SAVINGS ACHIEVED IN OPERATING ROOMS BY IMPLEMENTING VENTILATION AIR FLOW REGULATION STRATEGIES, IN SEVERAL CLIMATIC ZONES OF SPAIN

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Abstract. Hospitals are critical environments, characterized by the health and safety of patients and staff. Hospitals have uninterrupted operation of the facilities, thus requiring air conditioning and ventilation, in order to reduce physical, chemical and biological contaminants, such as the current Covid-19. Hospitals have different indoor environments due to the different comfort and health needs of their occupants. These are defined according to the hospital's own standards for IAQ for each specialized area. Currently, most hospital ventilation studies revolve around specialized areas such as operating rooms and infectious and immunosuppressed wards, etc. However, the best practices for achieving an adequate indoor environment are not yet unanimously recognized. This study focuses on the reduction of energy, economic and environmental costs, all of them obtained when a ventilation flow strategy, ventilation controlled by demand, is installed in the operating rooms in a Hospital in Spain. The ventilation air flow rates required in operating rooms, according to Spanish standard UNE 100713, are very high when they are in operation (with a minimum flow rate of 2400 m3/h or 20 ren/h). However, the regulations also allow reducing the air flow during periods of inactivity of the operating room, as long as the safety, availability and asepsis are guaranteed. In this study, experimental data have been collected by monitoring the operation of the air conditioning and ventilation system, as well as the occupancy of the operating rooms of a 900-bed Spanish hospital. With all these acquired data, it has been possible to model the real operation mode of a standard operating room. Due to the implementation of this proposed model, it has been possible to study different ventilation airflow regulation strategies, with the aim of improving hospital IAQ in Spain, in three different climatic zones.

The results obtained in operating rooms, through the implementation of the proposed strategy in ventilation, show that a good IAQ is achieved, reaching energy savings in heating, cooling and electricity consumption, between 20% to 70%. Therefore, the economic costs are drastically reduced, amortizing the investment required for the regulation and control system of the HVAC system in less than a year.

Keywords. Hospital; Operating Room; Ventilation Setback; Heat Recovery; Indoor Overpressure; Energy savings.
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1. Introduction

The study is carried out in a surgical area composed of 24 Operating Rooms (OR) of a 900-bed University Hospital Center (UHC), with a built-up area of 136,000 m2. The number of surgeries in 2019 conducted was 24,126, categorized into: scheduled, emergency and cancelled. Moreover they are divided into hospitalized and non-hospitalized, Table 1.

Tab. 1 - Surgical activity of the University Hospital Center in 2019.

	Scheduled	Emergency	Cancelled
Hospitalized	7,710	3,741	303
Non-hospitalized	12,470	205	353

Due to the high number of surgical interventions and operating rooms at the UHC, block three with four operating rooms was selected, corresponding to operating rooms 3.1, 3.2, 3.3 and 3.4, as shown in Figure 1.

Fig. 1 - Surgical block No. 3 with four turbulent flow operating rooms.

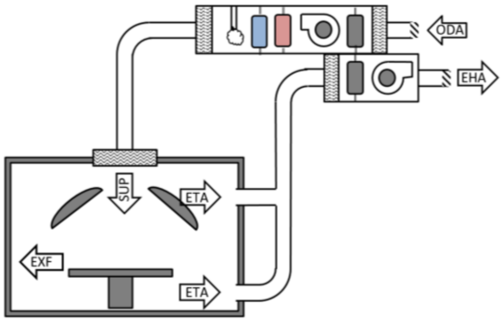
Tab. 2 - Average times and Standard Desviation in each operating room in minutes.

Operation Room	Occupation (h/year)	Average (min/Surgery)	Standard deviation (min)
3.1	2,199.4	358.6	11.8
3.2	1,538.0	177.8	7.89
3.3	1,774.2	131.1	9.95
3.4	1,639.3	132.2	9.25
Average	1,787.3	200	9.72

Considering 8,640 hours per year, the occupancy rate amounts to 20.68 % of the annual hours. In spite of the time margins between the intervention and the restitution of the aseptic conditions, it is estimated that the occupancy rate is around 25 %.

The operating rooms have been designed in accordance with the UNE 100713:2005 standard.

Each operating room has an Air Handing Unit (AHU), which has a Supervisory Control And Data Acquisition (SCADA) that manages and controls the operation of the system, a schematic diagram of the AHU is shown in Figure 2.



KeyMap.

ODA (Outside air) ***SUP*** (Forced air) ***ETA*** (Inside air) ***EXF*** (EXFiltration air) ***EHA*** (ExHaust Air)

Fig. 2 - Schematic diagram of the operating room' s AHU.

The AHU is regulated on the basis of three strategies that are monitored and recorded by the SCADA system on a 24/7 cycle.

Strategy A. - The thermal comfort of the OR is achieved with temperature and humidity sensors placed inside the OR, which adjust the temperature and humidity of the SUP. The ventilation load is considered as the only load to be compensated in the OR, and the rest of the loads are negligible compared to it. The temperature and humidity conditions are adjusted by the healthcare personnel according to the type of intervention, the comfort of the patient, and the comfort of the healthcare staff.

Strategy B. - SUP flow rate. The standard establishes that the OR must have more than: 20 Air changes per hour (ACH) or 2,400 m3/h. Therefore, the AHU has a nozzle that allows measuring and controlling the SUP flow rate. A frequency variator regulates the impulsion fan to maintain the flow rate when the climatic conditions change, or when the AHU filters become dirty.

Strategy C. - The OR overpressure in relation to adjacent enclosures is set at 20 Pa. For this purpose, a frequency inverter regulates the exhaust fan; when the pressure increases, the inverter regulates the exhaust fan to increase the ETA flow rate, and when the overpressure drops below the set value (20 Pa), the ETA flow rate is reduced.

Tab. 3 - Operating parameters of the ORs under study.

	OR 3.1	OR 3.2	OR 3.3	OR 3.4	Average
Discharge flow rate (m^3/h)	2,280	2,773	2,420	2,396	2,467
Extraction flow rate (m^3/h)	1,505	1,755	1,530	1,630	1,580

Overpressure (Pa)	20.5	22.3	20.9	21.5	21.3
Temperature (ºC)	24.5	23.8	24	24.5	24.2
Relative Humidity (%)	41.1	34.5	42.7	39.7	39.5

To determine the value of the runaround loop efficiency, the parameters recorded by the OR 3.1 SCADA for three months were taken, which means 98,000 records, containing about 400,000 data. The data are analyzed, and allow to determine the efficiency of the runaround loop as a function of the outdoor temperature via a least-squares interpolation. The results are shown in Figure 3.

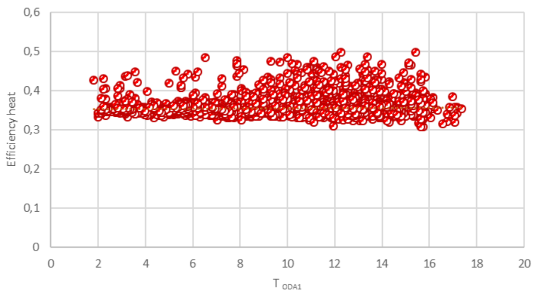


Fig. 3 - Efficiency Heat vs. Outside Temperature.

The equation obtained to determine ε versus T_(〖ODA〗_1) is shown below:

$$\varepsilon=0.0003*T_{ODA1}+0.3522 \quad (1)$$

2. Methodology

The methodology is carried out in this study, taking as outdoor conditions the five reference climates existing in Spain. It considers the indoor conditions in the R_w (Saturation mixing ratio with water) with constant temperature and humidity (24 ºC and 50 % RH), and it considers as a starting situation the operation of the system with a constant ventilation flow rate. Then it is studied by two ventilation flow control strategies: a) by occupancy and b) by schedule. Energy, economic and environmental savings are calculated.

Spain has five climatic zones, which are grouped into climates: Oceanic (C), Continental (D), Mediterranean (B), Mountain (E), and Subtropical (A). Spanish regulations have classified climatic zones according to climatic severity in winter and summer. The climatic harshness is determined according to the degree days and the accumulated solar radiation in winter and summer. Figure 4 shows the different climatic zones in Spain.

Once the climatic zones have been established, reference climates have been developed, which are freely accessible, containing the outdoor conditions hour by hour of a typical year for each zone. This data is the one used in this study.

Fig. 4 - Climatic zones in Spain.

The OR interior conditions depend on the surgical needs of the patient. Usually, 24 ºC and 50% RH are considered. In this study, SUP and ETA air conditions are also considered matching, since the outdoor air treatment is the only thermal load which depends on the outdoor conditions of the OR. The other loads are common to the three strategies under study. This study evaluates the energy, economic and environmental savings, thus they are common to the initial situation and to the strategies under study.

2.1 Ventilation control strategies under study

2.1.1. By occupancy: A presence sensor is installed in the OR.

2.1.2. By schedule: the occupancy of table 2, taking into account that they are not emergency operating rooms.

2.2 Energy demand assessment.

The thermal and electrical energy demand is determined hour by hour in: the standard case, the case of regulation by occupancy, and the case of regulation by schedule. It is shown in the flow chart in Figure 5.

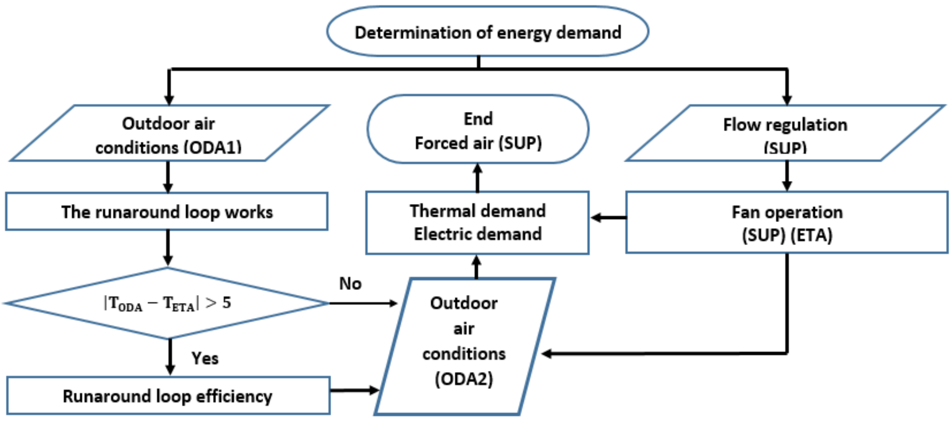


Fig. 5 - Flow chart used to determine thermal and electrical energy demand.

To calculate the thermal demand, the enthalpy of the air at the exhaust air of the ODA2 recovery unit, and the enthalpy of the supply air to the SUP room (24 ºC and 50% RH) are calculated. The heating and cooling needs to be provided to the outside air of the operating room are determined as the difference of enthalpies, multiplied by the supply air flow (Eq. 2)

$$\{\dot{m} * (h_{SUP} - h_{ODA_1})\} \begin{cases} > 0 \rightarrow \text{Heating} \\ \qquad\qquad (2) \\ < 0 \rightarrow \text{Cooling} \end{cases}$$

The standard allows reducing the ventilation flow rate of the operating room to 50% during periods without activity. A minimum air speed must be ensured to avoid the deposition of particles present in the OR, so two strategies can be established: i) establish periods of use of the OR, which together with some periods of restitution/safety, allow programming the system to reduce the flow rate to 50% , and ii) have a presence sensor in the OR, which adjusts the flow rate when the OR is without activity after a safety margin.

3. Analysis & Results.

The study has provided a multitude of data on the energy demand associated with ventilation. Figure 6 shows the heating and cooling demand due to the ventilation of an operating room for the different climatic zones.

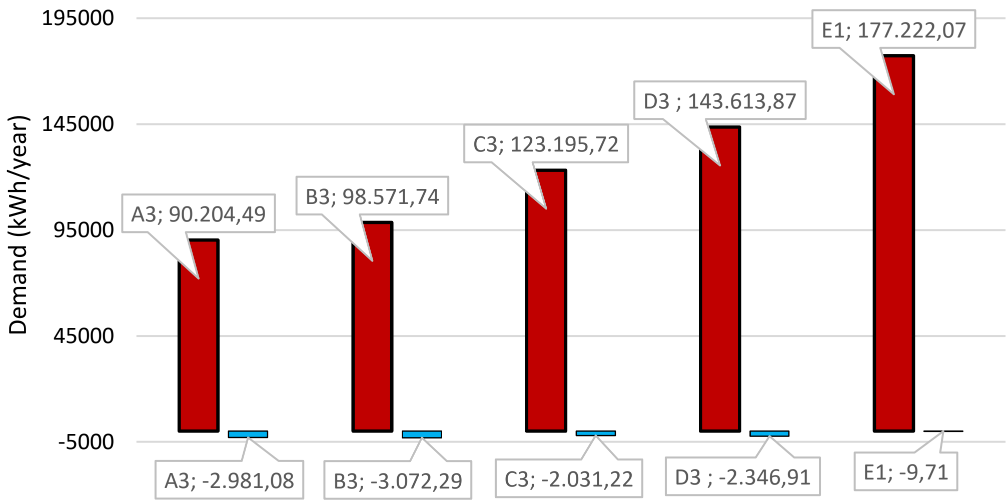


Fig. 6 - Heating and cooling demands for different climate zones.

As shown in Figure 6, it can be observed that the cooling needs are lower than the heating needs.

Table 4 shows the savings on primary energy (kWh/year), CO2 emissions (kg of CO2/year) and economic savings (€/year), using the parameters included in the methodology.

These savings could be extended to the hospital's 30 operating rooms. For the emergency operating rooms, it would be necessary to establish some presence control in order to provide continuous availability.

This would require a presence sensor and a time to restore conditions, which in no case should be more than 5 minutes.

Tab. 4 - Energy, emissions and economic savings from occupancy and schedule control.

A3		
	Occupation	**Schedule**
Primary energy (kWh)	63,244.45	72,250.24
CO_2 emissions (kg)	12,047.37	13,517.73
Economic (€)	3,604.43	4,301.03
B3		
	Occupation	**Schedule**
Primary energy (kWh)	67,220.72	76,383.78
CO_2 emissions (kg)	12,884.05	14,385.72
Economic (€)	3,770.95	4,475.71
C3		
	Occupation	**Schedule**
Primary energy (kWh)	78,501.06	88,074.49
CO_2 emissions (kg)	15,283.71	16,870.98
Economic (€)	4,220.41	4,943.02
D3		
	Occupation	**Schedule**
Primary energy (kWh)	88,234.12	98,112.69
CO_2 emissions (kg)	17,329.88	18,978.70
Economic (€)	4,629.65	5,367.37
E1		
	Occupation	**Schedule**
Primary energy (kWh)	103,335.27	113,610.87
CO_2 emissions (kg)	20,561.26	22,293.47
Economic (€)	5,214.70	5,969.18

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4. Conclusions

In this study, a simulation has been carried out for the five climates in Spain, making it possible to study the ventilation demand of operating rooms hour by hour, with data from a real Hospital Center. This study allows extrapolating the data and strategies to other operating rooms at Hospital Centers with great accuracy.

A 50% reduction of the supply flow rate has been applied in operating rooms where there is no healthcare activity, in accordance with the Spanish standard, allowing the asepsis of the operating room to be maintained, and the occupancy conditions to be restored in less than five minutes.

The regulation by schedule is shown to be the strategy that allows the greatest energy, emissions and economic savings, although the system by presence has been estimated to have a restitution time of 5% of the annual time.

The installation of a presence sensor in operating rooms would help to reduce this time and improve the scheduled regulation.

The primary energy savings range in the different climatic zones between 72,250 kWh to 113,610 kWh per year per operating room, with schedule control.

Emission savings range in the different climate zones between 13,517 kg CO2 and 22,293 kg CO2 per year per operating room with schedule control.

The economic savings are between €4,300 and €5,969 per year.

5. References

[1] F. J. Wang, T. B. Chang, C. M. Lai, and Z. Y. Liu, “Performance improvement of airflow distribution and contamination control for an unoccupied operating room,” 2012.
[2] M. Porowski, “Energy optimization of HVAC system from a holistic perspective: Operating theater application,” Energy Convers. Manag., vol. 182, pp. 461–496, Feb. 2019.
[3] Antón Cacabelos-Reyes, José Luis López-González, Arturo González-Gil, Lara Febrero-Garrido, Pablo Eguía-Oller and Enrique Granada-Álvarez “Assessing the Energy Demand Reduction in a Surgical Suite by Optimizing the HVAC Operation During Off-use Periods” Appl. Sci., 10, 2233; doi:10.3390/app1007223, 2020.
[4] Guangyu Cao et al. “Experimental measurements of surgical microenvironments in two operating rooms with laminar airflow and mixing ventilation systems”. Energy and Built Environment. 25 August 2020.
[5] Ching-Chieh Liang et al. “Effect of ventilation rate on the optimal air quality of trauma and colorectal operating rooms”. Building and Environment. 16 November 2019.
[6] M. Alsved et al. “Temperature-controlled airflow ventilation in operating rooms compared with laminar airflow and turbulent mixed airflow”. Journal of Hospital Infection. 24 October 2017.
[7] Masab Khalid Annaqeeb et al. “Influence of the surgical team activity on airborne bacterial distribution in the operating room with mixing ventilation system: A case study at St. Olavs Hospital”. Journal of Hospital Infection. 14 August 2021.
[8] Fan et al. “Suitability evaluation on laminar airflow and mixing airflow distribution strategies in operating rooms: A case study at St. Olavs Hospital”. Building and Environment. 12 February 2021.
[9] F. Memarzadeh , A. P. Manning , “Comparison of operating room ventilation systems in the protection of the surgical site” , Build. Eng. 108 (

2002) 3 –15 PART 2 .
[10] W. Whyte , “Sterility assurance and models for assessing airborne bacterial contamination “, J. Parenter. Sci. Technol. 40 (1986) 188 –197 .
[11] O. M. Lidwell , “Sepsis after total hip or knee joint replacement in relation to airborne contamination” , Phil. Trans. Roy. Soc. Lond. B 302 (1983) 583 –592.
[12] T. N. Verma et al. “Numerical Simulation of Air Pollution Control in Hospital”. Air Pollut. Control , Springer Singapore , Singapore , 2018 , pp. 185 –206
[13] P. N. Hoffman et al. “Microbiological commissioning and monitoring of operating theatre suites. a report of a working party of the hospital infection society” , J. Hosp. Infect. 52 (2002) 1 –28 .
[14] S. M. Mchugh et al. “Laminar airflow and the prevention of surgical site infection . More harm than good ? ” , Surg. , J. R. Coll. Surg. Edinburgh Irel. 13 (2014) 52 –58 .
[15] J. G. Whitcomb , W. E. Clapper. “Ultraclean operating room” , Am. J. Surg. 112 (1966) 681 –685
[16] T. Hirsch , et al. “Bacterial burden in the operating room: impact of airflow system”. Am. J. Infect. Contr. 40 (2012) e228 –e232 .
[17] S. Fischer et al. “Reduction of airborne bacterial burden in the OR by installation of unidirectional displacement airflow (UDF) systems” , Med. Sci. Mon. Int. Med. J. Exp. Clin. Res. 21 (2015) 2367 – 2374.