setup to make the valve ready in only a few steps. An exclusive Belimo Energy Valve™ feature is the glycol monitoring. It utilises an embedded temperature sensor and advanced logic algorithms to monitor the percentage of glycol content in the HVAC system.

Belimo Cloud – The future begins now

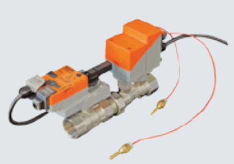
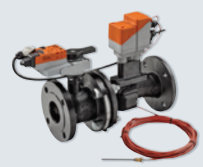
The Belimo Cloud Optimisations make full use of the energy potential. Cloud Analytics offers recommended Delta-T settings by Belimo experts for an efficient operation. Belimo Cloud Support helps to commission and produce the optimum setting for the Belimo Energy Valve™ in all operating phases.

The Belimo Cloud provides straightforward access to all data over the entire life cycle of the Belimo Energy Valve™, thus forming the basis for future operation optimisation. Belimo Cloud Reporting permits a complete overview of the current and previous performance data such as flows, energy consumption, power requirements and Delta-T with the most important performance indicators shown in graphs.

The Belimo Cloud Service regularly provides users with software updates and experienced Belimo technicians help users to solve technical problems and to improve system performance and stability. The access to the Belimo online services makes life easier and gives the security to always have the best settings for the devices.

More information: **www.belimo.eu**

Full range from DN 15 to DN 150 mm

Belimo Energy Valve™		
Nominal diameter DN [mm]	15…50	65…150
$\dot{V}_{nom}$ [l/s]	0.35…4.8	8…45
$\dot{V}_{nom}$ [l/min]	21…288	480…2700
Adjustable maximum flow rate [l/min]	6.3…288	216…2700

Medium temperature: -10 °C…120 °C **System pressure (ps):** 1600 kPa

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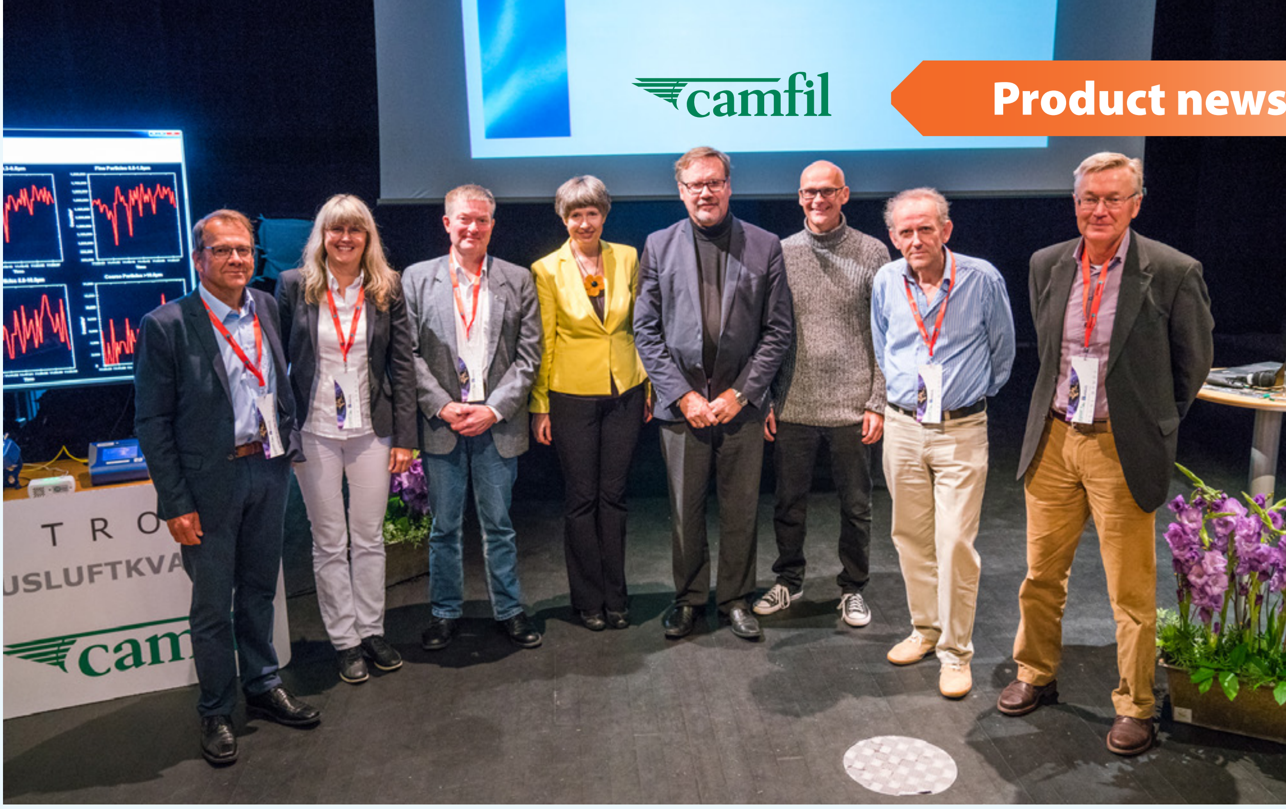

What is the difference between fresh air and fresh, clean air?

75 attendees. Seven noted speakers. Four professors. One mission – to discuss the importance of indoor air quality (IAQ). On Monday, September 5, 2017, Camfil AB and Trosa Kommun hosted a full day forum on IAQ.

Noted speakers included Professor Lidia Morawska, Professor Bertil Forsberg, Professor Magnus Svartengren, Assistant Professor Per Gerde, Britta Permats, M.D., IAQ Expert Anders Hedström and Filtration Expert Ulf Johansson. Presentations included:

- "The advancement of technologies and their impact on IAQ" – Professor Lidia Morawska, advisor of WHO (World Health Organization)
- "Adverse effects of fine particles from pregnancy and birth to cognitive aging and dementia – recent findings" – Professor Bertil Forsberg
- "Clean air – Yes! But how to put pollutants back in for research and remedy?" – Assistant Professor Per Gerde
- "Our future – Ventilation in schools" – Britta Permats, M.D.
- "Air filtration – The day after tomorrows" – Ulf Johansson, Filtration Expert
- "IAQ in a historical view" – Anders Hedström, IAQ Expert

The lectures covered a vast range of topics such as the future of air monitoring sensors, the effect of air pollution on our bodies, air quality of schools, subways and tunnels as well as energy savings versus health, research and testing capabilities.

The audience participated in open discussions with challenging questions from the presenters throughout the day. The forum was spent sparking ideas and conversations focused on the idea that clean air is a human right, just like clean water!

"Clean air matters to me because it makes for a pleasant environment," Morawska said. "But, it's also important to have the professional knowledge of what polluted air does."

Gathering the presenters on stage, the last hour was spent with an open panel discussion where the presenters answered questions together, some with similar answers and some with disputing answers.

"Facts about IAQ were raised to the panel and the conclusion around the carcinogenic risk from small particles within the PM1 range were clear," Hedström said. "Also, the panel questioned the legislation about IAQ and what recommendations were realistic or not. In turn, Prof. Morawska updated the audience on the conversations going on in WHO (World Health Organization) and how the next step must be to put pressure on politicians."

This concluded the conference with lots of dialogue and everyone in the room ready to go out and inspire a clean air revolution with hopes of the forum becoming a yearly or biyearly event.

To learn more about IAQ, contact Anders Hedström with Camfil. Presenters may also be available for interview per request. Attached is the IAQ Forum brochure with presenters' titles and bios.

About Camfil

Camfil is a global leader in the air filtration industry with more than half a century of experience in developing and manufacturing sustainable clean air solutions that protect people, processes and the environment against harmful airborne particles, gases and emissions. These solutions are used globally to benefit human health, increase performance and reduce energy consumption in a wide range of air filtration applications. Our 26 manufacturing plants, six R&D sites, local sales offices and 3,800 employees provide service and support to our customers around the world. Camfil is headquartered in Stockholm, Sweden. Group sales total more than SEK 6 billion per year.

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Romanian Association for Installations Engineers—Romania

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Association of Engineers in Heating, Ventilation, Air-conditioning, Heat Supply

Serbia HVAC&R Society—Serbia

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Swedish HVAC Society - Society of Energy and Environmental Technology - Sweden

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Send information of your event to Ms Chiara Girardi cg@rehva.eu

Events in 2017—2018

Conferences and seminars 2017

October 24-25	Ventilating healthy low-energy buildings	Nottingham, UK	http://www.aivc2017conference.org/
October 24-25	European Heat Pump Summit 2017	Nuremberg, Germany	https://www.hp-summit.de/en
October 31	7th International Conference on Solar Air-Conditioning – PV Driven/Solar Thermal	Abu Dhabi, UAE	http://www.solaircon.com/
November 1-3	XXXIV Conference and Exhibition "Moscow – energy efficient city"	Moscow, Russia	http://events.abok.ru/
November 10-11	Second ASHRAE Developing Economies Conference	Delhi, India	https://ashraem.confex.com/ashraem/de17/cfp.cgi
November 13-14	REHVA Brussels Summit	Brussels, Belgium	http://www.rehva.eu/
December 6-8	The 48th International Congress and Exhibition on Heating, Refrigeration and Air-Conditioning	Belgrade, Serbia	http://kgh-kongres.rs/index.php?lang=sr

Exhibitions 2017

October 10-12	HVAC 2017	Birmingham, UK	www.hvaclive.co.uk
November 7-10	INTERCLIMA+ELECHB	Paris, France	http://www.interclimaelec.com/

Conferences and seminars 2018

January 22-24	2018 AHR Expo	Chicago, IL	www.ahrexpo.com
February 7-10	ISK – Sodex	Istanbul, Turkey	http://www.sodex.com.tr/en
February 22-24	ACREX 2018	Bengaluru, India	http://www.acrex.in/home
March 12-15	Cold Climate HVAC Conference 2018	Kiruna, Sweden	http://www.cchvac2018.se
March 13-16	MCE – Mostra Convegno Expocomfort 2018	Milan, Italy	www.mcexpocomfort.it
April 12-14	13th International HVAC&R Technology Symposium	Istanbul, Turkey	https://goo.gl/bJmSo2
June 3-6	ROOMVENT & VENTILATION 2018	Espoo, Finland	http://www.roomventilation2018.org/

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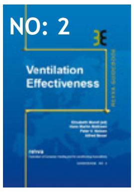
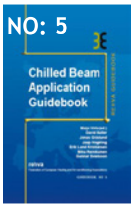
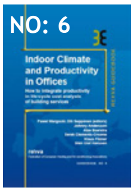


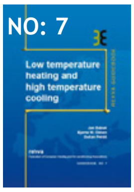
Improving the ventilation effectiveness allows the indoor air quality to be significantly enhanced without the need for higher air changes in the building, thereby avoiding the higher costs and energy consumption associated with increasing the ventilation rates. This Guidebook provides easy-to-understand descriptions of the indices used to mesure the performance of a ventilation system and which indices to use in different



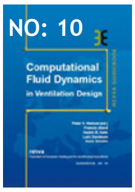
Chilled beam systems are primarily used for cooling and ventilation in spaces, which appreciate good indoor environmental quality and individual space control. Active chilled beams are connected to the ventilation ductwork, high temperature cold water, and when desired, low temperature hot water system. Primary air supply induces room air to be recirculated through the heat exchanger of the chilled beam. In order to cool or heat the room either cold or warm water is cycled through



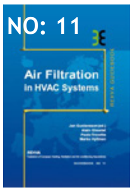
Indoor Climate and Productivity in Offices Guidebook shows how to quantify the effects of indoor environment on office work and also how to include these effects in the calculation of building costs. Such calculations have not been performed previously, because very little data has been available. The quantitative relationships presented in this Guidebook can be used to calculate the costs and benefits of running and operating the building.



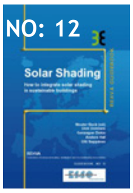
This Guidebook describes the systems that use water as heat-carrier and when the heat exchange within the conditioned space is more than 50% radiant. Embedded systems insulated from the main building structure (floor, wall and ceiling) are used in all types of buildings and work with heat carriers at low temperatures for heating and relatively high temperature for cooling.



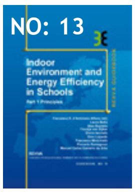
CFD-calculations have been rapidly developed to a powerful tool for the analysis of air pollution distribution in various spaces. However, the user of CFD-calculation should be aware of the basic principles of calculations and specifically the boundary conditions. Computational Fluid Dynamics (CFD) – in Ventilation Design models is written by a working group of highly qualified international experts representing



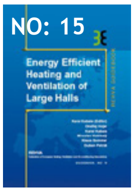
Air filtration Guidebook will help the designer and user to understand the background and criteria for air filtration, how to select air filters and avoid problems associated with hygienic and other conditions at operation of air filters. The selection of air filters is based on external conditions such as levels of existing pollutants, indoor air quality and energy efficiency requirements.



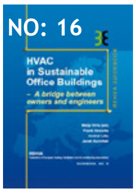
Solar Shading Guidebook gives a solid background on the physics of solar radiation and its behaviour in window with solar shading systems. Major focus of the Guidebook is on the effect of solar shading in the use of energy for cooling, heating and lighting. The book gives also practical guidance for selection, installation and operation of solar shading as well as future trends in integration of HVAC-systems with solar con-



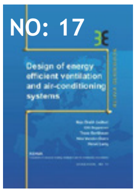
School buildings represent a significant part of the building stock and also a noteworthy part of the total energy use. Indoor and Energy Efficiency in Schools Guidebook describes the optimal design and operation of schools with respect to low energy cost and performance of the students. It focuses particularly on energy efficient systems for a healthy indoor environment.



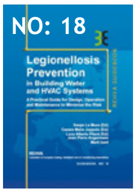
This guidebook is focused on modern methods for design, control and operation of energy efficient heating systems in large spaces and industrial halls. The book deals with thermal comfort, light and dark gas radiant heaters, panel radiant heating, floor heating and industrial air heating systems. Various heating systems are illustrated with case studies. Design principles, methods and modeling tools are presented for various



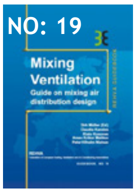
This guidebook talks about the interaction of sustainability and heating, ventilation and air-conditioning. HVAC technologies used in sustainable buildings are described. This book also provides a list of questions to be asked in various phrases of building's life time. Different case studies of sustainable office buildings are presented.



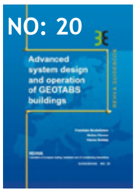
This guidebook covers numerous system components of ventilation and air-conditioning systems and shows how they can be improved by applying the latest technology products. Special attention is paid to details, which are often overlooked in the daily design practice, resulting in poor performance of high quality products once they are installed in the building system.



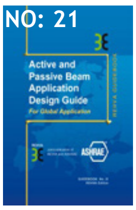
This Guidebook is a practical guide for design, operation and maintenance to minimize the risk of legionellosis in building water and HVAC systmes. It is devided into several themes such as: Air conditioning of the air (by water – humidification), Production of hot water for washing (fundamentally but not only hot water for washing) and Evaporative cooling tower.



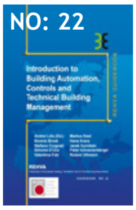
In this guidebook most of the known and used in practice methods for achieving mixing air distribution are discussed. Mixing ventilation has been applied to many different spaces providing fresh air and thermal comfort to the occupants. Today, a design engineer can choose from large selection of air diffusers and exhaust openings.



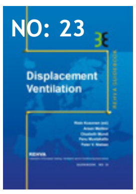
This guidebook provides comprehensive information on GEOTABS systems. It is intended to support building owners, architects and engineers in an early design stage showing how GEOTABS can be integrated into their building concepts. It also gives many helpful advices from experienced engineers that have designed, built and run GEOTABS systems.



The Active and Passive Beam Application Design Guide is the result of collaboration by worldwide experts. Active and Passive Beam Application Design Guide provide energy-efficient methods of cooling, heating, and ventilating indoor areas, especially spaces that require individual zone control and where internal moisture loads are moderate. The systems are simple to operate, with low maintenance requirements. This new guide provides up-to-date tools and advice for designing, commissioning, and operating chilled-beam systems to achieve a determined indoor climate and includes examples of active and passive beam calculations and selections.



This guidebook aims to provide an overview on the different aspects of building automation, controls and technical building management and steer the direction to further in depth information on specific issues, thus increasing the readers' awareness and knowledge on this essential piece of the construction sector puzzle. It avoids reinventing the wheel and rather focuses on collecting and complementing existing resources on this topic in the attempt of offering a one-stop guide.



Displacement ventilation has been originally developed in Scandinavian countries over 30 years ago and now it is also a well-known technology in different countries and climates. Historically, displacement ventilation was first used for industrial applications but nowadays it is also widely used in commercial premises.

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