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Comparative study of HVAC systems in hospitals: chilled beams and fan coils

The present study describes the methodology used for the determination of carbon emissions from HVAC systems in order to assess possible options for greener systems. Simple tools were developed and applied for this purpose [1] and a case study was performed on an inpatient ward of an hospital building located in Faro, Portugal, being considered fan coils and chilled beams as terminal units.

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The analyzed terminal units are part of an HVAC centralized air-to-water system composed of a chiller and gas boiler for cold and hot water production, an Air Handling Unit (AHU) and electric pumps for the hydraulic circuits.

HVAC Systems

Fan coils (FC) - compact high performance heat transfer units, consisting of a fan, return air filter, water coils and a condensate drain pan. Horizontal concealed units were considered, installed in false ceilings, supplied with 100% fresh air through an AHU.

Chilled beams (CB) - Active CB [2], which are the object of this work, are induction units linked to 100% fresh air circuit by an AHU and to the hydraulic system by water coils. Due to higher cooling water temperatures than the conventional 7/12ºC there is no need for condensate drain pan nor return air-filter, since the cooling process is not followed by dehumidification or condensation.

Given the terminal unit location (**Figures 1 and 2**) and its air diffusion conditions, it was admitted a ventilation efficiency of 100% for CB and 80% for FC.

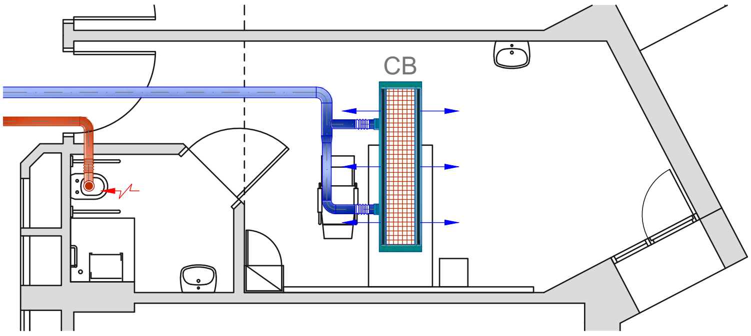

Figure 1. Chilled beam location in hospital bedroom.

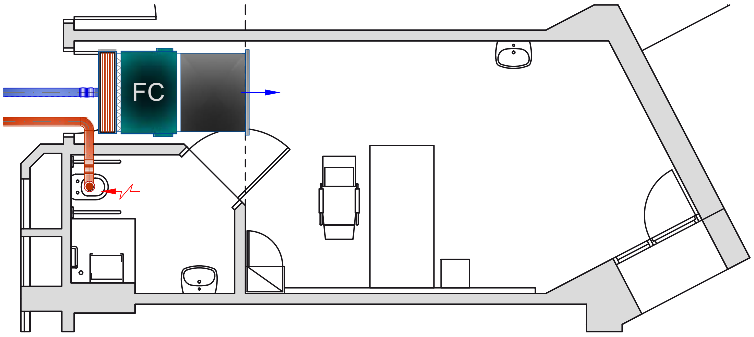

Figure 2. Fan coil location in hospital bedroom.

Methodology

Annual thermal needs - The method used for calculating thermal needs was based on thermal load and annual energy balance methods, adapted from former Portuguese Decree-Law No.40/90, with the introduction of some parameters from former Portuguese Decree-Law No.118/98 and adjustments regarding the Portuguese Decree-Law No.79/2006, in order to meet the latest regulation requirements. Some parameters were also introduced to estimate the actual operation of the HVAC system.

This solution was adopted, rather than a detailed computer simulation, since it's intended to develop an expedite tool for predicting energy consumption, allowing a simple way to compare two systems, in order to obtain gross comparable values.

Degree-day and humidity-day - To determine the annual thermal needs it's necessary to consider a set of climatic data representative of the building's location, being used for this purpose the database of *Solterm* Portuguese software. Determination of temperature annual evolution was based on Degree-Day concept. Since this concept only allows to estimate sensible needs arising from the difference of temperatures, a new concept is introduced, **Humidity-Day**, in order to estimate latent needs arising from the difference of absolute humidity - particularly because the compared units, namely CB, require humidity control. It was assumed that, generally, latent needs in the cooling period are due to dehumidification and in the heating period due to humidification.

Electrical and gas consumption – Energy consumption of HVAC equipment was calculated taking into account data provided by suppliers.

Carbon emissions – Life cycle assessment methodology was used for calculating HVAC systems carbon emissions, considering the following stages:

1. Manufacturing of equipment;
2. Transportation of equipment;
3. Energy consumed during operation;
4. Maintenance activities;
5. Waste end-of-life disposal.

The calculation methodology adopted in this work, in particular emission factors, were based on the manuals provided by ADEME, referring to the *Bilan Carbone* method [3] [4], while still subject to some adjustments to the national context.

Results

The current study was carried out for a set of 106 terminal units, 4 circulation pumps and 1 AHU, over a 30 years life cycle, for each HVAC system.

Annual thermal needs - From the results, shown in **Figures 3 and 4**, the following items should be emphasized:

- The temperature difference guaranteed by the CB-AHU in the cooling period (T_{ins} = 15°C), higher than the temperature difference in the FC-AHU (T_{ins} = 22°C), implies that the energy carried by primary air in the CB system is higher, which represents a decrease of the local sensible needs, approximately 60% of the FC units thermal needs. Overall, sensible cooling needs of both systems are nearly identical, with a relative difference of 4%;
- Since CB units are unable to remove latent load, the CB-AHU must ensure additional dehumidification, contributing not only to fresh air latent load, but also to internal latent load. Thus, CB-AHU requires about two times more energy for dehumidification than FC-AHU;
- During the heating period, local needs are not important, showing a residual value of 4% on global needs, which may be a consequence of net heat gain from solar radiation, but mainly due to net internal loads, significant in such areas with permanent occupation.

Overall, global cooling needs difference of both systems is not significant, representing about 1%.

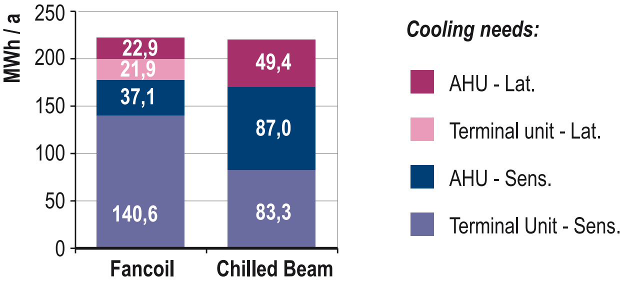

Figure 3. Cooling annual needs (MWh/year).

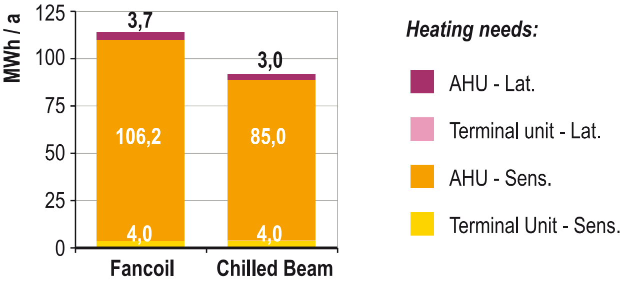

Figure 4. Heating annual needs (MWh/year).

Heating needs are significantly lower in the CB system, with a relative difference of about 19% - since the fundamental weight lies in the AHU sensible needs, it's not surprising that the relative difference between the two HVAC systems corresponds roughly to the difference between the fresh-air flows, and their considered ventilation efficiencies.

Energy consumption – Given the obtained results, shown in **Figures 5 and 6**, the following comments should be highlighted:

- In the overall balance, the annual cooling needs are approximately equal for both systems which represents identical electrical consumption for the chiller, with a relative difference of about 1%;
- CB application helps to reduce ventilation consumption by 30%, since the absence of motors in the CB units contributes significantly to its decline. With regard to AHU fans, despite the CB-AHU fresh-air flow represents 80% of the FC-AHU fresh-air flow, its electrical consumption are approximately equal, which is mainly due to the additional pressure loss of about 125 Pa in CB units.

Overall electrical consumption represents a relative difference of 18.5%.

Regarding boiler gas consumption, the relative difference between the CB system over the FC system is about 19%, a direct consequence of its heating needs.

Carbon emissions - Estimated emissions over a 30 years period are 879.0 ± 14% ton C_{eq} for the FC system and 707.0 ± 13% ton C_{eq} for the CB system. Looking at the proportions of the analyzed categories shown in **Figure 7**, it's clear that the main factor for emissions lies in the energy consumed during operation, corresponding to electricity and gas consumption, affecting about 95% of global emissions.

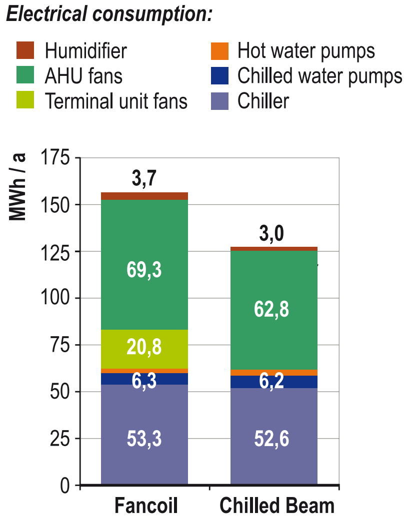

Figure 5. Electrical annual consumption (MWh/year).

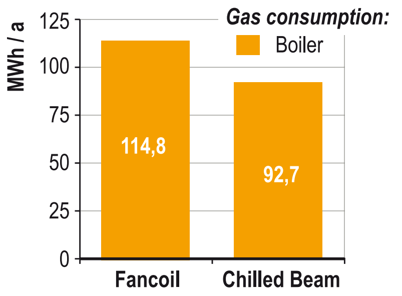

Figure 6. Gas annual consumption (MWh/year).

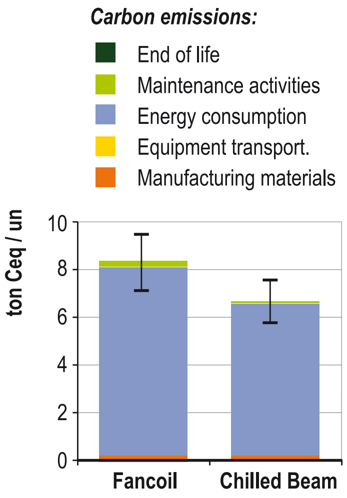

Figure 7. Global carbon emissions (tonC$_{eq}$/un).

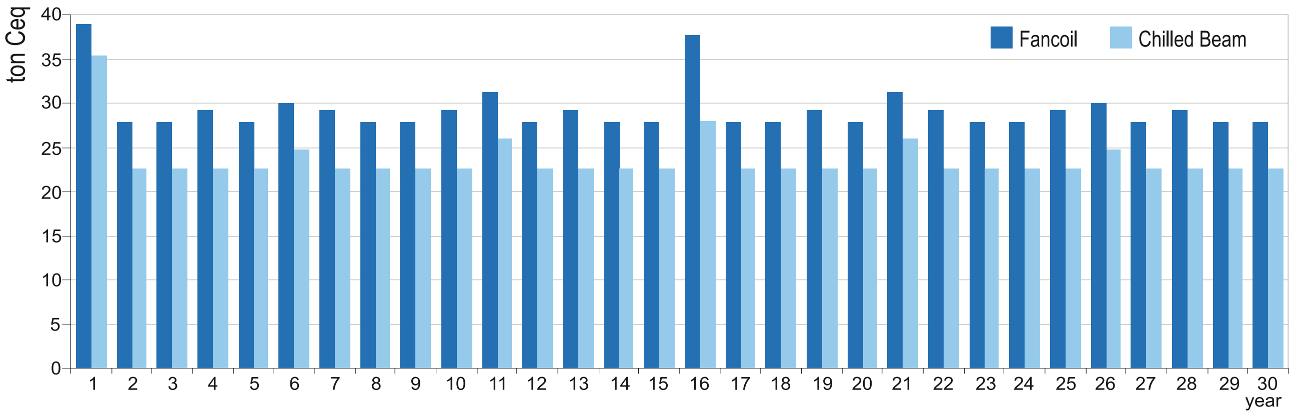

Figure 8. Distribution of carbon emissions in a 30 years period (ton C_{eq}).

The average annual carbon emissions distribution of both systems, shown in **Figure 8**, allows the following comments:

- Carbon emissions peaks for both systems occurs on the 1st and 16th year, when new HVAC equipment installation takes place, in particular, FC units and AHU, which have a 15 years average lifetime. CB manufacturing and transportation only contributes in the 1st year due to its 30 years average lifetime;
- In general, CB system carbon emissions have less fluctuation during the analysed period, which is due to less frequent maintenance operations, and so it's verified that the most important contribution takes place on the 6th, 11th, 21st and 26th year, when AHU motors and coils are replaced. Regarding the FC system, in addition to the mentioned maintenance operations, additional motors rewinding operation every 3 years and return-air filter replacement every 5 years contributes also to its carbon emissions.

Comments and conclusions

Using the developed tools for estimating energy consumption and carbon emissions, it can be concluded that:

Final energy consumption - CB system operation provides an annual reduction in energy consumption, 18.5% in electricity and 19.3% in gas, when compared to the FC system.

Carbon Emissions - In a 30 years life cycle the reduction of carbon emissions is about 20%, when opting for CB instead of FC, featuring per terminal unit, 8.3 ± 14% ton C_{eq}/ unit against 6.7 ± 13% ton C_{eq}/ unit. The main factor for emissions lies in the energy consumed during operation, affecting about 95% of global emissions.

Also worth noting is the concept of humidity-day that proves to be both effective and simple to use.

The results of this study reinforce the advantages of using CB in hospitals and contribute for their possible application in Portuguese hospitals, which were recently allowed to be considered by national health recommendations. ■

Acknowledgements

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References

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