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# Primary energy efficiency assessment of a coil heat recovery system within the air handling unit of an operating room

F J Rey-Martínez, J F San José-Alonso<sup>1</sup>, E Velasco-Gómez, A Tejero-González and P M Esquivias

GIR Termotecnia, Dpto. Ingeniería Energética y Fluidomecánica, Universidad de Valladolid. Paseo del Cauce, No.59 (47011) Valladolid, Spain.

julsan@eii.uva.es

**Abstract.** Heat recovery systems installed in Air Handling Units (AHUs) are energy efficient solutions during disparate outdoor-to-indoor temperatures. However, they may be detrimental in terms of a primary energy balance when these temperatures get closer, due to the decrease in the thermal energy recovered compared to the global energy consumption required for their operation. AHUs in surgical areas have certain particularities such as their continuous operation throughout the year, the large airflows supplied and the strict exigencies on the supply air quality, avoiding any cross contamination. This work presents the measurements and analysis performed on a coil heat recovery (run-around) loop system installed in the AHU that serves a mixed-air ventilation operating room in a Hospital Complex. A primary energy balance is studied, including the thermal and electric energy savings achieved, considering the electric energy consumption by the recirculation pump and the additional power requirements of fans due to the pressure drop introduced. The obtained value is then used to predict the thermal energy savings achieved by the heat recovery system. Results are extrapolated to the Typical Meteorological Year to provide an order of magnitude of the primary energy and CO<sub>2</sub> emissions saved through the operation of the coil heat recovery system.

## 1. Introduction

Hospitals are energy-intensive buildings. Their global energy consumption is 2.7 times that of a commercial building [1]. In 2017, the Spanish hospitals consumed 847 ktoe, being 8.5% of the energy consumed by the service sector. The Spanish energy consumption per bed ratio reaches an average value of 28 MWh/bed per year, being similar to the Austrian ratio. Their elevated energy consumption is due to the need to fulfill exigent Indoor Air Quality (IAQ) and thermal comfort levels under a continuous operation and to the specific medical equipment, which also represents a thermal load to be neutralized by the Heating, Ventilation and Air Conditioning (HVAC) system [2].

Current European policies set ambitious targets for 2030, among which outstands the energy efficiency improvement above 32.5% involving measures to be taken in the building sector, but in the case of Hospitals safety questions are above energy efficiency [3].

According to ventilation requirements and standards to avoid pathogens airborne in operating rooms (OR), supply air must: a) do not exceed the maximum concentration of different sizing particulate matter, according to standard EN-ISO 14644-1 [4]; b) surpass the minimum ventilation airflow of

<sup>1</sup> Author to whom any correspondence should be addressed



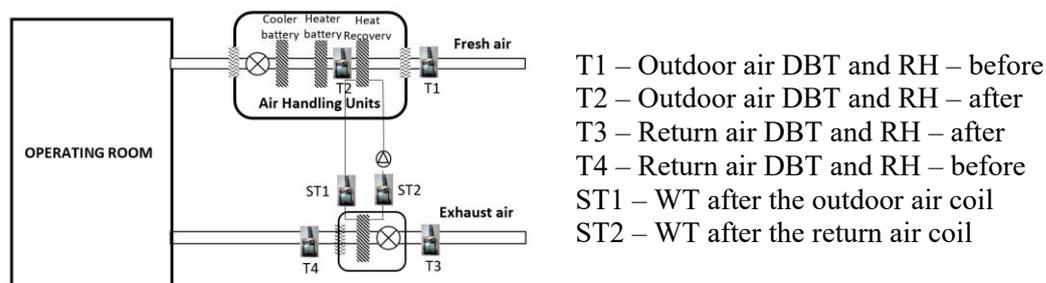
2400 m<sup>3</sup>/h or 20 air change per hour (ACH) [5]; and c) avoid infiltration from adjacent spaces by ensuring a rigorous pressure difference among different rooms [6]. Due to the high ventilation rates required, which must necessarily be all outdoor air, and the operational conditions (24/7), the energy consumption of operating rooms is a considerable contribution to the global energy consumption of an hospital.

In order to reduce the OR energy consumption, there are several alternatives to improve the HVAC system energy efficiency [7–9], such as installing a heat recovery system to transfer sensible heat from the return to the outdoor airflow [10,11]; setback of the supply airflows during inactivity periods while maintaining the required overpressure [9,12]; outdoor air pretreatment through Earth-Air Heat Exchangers; etc.

## 2. Methodology

The case study is an Air Handling Unit (AHU), monitored and controlled through a Supervisory Control And Data Acquisition (SCADA) system, providing Heating, Ventilation and Air Conditioning (HVAC) to an operating room in the University Clinical Hospital of the University of Valladolid (HCUVa). Although this hospital was built in 1978, the operating room corresponds to an extension of the hospital, built in 2013 in order to add 18 operating rooms to the hospital. Based on the air diffusion, there are two types of operating rooms: mixed ventilation OR and unidirectional flow OR. Each OR is equipped with an individual AHU that includes a coil heat recovery (run-around) loop that operates when the temperature difference between outdoors and indoors exceeds the setpoint of 5°C.

To characterize the operation of the heat recovery system, air dry bulb temperature (DBT) and relative humidity (RH) have been measured each 2 minutes at both coils inlets and outlets, as well as the water temperature (WT) at both sides of the water loop (Figure 1). The formers are measured with temperature and humidity Testo sensors, model 175H1, while the latter are registered with Testo 175T2. All sensors were previously calibrated. Measurements were performed during February 2020. Airflows are registered from the monitored values in the SCADA.



**Figure 1.** Sensors position in the coil heat recovery (run-around) loop.

The sensible heat recovery efficiency would be [13]:

$$\varepsilon = \frac{\dot{m}_{OA} \cdot (C_{p,OA-2} \cdot T_{OA-2} - C_{p,OA-1} \cdot T_{OA-1})}{\dot{m}_{min} \cdot (C_{p,RA-1} \cdot T_{RA-1} - C_{p,OA-1} \cdot T_{OA-1})} \quad (1)$$

Where  $m$  is the air mass flow,  $T$  is the dry bulb temperature (°C),  $C_p$  the specific heat (kJ/kg·°C); while subindices  $OA$  and  $RA$  refer, respectively, to “Outdoor Air” and “Return Air”,  $min$  refers to the minimum air mass flow between outdoor and return air,  $1$  denotes the coil inlet and  $2$  the coil outlet.

Operation of the heat recovery system introduces electric energy consumption due to the water recirculation pump and additional requirements in the AHU fans. Consequently, the study of the actual energy saved with the heat recovery system should evaluate the supply energy savings,  $W_{SE-R}$ . The reduction in the power needs can be calculated through equation (2):

$$\dot{W}_{SE-R} = \frac{\dot{W}_{t-R}}{\eta_{Boiler}} \cdot n_{GN} - \frac{\dot{W}_{e-F}}{\eta_F} \cdot n_e - \frac{\dot{W}_{e-P}}{\eta_P} \cdot n_e \quad (2)$$

Where  $\dot{W}_{t-R}$  is the thermal power recovered in the system (kW);  $\eta_{Boiler}$  is the performance of the natural gas boilers, being 0.80;  $n_{GN}$  is the conversion factor from Natural Gas to primary energy [14], being 1.07 toe PE/toe FE;  $\dot{W}_{e-F}$  is the additional electric power required by the fans due to the pressure drop (kW);  $\eta_F$  is the performance of the AHU fans (data from manufacturer), being 0.92;  $n_e$  is the conversion factor from electric energy to primary energy [14], being 2.21 MWh<sub>PE</sub>/ MWh<sub>FE</sub>;  $\dot{W}_{e-P}$  is the electric power required by the recirculating pump (kW) and  $\eta_P$  is the performance of the water pump (data from manufacturer), being 0.90.

Thermal power recovered in the system,  $\dot{W}_{t-R}$ , can be calculated by the following expression:

$$\dot{W}_{t-R} = \frac{\dot{V}_{OA}}{v_{OA}} \cdot (h_{OA2} - h_{OA1}) \quad (3)$$

Where  $\dot{V}$  is the air volume flow (m<sup>3</sup>/s);  $v$  is the air specific volume (m<sup>3</sup>/kg) and  $h$  is the specific enthalpy (kJ/kg).

The additional electric power required by the fans due to the pressure drop,  $\dot{W}_{e-F}$ , in the coils is determined by:

$$\dot{W}_{e-F} = \dot{V}_{OA} \cdot \Delta P_{OA} + \dot{V}_{RA} \cdot \Delta P_{RA} \quad (4)$$

Where  $\dot{V}$  is the air volume flow (m<sup>3</sup>/s);  $\Delta P_{OA}$  is the pressured drop in the outdoor air coil (Pa) and  $\Delta P_{RA}$  is the pressured drop in the return air coil (Pa).

The electric power required by the recirculating pump,  $\dot{W}_{e-P}$ , can be calculated using the following equation:

$$\dot{W}_{e-P} = V \cdot I \cdot \cos(\delta) \quad (5)$$

Where  $V$  is the voltage in the pump (kV);  $I$  is the electric current in the pump (A) and  $\cos(\delta)$  is the power factor.

Finally, the total supply energy consumption saved ( $E_R$ ) during winter period ( $t_i$ ) is calculated through equation (6):

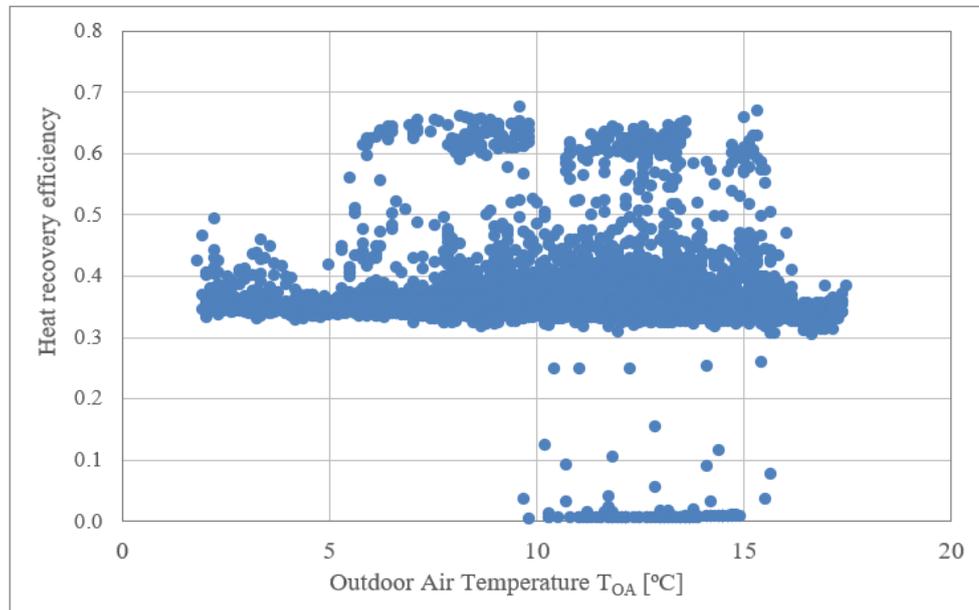
$$E_R = \sum_{i=1}^n (\dot{W}_{SE})_i \cdot t_i \quad (6)$$

### 3. Analysis of results

In order to obtain the relationship between the efficiency under real conditions of the studied HRU and the outdoor air temperature, results obtained from equation 1 using the monitored data are analyzed. The analysis is developed on the following considerations:

- i) Heat recovered corresponds to the energy supplied to the outdoor air to be treated.
- ii) The coil heat recovery (run-around) loop system is considered adiabatic, so that there is no energy loss to the environment.
- iii) Only the stationary periods are considered.

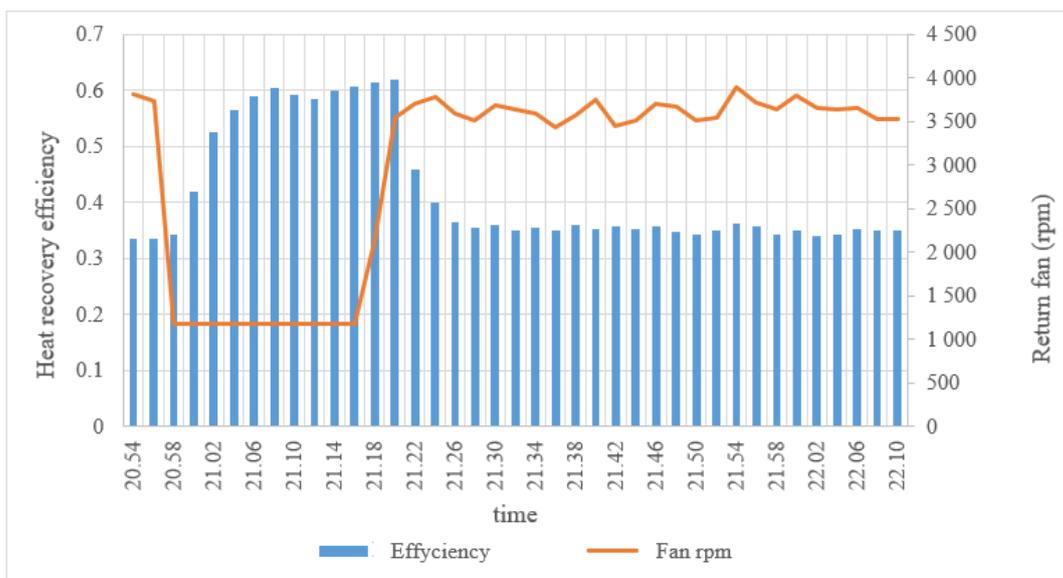
All data fitting the above considerations are gathered in figure 2.



**Figure 2:** Coil heat recovery (run-around) loop efficiency face to outdoor air temperature.

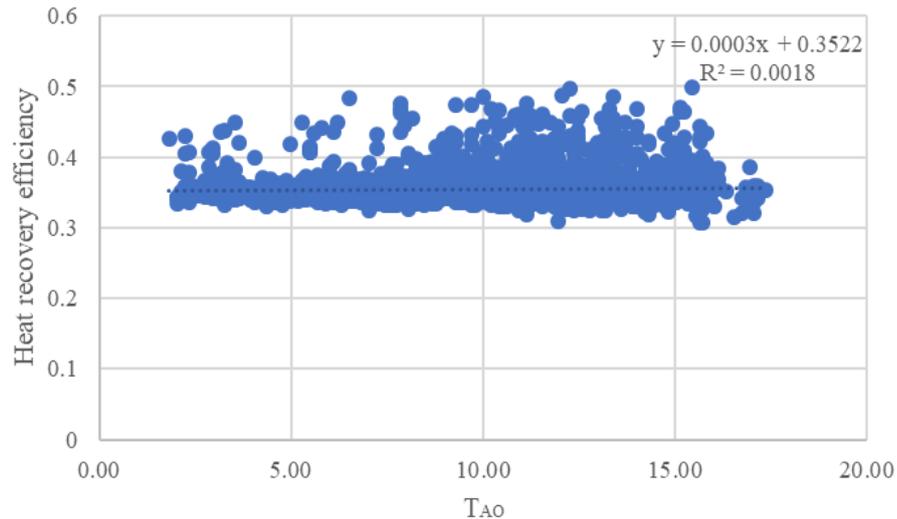
It can be seen how most data are close to 0.4. However, figure 2 also reveals many situations when the efficiency calculated falls far from the value 0.4. Values beyond the main trend are due to transient periods during door opening. Immediately after a door is open, the velocity of the return fan drops to ensure the required overpressure of 20 Pa inside the operating room. The reduced return airflow yields extreme efficiencies because the maximum heat recoverable drops while the actual heat recovered on the instant maintains due to the coil thermal inertia.

Figure 3 shows the return fan rpm during a period of activity when a door is open, face to the value of the efficiency calculated. It can be seen how while the door is closed, the velocity of the return fan stays around 3500-3800 rpm but drops to a minimum of 1178 rpm; then recovers once the door is closed again.



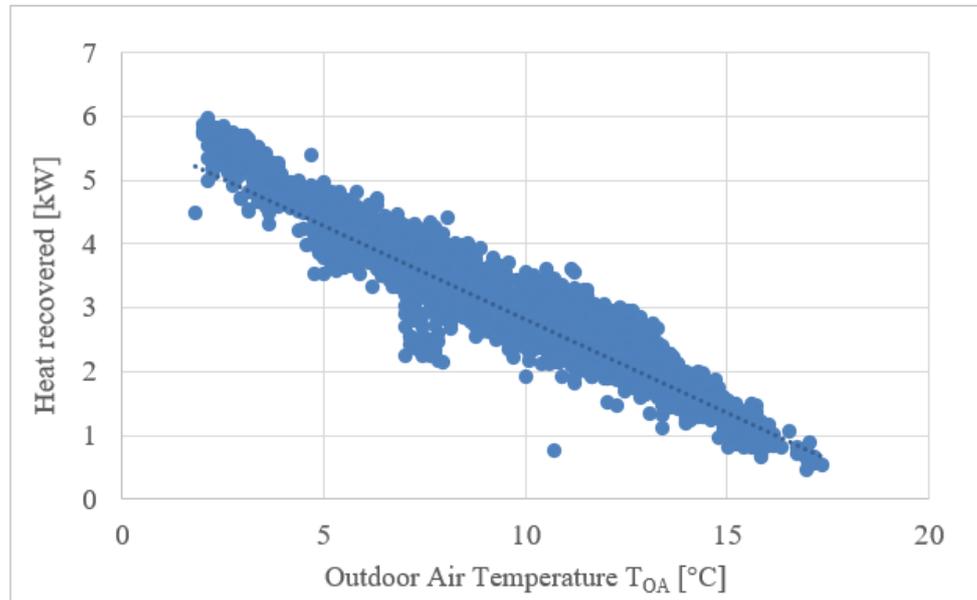
**Figure 3:** Time variation of the return air fan velocity and the energy efficiency calculated during door opening.

Then, the maximum heat recoverable drops while the actual heat recovered on the instant maintains due to the coil thermal inertia. Indeed, it is checked that the value calculated for the efficiency increases considerably while the door is open but returns to an almost constant value close to 0.4 when the door remains closed. Once these non-steady cases are filtered, the heat recovery efficiency remains between 0.3 and 0.5, yielding an average efficiency of 0.34, which stays almost constant with the outdoor air-dry bulb temperature. Figure 4 corresponds to data gathered in figure 2, once filtered the non-stationary conditions when the doors are open.



**Figure 4:** Data filtered for the coil heat recovery (run-around) loop efficiency face to outdoor air temperature.

Once known the sensible energy efficiency of the heat recovery system in terms of the outdoor air-dry bulb temperature during steady operating conditions, it becomes possible to calculate the heat recovered and supplied to the outdoor air (Figure 5). It can be seen how the energy recovered decreases considerably as the outdoor air-dry bulb temperature increases, given the lower temperature drop between return and outdoor airflows. Maximum heat recovered reaches above 5.5 kW at 2°C outdoors but decreases down to 0.5 kW when the outdoor air is milder (18°C). Even higher outdoor air temperature result into temperature differences between airflows below the operating setpoint of 5°C.



**Figure 5:** Heat recovered face to outdoor air temperature.

Because measured data belong to February 2020, characterization of the energy savings during wintertime are extrapolated from November to February using the Typical Meteorological Year data of Valladolid. Through equation (6), total energy saved during winter would be 16 901.4 kWh. Given the emission factors in Spain for the Natural Gas (0.252 kg CO<sub>2</sub>/kWh) and the electricity (0.331 kg CO<sub>2</sub>/kWh) [14], for the target period a total emissions of 5.801 kg CO<sub>2</sub> would be avoided.

#### 4. Conclusions

Air and water temperatures are measured in the coil heat recovery (run-around) loop installed in the Air Handling Unit that supplies Heating, Ventilation and Air Conditioning to an operating room, while airflows are monitored through the SCADA. Data registered are used to calculate the heat recovery efficiency of the system. Non-steady operating conditions that occur during door opening result into extreme values of the efficiency, thus disregarded. Results yield an average efficiency of 0.34, which stays almost constant with the outdoor air dry bulb temperature.

The evaluation of the actual primary energy savings achievable through the heat recovery system considers the additional electric energy consumption introduced due to the pump and fan requirements. Wintertime savings are predicted from November to February based on the Typical Meteorological Year data. Total supply energy savings calculated are 16 901.4 kWh and would reduce emissions in 5.801 kg CO<sub>2</sub>.

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#### References

- [1] Pastor Pérez P 2012 *Documentos Técnicos de Instalaciones en la Edificación DTIE 1.06: Instalación de climatización en hospitales* (Madrid: Atecyr)
- [2] Tejero-González A, DeFreitas-Barros-Galvão V, Zarzuelo-Sánchez A M and San José-Alonso J F 2021 Energy use optimization in ventilation of operating rooms during inactivity periods *Building Research & Information*. **49** 308-324

- [3] Commission E 2030 climate & energy framework
- [4] Anon 2015 ISO 14644-1. Cleanrooms and associated controlled environments. Part 1: Classification of air cleanliness by particle concentration
- [5] AENOR 2015 UNE 100713:2005 Instalaciones de acondicionamiento de aire en hospitales.
- [6] Castro Ruiz F, San José-Alonso J F, Villafruela Espina J M and Guijarro Rubio Á 2011 *Manual de diseño de la climatización y ventilación de quirófanos y habitaciones en centros hospitalarios en Castilla y León* (Valladolid)
- [7] Chow T T and Yang X Y 2003 Performance of ventilation system in a non-standard operating room *Build. Environ.* **38** 1401–11
- [8] Teke A and Timur O 2014 Assessing the energy efficiency improvement potentials of HVAC systems considering economic and environmental aspects at the hospitals *Renew. Sustain. Energy Rev.* **33** 224–35
- [9] Cacabelos-Reyes A, López-González J L, González-Gil A, Febrero-Garrido L, Eguía-Oller P and Granada-Alvarez E 2020 Assessing the energy demand reduction in a surgical suite by optimizing the HVAC operation during off-use periods *Appl. Sci.* **10**
- [10] Noie-Baghban S H and Majideian G R 2000 Waste heat recovery using heat pipe heat exchanger (HPHE) for surgery rooms in hospitals *Appl. Therm. Eng.* **20** 1271–82
- [11] Yau Y H 2008 The use of a double heat pipe heat exchanger system for reducing energy consumption of treating ventilation air in an operating theatre-A full year energy consumption model simulation *Energy Build.* **40** 917–25
- [12] Mathews E H, Botha C P, Arndt D C and Malan A 2001 HVAC control strategies to enhance comfort and minimise energy usage *Energy Build.* **33** 853–63
- [13] ASHRAE Chapter 44. Air-To-Air Energy Recovery *ASHRAE Handbook-Fundamentals*
- [14] Anon 2016 Factores de emisión de CO<sub>2</sub> y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España *Documento reconocido del Reglamento de Instalaciones Térmicas en los Edificios (RITE)*