LANDELIJK NETWERK
DE GROENE OK.

Operating room air handling: great potential for energy savings

Radboudumc TU Delft UMC Utrecht TNO innovation for life Royal HaskoningDHV Enhancing Society Together Pro OK Advies Ministerie van Volksgezondheid, Welzijn en Sport

The National Green OR Network

Air treatment

Results of research by the Energy Consumption Working Group

LANDELIJK NETWERK DE GROENE OK.

Foreword

This document marks an important step in making healthcare more sustainable and contributes to achieving the climate objectives as set out in the Green Deal 3.0 'Working together for Sustainable Healthcare'; an agreement between the Dutch Government and other (healthcare) partners for the implementation of sustainable plans.

Operating rooms (ORs) are a unique part of the hospital with a particularly high energy consumption, largely caused by air treatment. Reducing this consumption not only offers significant opportunities for CO_2 reduction, but also contributes to substantial cost savings. In this report we present the results of research into concrete and feasible measures that contribute to more sustainable and energy-efficient use of operating rooms.

This report is the result of a collaboration between The National Green OR Network and partners:

- RadboudUMC
- TU Delft
- UMC Utrecht
- TNO
- Royal HaskoningDHV
- Pro OK Advice
- Ministry of Health, Welfare and Sport

Their expertise and involvement were invaluable in the creation of this document.

With this document we hope to not only provide insight into the energy saving potential, but also to inspire and support healthcare professionals and hospitals in their pursuit of sustainable healthcare.

Together we can take steps towards a future in which high-quality care goes hand in hand with climate-conscious action.

We trust that reading this report will offer you both inspiration and practical guidance.

The National Green OR Network
On behalf of the Energy Consumption Working Group

Contents

Summary

Air handling units are advanced, energy-intensive systems, first developed when energy saving and sustainability in the healthcare sector were not yet prominent themes. Adjusting the air handling in operating rooms (ORs) can lead to a large reduction in energy consumption. This boosts the sustainability of care provided in ORs and reduces energy costs.

The Energy Consumption Working Group, part of the National Green OR Network, has conducted research into the potential energy savings of air treatment in Dutch operating rooms. This research was financed by the Ministry of Health, Welfare and Sport (VWS) on the basis of the Urgenda agenda measure 51.

With a survey among 51 (55%) operating complexes we gained insight into the current state of affairs and were able to define potential energy saving measures. Through measurements in 9 operating rooms (of 8 hospitals) we were able to feed a calculation model, and assess the potential energy reduction. The potential energy reduction is considerable. The associated reduction in CO_2-emissions depend on the method with which the energy was generated. This was not included in this study.

The measures with the most interesting saving opportunities are:

- Widening the humidity limits to 30-70%
- Setting clock times/sensors (switching to a lower setting outside working hours)
- Reducing the amount of supplied air from outside (ODA) that needs to be heated, cooled, and humidified/dehumidified
- Reducing the total amount of air exchanged per hour (switching between OR 'classes')

Relatively simple adjustments to save energy include widening the relative humidity limits and introducing operational clock times. Installing a motion sensor can also reduce ventilation during daytime when the OR is not in use.

Lowering ODA has a major effect on energy savings compared to the reference situation. Lowering ODA is often not easy in existing facilities. Switching between Class 1+ and Class 1 could be done with an additional switch from the control panel.

For each hospital, what is technically feasible will depend on the type of air treatment system and the current use. Which measures are interesting, also depends on the measures already taken, the design of the system and the current situation.

Introduction

Towards a greener and more energy-efficient operating room

The National Green OR Network is a collaboration of fifteen scientific and professional associations that want to make healthcare in the OR more sustainable, and is a co-signatory of the Green Deal 3.0 'Working Together on Sustainable Healthcare'. The National Network encourages and supports individual medical specialists and healthcare professionals who work in the OR to contribute to the climate objectives in a sustainable way.

There are 5 pillars within the network: the National Sustainability Guideline, Anaesthetic vapours and drug residues, the Green Barometer, Circular waste management and plastic waste, and Energy Consumption. The Energy Consumption Working Group is concerned with energy conservation and CO_2-reduction at the operating complex, with a focus on air treatment.

The energy consumption of an operating complex is fundamentally different from that of a complete hospital. For an operating complex, more than 90% of the energy consumption is caused by air treatment. Achieving energy savings in the operating complex results in a significant reduction in CO_2. Previous research has already shown that isolation rooms and operating rooms have the highest energy saving potential in a hospital [1] and that worldwide approximately 6% of the total energy consumption in the building sector consists of energy consumption in medical centres [2].

We were able to conduct research into the potential savings of operating rooms in the Netherlands. This research is financed by the Ministry of Health, Welfare and Sport (VWS) based on the Urgenda agenda measure 51.

The results of this research contribute directly to the goal of hospitals to achieve CO_2 reduction and can be included in the CO_2 roadmaps of each hospital.

Background

What is air treatment and what is its function?

Air treatment means that the air is refreshed by installations, creating an environment in which as few particles as possible float around. This is done because bacteria can travel on those particles and could therefore possibly cause a postoperative wound infection (POWI).

To achieve clean air, impressive installations are located on a floor above the operating rooms, hidden from view. Part of the air is ('expensive') air from outside and part is recirculated. The air from outside is expensive because it has to be heated, cooled, and humidified/dehumidified. Also, a large volume of air has to be transported through ducts to and from the operating rooms. The more bends and the longer these ducts are, the more resistance is created. And: the more resistance, the more fan energy is needed to transport this volume of air. This video shows the technical layer of an operating complex.

We distinguish three classes of operating rooms, namely: class 1+, class 1 and class 2 (FMS guideline 2022 [3]). For an OR class 1+ and 1, three pressure zones in the OR complex are required. For an OR class 2, 2 pressure zones are sufficient.

Besides the difference in the number of pressure zones, other requirements vary per class, such as the minimum number of air changes and the ISO classification, according to NEN-EN-ISO 14644-1, regarding to the maximum particle concentration of the room. Increasing the amount of air supplied to the operating room results in fewer particles in the room and also in a faster recovery of the air quality in the operating room (recovery time) [4]. A shorter recovery time of the air quality in the operating room also results in a lower number of measured colony-forming units per m^3 (CFU/m^3). ISO 5 and ISO 7, according to NEN-EN-ISO 14644-1, relate to the maximum permitted concentration of particles in the air in a certain situation. At ISO 5, the number of permitted particles/ m^3 with a size of >=0.5 µm is 3,520 per m^3 and at ISO 7 the number of permitted particles/m^3 of ≥0.5 µm is 352,000 per m^3.

For infection-sensitive operations (major joint replacement procedures = class 1+), more air changes are required than for other types of operations [5]. The number of air changes in the operating room is higher than the minimum number of 20 per hour for a class 1+. In actual practice, the number of changes is often above 60 per hour. For each specialty and each procedure, the FMS guideline indicates in which OR class it should take place (FMS guideline 2022).

In the Netherlands, it turns out that in actual practice, almost all operating rooms are Class 1+, while this is not necessary for the type of procedures performed. This is a waste of money and energy. The cost of the air treatment and supply system of a class 1 room is about half the investment compared to Class 1+.

In addition, it is important to realize that the occurrence of POWI's is influenced by many factors. The type of surgery and the health status of the patient are the most important factors. Other important factors are (hand) hygiene, correct use of antibiotics (prophylaxis), adequate disinfection, prevention of hypothermia of the patient, clothing discipline and movements of personnel in the operating room. In order to prevent POWI's due to airborne microorganisms in the operating room, sufficient ventilation and the total number of air changes are important.

In the Netherlands, humidity in operating rooms is often kept within a narrow range, for example 50%-65%. However, the FMS guideline only sets an upper limit for all operating rooms of 65% and research has shown that the range can be much wider, for example 30%-70% [6].

In summary

- We operate in operating rooms where, in some cases, the air handling systems run at full capacity day and night.
- The classification of the operating room is usually set too high.
- Humidity is often regulated more precisely than necessary.

Phase 1

Energy saving options

The research question was: how can we reduce the energy consumption of operating rooms without affecting the air quality. In other words: where in the Dutch operating rooms is potential to save energy. We saw possibilities in the following adjustments:

- A “day” and “night” mode, with the lowest possible “standby mode” when not in use.
- This can be done even more efficiently with motion sensors.
- Switch between a Class1+ and a Class1 operating room (OR).
- Reducing fresh air from outside and lowering the total air volume.
- Widening the accepted humidity range.

Phase 2

Survey Dutch hospitals

Since every hospital has different installations and operating room usage, we conducted a survey to determine the current state of affairs.

In the second half of 2023, 93 hospitals were approached to complete a survey about the air treatment system for the operating rooms and the use of the operating rooms [7]. Of the 93 hospitals approached (including the 7 University Medical Centres), 51 completed the questionnaire (55%). The survey shows that 55% of the operating complexes are older than 10 years and 12% were even built before 1995 and are therefore older than 30 years. This is remarkable because the technical lifespan of an air treatment system for an operating room (complex) is generally no more than 15-20 years.

There are three basic systems to distinguish, Figure 1.

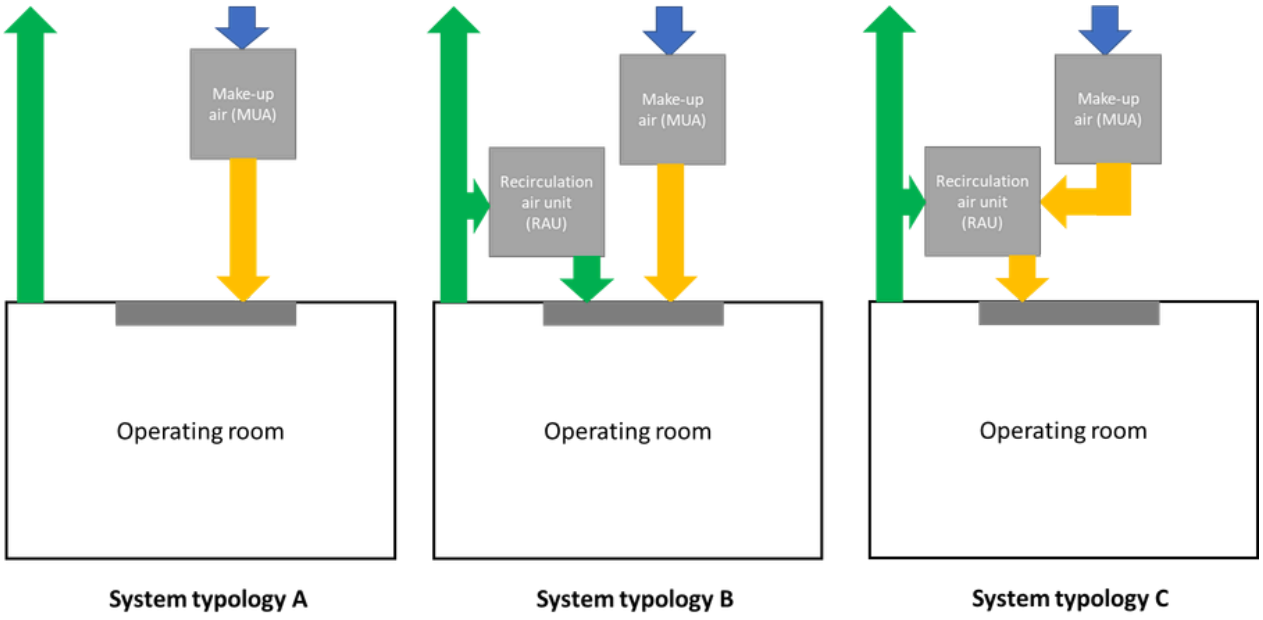

Figure 1. System typologies of air treatment systems for operating rooms.

The analysis shows that 16% of the included OR centres use air treatment system typology A, 41% use system typology B and 43% use system typology C. In particular, the operating rooms from before 1995 are designed as typology A. The air volumes used are shown in figure 2.

The amount of fresh air from outside (ODA) varies between 1,000 and 4,500 m³/h with a maximum of 9,000 m³/h. When using inhalation anaesthetics, Occupation Health and Safety rules for University Medical Centres (the Arbocatalogus UMC's) state that, depending on the anaesthetic system used, the fresh air volume should be between 1,000 and 2,000 m³/h [8]. This catalogue was drawn up at a time when energy reduction played no role and, moreover, vapour anaesthetics and nitrous oxide were used intensively.

This means that in a number of hospitals, considerably more fresh air from outside is used than is minimally required. This fresh air from outside is energy-intensive because it is heated, cooled, humidified and dehumidified in the ODA. The “recirculation air” needs limited conditioning in the RAU. The total air volume supplied to the operating rooms (Total Air Volume) is between 2,200 m³/h and 12,500 m³/h.

The number of air changes in the space is called circulation rate. Our research shows that the operating rooms have an average circulation rate of 60 per hour. The circulation rate is considerably higher than the requirement for a class 1 and class 1+ operating room (circulation rate 20 per hour) according to the FMS guideline Air treatment in operating rooms and treatment rooms. A higher circulation rate is necessary to meet the position statement of the Dutch Orthopaedic Association (NOV) regarding the requirements for a class 1+ operating room. (https://www.orthopeden.org/media/agbpatrj/6245a0933cafastandpunt-nov-luchtbehandeling-operatiekamer-klasse-1-voor-websitenov.pdf) [9].

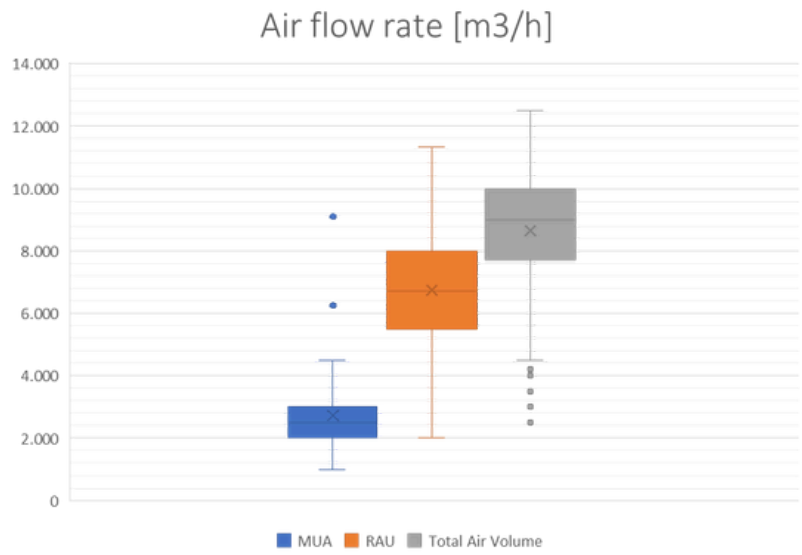

Figure 2. Air volumes in operating rooms in m³/h (n=51). MUA: Make Up Air (=treatment of air from outside) and RAU (Recirculation Air Unit)

Our study shows that in 32% of hospitals all operating rooms are used for major joint replacement procedures. In 42% of hospitals these procedures are performed in only 25% of the operating rooms.

The results show that almost all operating rooms are Class 1+, which makes them suitable for performing major joint replacement surgeries, but they are not actually used for this. Many operating rooms therefore use more (recirculated) air than required for a large part of the time, which means that more energy is used than necessary.

The vast majority of operating rooms, 94%, use heat recovery from the exhaust air. This recovers a large part of the energy from the exhaust air.

In 72% of hospitals, the amount of air is reduced by at least 50% at night and at weekends. There are even hospitals (4%) that completely turn off recirculation and only supply the necessary fresh air from outside, needed for the overpressure (figure 3).

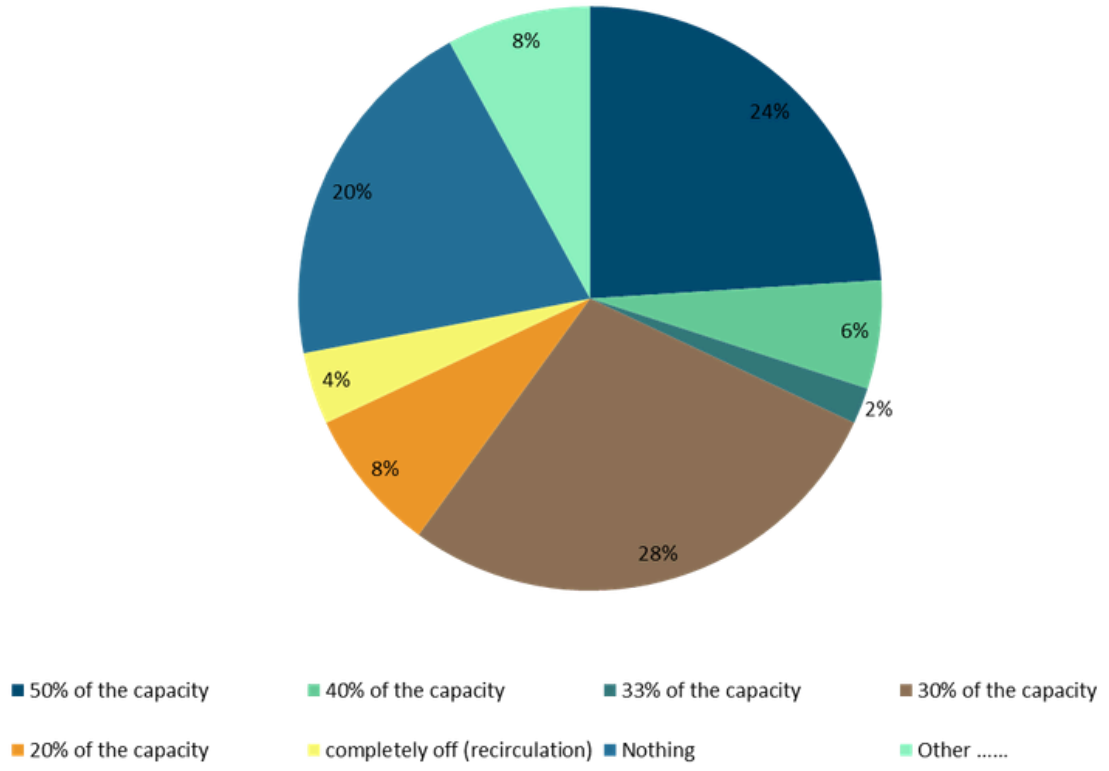

Figure 3. Reduction of air volume during night and weekend.

Humidification costs a lot of energy and 76% of hospitals still use steam that is centrally generated using natural gas, 20% of hospitals use local electric humidifiers placed near the air treatment unit and 4% use adiabatic humidification (the most energy-efficient method). Despite the research by the Expertise Centre for Sustainable Healthcare [10], operating rooms are still humidified at a high level. In 57% of operating rooms, humidification is still at a level of between 50 and 65% (Figure 4).

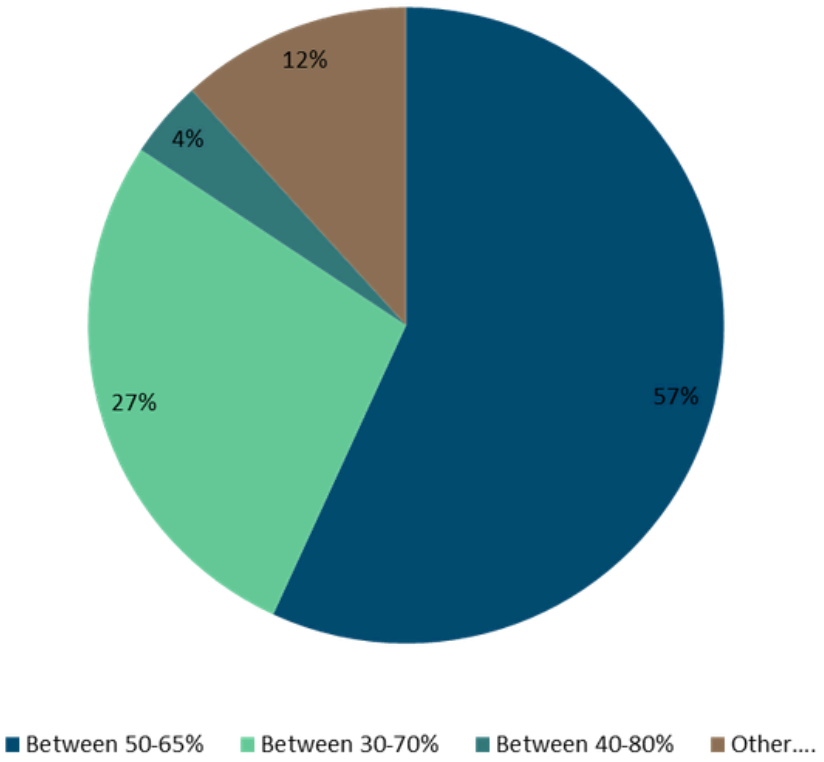

Figure 4. Humidification in operating rooms.

Finally, the survey also shows that only 4% of hospitals (n=51) measure and analyse the energy consumption of the air treatment system for operating rooms, and use this information to adjust its settings.

In summary

In most hospitals participating in the survey, measures are already being taken to reduce the energy consumption of the air treatment system in operating rooms. Almost all hospitals use heat recovery systems to recover energy from the exhaust air flow. The air volume is also often reduced at night and during weekends. However, switching in air volume based on the need for a class 1 or class 1+ operating room, is hardly done, and the supplied and treated air volumes are much larger than required.

Phase 3

Measurements conducted at 8 hospitals in 9 operating rooms, calculations using a model to assess the potential for energy savings

In the period from June to August 2024, measurements were performed on the air treatment systems of 9 operating rooms. These were operating rooms at three academic hospitals, three district hospitals and two private clinics. These operating rooms are geographically distributed across the Netherlands. The temperature and relative humidity of the air flow before and after the various components in the air handling unit as well as the power consumption of the fans were measured. This reference set of operating rooms consisted of system typology B (4 locations) and system typology C (5 locations).

Based on the measurements performed and the data obtained from the survey, the potential energy savings have been identified. A calculation model was used in which values obtained by measurements were used as input. A reference situation was defined and scenarios with measures were calculated to determine the possible annual savings in the energy requirement. The associated CO_2 emissions were not considered in this study because we did not perform an analysis of the origin of the energy.

Reference situation

A reference situation was used to determine the potential energy savings of the individual measures. The reference situation was based on the results of the survey and measurements that were carried out and has the following characteristics. The relative humidity was set between 50-65% for 57% of the respondents. The average air from outside percentage (ODA) was approximately 2,700 m³/h and the total air volume (SUP) approximately 8,600m³/h. The operating rooms in the reference set had an average amount of fresh air from outside of 2,367 m³/h (min. 1,000 – max. 3,000 m³/h) and a volume supplied to the operating room of 9,691 m³/h (min. 3,000 -15,129 m³/h). The reference set consisted of 7 class 1+ operating rooms and 2 class 1 operating rooms. The air temperature supplied to the operating room was on average 19.7 °C (min. 19.0 – max. 21.2 °C) and the temperature increase in the operating rooms was 0.9 °C (min. 0.0 – max. 2.1 °C).

Despite the fact that a large proportion of respondents (80%) indicated in the survey that they had taken measures to switch back the air-technical installation during the night and on weekends, we have chosen a reference situation in which the installation is continuously running fully. We made this choice because 20% of respondents do not yet switch off the installation and this is a zero situation to which we can relate the other measures (scenarios).

Scenarios

Compared to the reference situation, the energy saving potential for different scenarios was determined. The four realistic scenarios that were considered were:

- Scenario A, where the relative humidity limits are widened. The relative humidity was changed from 50-65% to 30-70%.
- Scenario B, switching to a standby mode when the OR is not in use, at night or during the weekend [2]. The operating hours were changed from 00:00h - 24:00 on 7 days per week, to 07:00h-18:00h 'on' and weekend 'off'.
- Scenario C, reduction of the outdoor air quantity (ODA). The ODA was reduced from the original values to 1,000 m³/h during operating hours and 500 m³/h in standby and at weekends.
- Scenario D, reduction of the total supply air (SUP) introduced into the OR. The SUP was set to 3,000 m³/h (generic/ conventional operating room).

The reduction of the amount of fresh air from outside supplied was based on the minimum required level from the Occupational Health and Safety rules (Arbo catalogus) for inhalation anaesthetics. The broader limits for relative humidity were based on the 'Sustainability map' of the Expertise Centre for Sustainable Healthcare [10].

To go from an operating room class 1+ to class 1, a volume of air supplied to the operating room of 3,000 m³/h was assumed. The starting point here is that this air volume meets the requirements of a Class 1 (circulation rate ≥ 20 and ISO particle class 7 according to NEN-EN-ISO 14644-1). We assumed that the temperature increase in the operating rooms remains the same when reducing the air volume (from class 1+ to class 1). This means that we assume a lower internal heat load in a Class 1 operating room. This will probably be correct because other types of procedures may be performed in a Class 1+ operating room than in a Class 1 operating room (FMS air treatment guideline).

Results*

Scenario A: Relative humidity (30 - 70%)

- Widening relative humidity range to 30 - 70%
- **Result:** On average 33% lower thermal energy demand

Scenario B: Night and weekend settings

- Switching back air treatment units.
- **Result:** 41% thermal and 60% electrical/mechanical reduction of the demand.

Scenario C: Outdoor Air (ODA)

- Reduce ODA to 1,000m³/h (working hours)and 500 m³/h (outside working hours).
- **Result:** On average 53% thermal and 49% electrical/ mechanical reduction of the demand.

Scenario D: Lower OR classification

- Transfer from class1+ to class 1.
- **Result:** 36% less electrical/mechanical reduction of the demand.
- Extra: Reduced support heating for even more savings.

If all four of the measuresmentioned are implemented, this could result in reduction of the energy demand of an OR between 70 and 80% compared to the reference situation (page 17).

*All energy savings are compared to the reference study (p.18)

Conclusion

In hospitals, measures are already being taken to reduce the energy consumption of the air treatment system in operating rooms. Most hospitals in our survey use heat recovery systems to recover energy from the exhaust air flow. Also, the air volume at night and weekends is already reduced by 80% of the respondents.

In almost all hospitals, however, there is the possibility to save even more energy. There are several ways to save energy in existing operating rooms with regard to the air treatment system. We did calculations based on a reference operating room, and the possible energy savings will be much greater for some hospitals (where no measures have been taken yet).

Relatively simple adjustments to save energy include widening the range of relative humidity and introducing operational clock times. Installing a motion sensor can also reduce ventilation during the day when the OR is not in use.

Lowering the ODA has a major effect on energy savings compared to the reference situation. Lowering the ODA is often not easy in existing facilities. To do this, the possibilities must first be investigated by considering the technical design of the air treatment system and the air tightness of the building shell of the operating room. Before an existing air-technical installation is modified, it is important to know how it is constructed. In many hospitals, the primary air-technical installation is not only used for the operating room. Other rooms within the operating room complex are often linked to this. This must be taken into account when optimising the air treatment of connected operating rooms. The increasing call for energy saving requires an air-handling system that can handle these developments.

Many operating rooms seem to be unnecessarily built as ultra clean operating rooms, class 1+ with a high number of air changes per hour and the ODA volume introduced into the OR is relatively high. With air treatment installation typology C it is easy to responsibly and safely reduce the classification of the operating room from a class 1+ to a class 1.

It is clear that there is still a great potential to save energy and to achieve the ultimate intended reduction in CO_2 emissions by implementing one or more of the measures mentioned.

Follow-up

The Energy Consumption Working Group will continue to support hospitals in actually realizing energy savings and related CO_2 emission reduction in the operating rooms. To this end, the working group will continue to contribute to:

- Communication: distribute the results of the research widely among hospital administrators, users and technical managers, as well as scientists, building installation consultants and installers.
- Standardization: Proactively include the suggested measures, including points of attention per situation, in the relevant standards and guidelines.
- Method and model development: Further develop the created method and models so that the most effective measures to save energy, CO_2 emissions and costs in an operating room can be selected in a practical, safe and reliable manner for each specific situation.
- Analyse the status of laboratories and clean rooms.
- Implementation study: identifying factors that obstruct or facilitate the implementation of the identified energy saving opportunities in Dutch operating room complexes (CAREFREE study).
- Education: integrating the findings into local and national education of (future) staff; including through the air treatment module in the e-learning of The National Green OR Network.

About the authors

The composition of the Working Group has changed somewhat over the past 5 years due to illness, retirement and emigration, but the core has remained constant and consists/consisted of very passionate people, largely participating in their own time.

Lise van Turenhout, anesthesiologist at the UMCU

Lise has been an anesthesiologist since 2020 and has been involved in the Energy Consumption Working Group since then. In our daily work, there is much more to be achieved in the field of sustainability than in our private lives. Well-considered use of raw materials and energy is not only essential because of depleting resources, a global warming and growing mountains of waste, but also fair to fellow human beings here and elsewhere in the world. That is why she has been an active member of the Green Team OR in various hospitals, and since 2023 she has been committed to making care in the Emergency Department at the UMC Utrecht more sustainable.

Wim Maassen, senior expert, consultant Royal HaskoningDHV

Wim is a Senior Advisor/Expert Energy and Sustainable Building who supports clients in the realization of sustainable future-oriented buildings. He is a BREEAM-NL/INT Assessorand a BREEAM/LEED Commissioningsmanager/-authority and has more than 29 years of experience in advising in the areas of energy saving, sustainable energy generation, optimization of the energy demand of buildings and defining, optimizing and measuring sustainability. In 2014, Wim was appointed TU/e Fellow/Departmental Professional Expert at the Eindhoven University of Technology and has conducted research into energy saving possibilities in collaboration with various hospitals, about which he publishes in national and international journals. He is editor-in-chief and co-author of the ASHRAE-REHVA-TVVL Guidebook Towards Energy Positive Hospital Buildings.

Roberto Traversari, senior researcher/consultant TNO

Roberto is a researcher and consultant specialized in contamination control, energy and installation technology, with a particular focus on air treatment systems in operating rooms. He holds a PhD on the topic "Aerogenic Contamination Control in Operating Rooms" from Maastricht University and conducts research on air quality, operational processes and the relationship between the physical environment, efficiency and patient safety, using the principles of Evidence-Based Healthcare Design (EBHD). His work focuses mainly on the Dutch healthcare sector, where he connects governments and companies with TNO healthcare teams, specifically focused on energy efficiency and indoor air quality. Roberto actively seeks new opportunities to develop and to implement innovations in these areas. In addition, he is scientific leader of the DutchP3Venti program, which conducts research on pandemic preparedness and ventilation.

Gerbrand van Middelkoop, expert in air treatment, energy flows and building management

Gerbrand has been the owner of Pro OK Advies, a specialist consultancy for hospitals and clinics, since 2020. Within the Energy Consumption Working Group of the Groene OK, he has contributed to the translation between science and daily practice.

Jos Lans, TU Delft and CEO Medexs

After obtaining his bachelor's degree in mechanical engineering at the Hogeschool Utrecht in 1997, he studied at Nyenrode Business University. He completed his Master of Science in Management in 2003 with a thesis on the failure of organizational change. He won the Nyenrode Ondernemersprijs in 2002 with his concept for a movable modular operating room. After a successful career and various management positions in companies active in the medical sector, he has been an entrepreneur since 2007 and owns several companies, including Medexs BV. In addition to his job as CEO of Medexs, he obtained his PhD in 2024 from the Faculty of Architecture and Built Environment at Delft University of Technology. His research focused on innovations and the effectiveness of ventilation and air treatment in generic and ultra-clean operating rooms.

Sandra Lako, anesthesiologist Radboudumc

Sandra has been an anesthesiologist at Radboud UMC since 1996. Sustainability is very close to her heart, she is chair of the working group The Green OR at Radboud UMC and was present at the establishment of the National Network the Green OR, where she participates in various working groups. She is chair of the Energy Consumption Working Group of the National Network the Green OR. She is also a member of the “green working group” of the Dutch Society for Anaesthesiology.

Egid van Bree, doctor, and PhD candidateMaastricht University/Amsterdam UMC

Egid is a passionate doctor with a passion for sustainable care and planetary health. In his PhD research, he focuses on measuring, weighing and improving the environmental impact of (mainly) hospital care. He also focuses on the implementation of the energy saving options in this guideline – and has therefore become involved in the Energy Consumption Working Group. In addition to his research, Egid is a board member of the Groene Zorg Alliantie: a national network of workplace initiatives that is committed to a greener healthcare sector.

Thanks also to:

- Johan Laurensse, consultant and project leader air treatment
- Anne Brouwer, consultant Royal HaskoningDHV
- Elmar Helmich, anesthesiologist at the Whangarei hospital, New Zealand.

Appendix I

References

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Appendix 2

Participating OR centres survey

- ADRZ Goes
- Alrijne hospital
- Amphia
- Amphia Old Building
- Amsterdam VUMC
- Bernhoven
- Bravis Hospital
- Canisius Wilhelmina Hospital Nijmegen
- Catharina Hospital
- Diakonessenhuis Utrecht
- Diakonessenhuis Zeist
- Dijklander Hospital Hoorn
- Elisabeth Tilburg
- Erasmus MC
- Flevo OR 2 t/m 5
- Flevo OR 6-10
- Gelre Apeldoorn
- Gelre Zutphen
- Groene Hart Hospital
- Ijsselland Hospital
- Ikazia Hospital
- Jeroen Bosch Hospital
- LUMC CVIC
- LUMC cluster 2 en 3
- MUMC
- Maas Hospital Pantein
- Martini Hospital
- Maxima Medical Centre Eindhoven
- Maxima Medical Centre Veldhoven
- Meander Medical Centre
- Medical Centre Leeuwarden
- Nij Smellinghe
- OLVG West
- OLVG West-Oud
- Radboud UMC
- Reinier de Graaf Hospital
- Rijnstate Arnhem
- Rivierenland Tiel
- SKB Winterswijk
- Saxenburg Medical Centre
- Spaarne location Hoofddorp
- St. Jans Gasthuis
- St. Maarten's Clinic
- Ter Gooi MC Hilversum
- Treant Hoogeveen
- Treant Stadskanaal
- UMCG
- UMCG Old Building
- UMC Utrecht
- Wilhelmina Hospital
- Zorgsaam Terneuzen

Hospitals that allowed us to perform measurements

- Antonius Hospital Sneek
- Erasmus Medical Centre
- Eyescan Utrecht
- Flex Clinics Utrecht
- IJsselland Hospital Capelle a/d IJssel
- Leids University Medical Centre
- Máxima Medical Centre Veldhoven
- University Medical Centre Utrecht

LANDELIJK NETWERK
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