Hybrid ventilation free-cooling simulation in Energy Plus. Application on a shopping center retrofitting, in Portugal.

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ABSTRACT

Buildings take a great share on the total energy consumption and CO_2 emissions in Portugal. Poorly thought buildings pollute the urban space, and contribute to the increasing buildings sector energy demand. When thinking in retrofitting old buildings, the common thought is that huge amounts of money must be spent on it. This paper, presents a case study on a poorly energy performing commercial building, where a hybrid ventilation free-cooling technique is used to demonstrate its potentiality to efficiently decrease building energy consumption, without requiring huge investments. The original building configuration, without free-cooling, originates high inside temperatures throughout the year. The energy needed for space cooling represents 48% of total building annual consumption.

Generally, results show that hybrid ventilation free-cooling, using the cold mountain air at nighttime has a great potential for reducing energy consumption, of the order of 10% of total building climatization energy demand. Sensitivity analysis provided parametric knowledge about the performance of the technique when applied to this building under different conditions. A reduction of 142 tCO_2/year, in the total building Carbon emission is estimated.

1. INTRODUCTION

Today's energy scarcity and pollution concerns, motivate a huge new set of approaches that lead to improvements in several energy consumption systems.

Buildings are one of the most important energy consumption sources. In Europe, more than 30% of the total energy is consumed in buildings (DGET, 2007). One of the most important source of energy consumption in buildings, particularly in services or commercial ones, are due to the mechanical systems that provide heating, cooling and ventilation (Tovar, 2007).

As long as the years go by, and the energy concerns are getting more present, the general trend is to conceive new energy consumption devices with improved energy efficiency ratings. Together with this, building design is also in evolution, bringing new techniques and new materials. Unfortunately, there are some cases of poorly conceived buildings, that sacrifice energy performance in favour of design. Recent design trends increase building glazed area, resulting in higher passive solar gains. Due to this, large amounts of energy must be spent in order to achieve thermal comfort conditions. This motivates the research for new techniques of building retrofitting. These techniques include, mostly, changes in building constructive issues, changes in installed equipments and changes in building operation strategies.

A well known way of reducing building energy consumption is to perform free-cooling taking advantage of external cooler air (Pfafferott, 2004 and Pfafferott, 2003). This technique can in some situations be applied without any spend of energy, and with good results. Nevertheless free-cooling is not easy to control in terms of the characteristics of the intake air (i.e. temperature, quality, velocity), and so it can lead to non desired interior conditions, mostly concerning air quality. In order to deal with this limitation, intake air admission should be controlled. An efficient control can be done with mechanical means and the consequent energy consumption.

Hybrid Ventilation free-cooling strategy provides efficient control of the intake air while optimizing the energy consumption. This strategy uses the building ventilation system to control the intake air, and can be automatically controlled.

The present paper makes an assessment on the performance of hybrid ventilation free-cooling, when applied to a building with high cooling energy demand. The assessment is made by a computational simulation of the building with Energy Plus.

2. METHODOLOGY

2.1. Site description

The building is located in *Serra da Estrela*, a very well known mountain place in Portugal. In fact this is the highest place in the Portuguese mainland, with 2000 m high. *Serra da Estrela* is characterized by a mountain type climate, with cold winters and mild (sometimes hot) summers. The temperatures measured in the building, during 2006, are presented in Figure , where it possible to see the high thermal amplitude of the local temperatures during a year time span. The building is located at an altitude of 600 m.

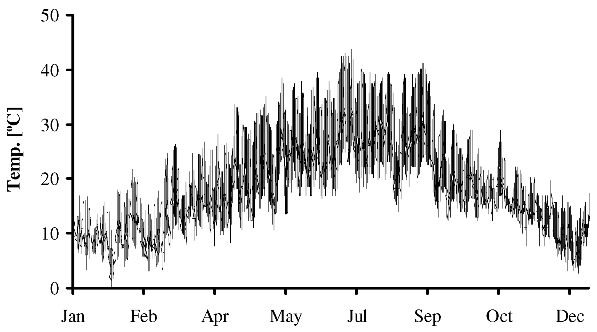

Figure 1. Exterior temperatures measured in the building, in 2006.

2.2. Building description

The building in study is a shopping centre, mainly composed by two commercial, floors (floor 0 and 1) with stores and restaurants, and 2 underground floors destined to parking place (floors -1 and -2). Due to the topography of the place, the two parking floors are only under grounded in the North and part of the East side of the building. There is an exterior parking, al the level of floor 0. In Figure it is presented the exterior view of the building, obtained from the computational model created in EnergyPlus.

The building was built in 2005, and presents a very characteristic design, incorporating several architectonic solutions that promote passive heating of its interior. These solutions are based on two curved skylights oriented towards East, South and West, without any external shadowing devices. The South façade, that covers all the building height, is all made of glass with no shading devices. The building has a total area of 17000 m^2, including parking spaces.

The building climatization is provided by central four tube type system, with cold water produced by two compression chillers with 310 kW each, and hot water provided by two Natural Gas boilers, with 670 kW each.

2.3. Energy audit procedure

A detailed energy audit was performed in the building under study, in order to completely characterize the building energy demand. During this process, several information was collected, such as daily occupation profiles, energetic equipments characteristics, building envelope constitution, among others.

The energy demand was characterized in a first approach by analyzing the energy

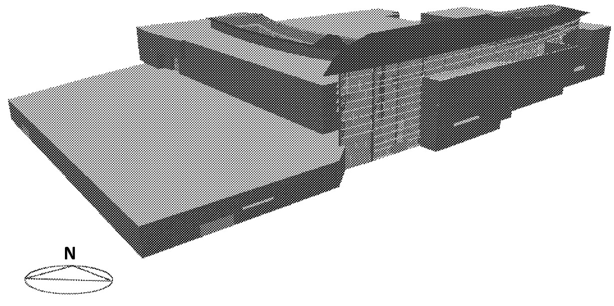

Figure 2. External view of the building. Model created in Energy Plus.

consumption records, corresponding to the year 2007. After this first phase, several physical measurements were made (temperatures, energy consumption, etc), in order to perform a detailed characterization of the energy demand, allowing to distribute the total energy demand by each utility in the building.

2.4. Creation of the computational model

The computational model was created in Energy Plus, version 2.0 released in April 2007. The data collected during the energy audit was used to build the computational model. This data was essentially composed by information about the building constructive characteristics, the installed equipments and the occupation profiles. The weather file was constructed with data collected at the building site.

The validation of the computational model was performed by comparing the values of building heat and cooling requirement, determined by simulation, with the corresponding determined during the energy audit.

3. RESULTS

3.1. Energy audit and model validation

The energy audit initiated by analysing the energy consumption during the year 2006. concerning electricity and Natural Gas, the only two forms of energy consumed in the building. Table *1* presents the total energy consumption in the building during the year 2006.

Table 1. Total energy consumption during 2006.

	Energy demand in 2006	
	MWh	%
Electricity	2848	94%
Nat. Gas	173	6%
Total	3021	

Electricity is the most consumed energy form in the building, with a share of 94% of the total energy consumed in the building, during 2006. This is coherent with the nature of the appliances installed in the building. Only a small fraction of the total energy demand, corresponding to 6%, concerns with the consumption of Natural Gas. This energy form is only consumed in the two boilers, destined to heat the building.

As a result of the energy audit, the energy consumption is divided by each utility in the building. Figure presents the desegregation of the total energy consumption, by each energy utility in the building.

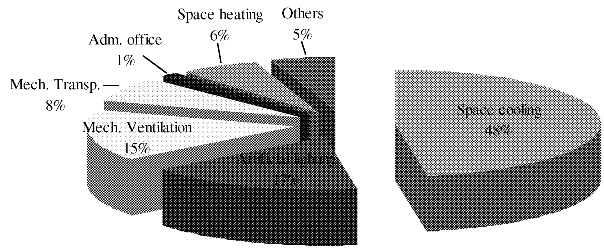

Figure 3. Fraction of energy consumed by each utility in the building.

Space cooling requires the most part of the energy consumed, with a 48% share. Space heating requires only a small fraction of energy, with 6%. These values evidence a discrepancy to what are the typical values of energy consumption in commercial buildings in Portugal. Specially if the building is located in a mountain city, where there are near zero temperatures in winter.

After analysing the energy use conditions in each equipment, it is concluded that there is no noticeable inefficiency in any equipment that justifies the referred discrepancy in the energy spent for space cooling and heating. This fact is due to the characteristics of the building that promote passive heating, with 62% of the total annual heat gain of the building, resulting from passive solar gains.

The energy plus simulation took into account the boundary conditions defined in 2.4. The model calibration was performed by comparing the computational results from the model, with the values measured in the energy audit. The main comparison was performed in terms of the building heating and cooling energy requirements.

Table 2 presents the values of energy for space cooling and heating obtained by simulation, and the equivalent from energy audit.

Table 2. Cooling/heating energy requirements.

	Annual energy requirement [MWh]		
	En. Audit	Simulation	Diff.
Cooling	1436.0	1519.5	5.8%
Heating	173.0	164.0	5.2%

The results from the computational simulation show good agreement with the energy audit results, with a difference of the order of 5%, which states the good approximation between the model and the reality.

3.2. Building retrofitting with hybrid ventilation

In order to evaluate the performance of hybrid ventilation free cooling, three different scenarios were simulated in the created model. The first one concerns the simulation of the building in its actual configuration, without the application of any retrofitting. This will be considered the base case, and named as BC.

In the second case, the building was simulated with the application of free cooling during the night in summer, without any active control. This case will be named as FC. In this scenario, the ventilation is achieved by opening some external doors and windows at selected locations in the building, in order to achieve crossed ventilation due to differences in pressure between different points of the building, and buoyancy effect.

Hybrid ventilation free-cooling is achieved by forced air intake using the building ventilation system, and will be named as HV. The control of the ventilation units takes into account the following variables:

- Outside air temperature;
- Inside air temperature;
- Temperature of the intake air;

Since the ventilation in the HV scenario is mechanically driven, the outside air will heat up under the action of the ventilators and flow through ducts. This fact shall be considered in order to prevent the intake of outside air at a higher temperature that is higher than the building temperature. In this context, the HV model was programmed to admit outside air, only if is cooler than the inside air, at least 4 ºC. This value was established from measurements taken in the building ventilation system.

Another criteria to allow HV, is to ensure that the building thermal comfort is not compromised, and so HV ventilation is only allowed if the inside air temperature is higher then 24 ºC.

Passive cooling techniques in mediterranean climate, are more suitable of being used during the mid season before and after winter, since daily exterior air temperatures fluctuate between values higher and lower to the building comfort temperature.

In order to illustrate the main differences and gains between FC and HV, Figure 5 presents the building interior temperature, obtained by the computational simulation, during one week of April, which external temperature is presented in Figure 4.

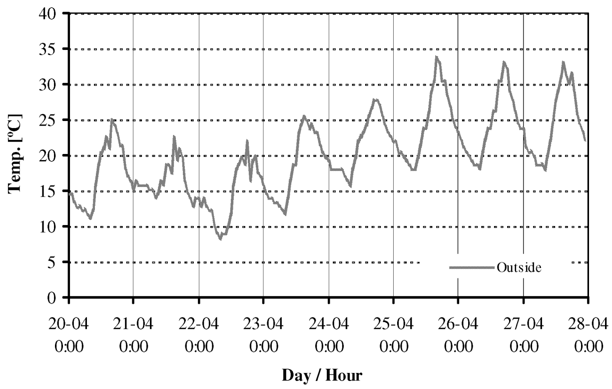

Figure 4. External temperature during one week in April.

The three cases present similar temperature evolutions that increase during the day, as a result of the building heat gains. Both HV and FC have the desired effect of lowering the building temperature, during the night, at an higher rate than BC. In the FC case, the building internal temperature starts to raise after the end of the external air intake, as a result of the building internal thermal mass heat release, and the increase in the solar gains in some zones of the building. Nevertheless FC lowers the building temperature, resulting in lower requirement of energy for cooling the building interior.

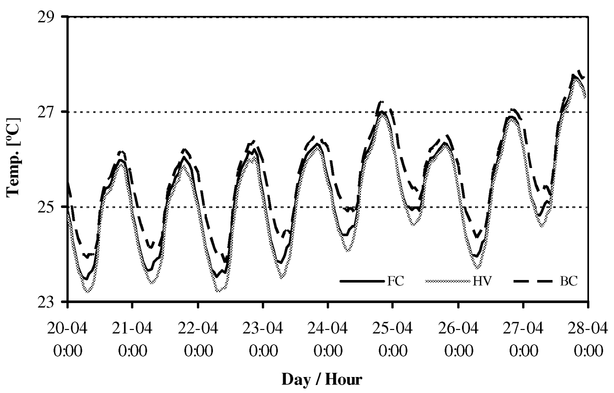

Figure 5. Interior temperature variation in the three simulated scenarios.

As said before, HV provides control of the free-cooling process in order to take full advantage of the cooling potential of external air. This result is well illustrated in Figure 5, since HV scenario continues to cool the building when FC ends its effect. After the end of FC, HV lasts for a variable period during the morning as a function of the exterior temperature. This fact is well illustrated in day 22 and 27, since in day 22 the outside temperature is lower during the morning which allows to provide more external air to the building. In day 27 the temperatures are globally higher, and close to the interior comfort temperature, this way HV cooling is more similar to FC, the advantage of HV is lower.

The annual simulation of the building performance under the three considered scenarios lead to conclude that FC reduces the building total energy consumption in 7.4%. HV presents a higher reduction in the building total energy consumption, with a value of 10.6%.
As a consequence of the increased energy efficiency, there is a reduction of the building CO_2 emissions equivalent to 142 tCO_2/year.

3.3. Hybrid ventilation performance

Although hybrid ventilation provides promising results as an efficient passive cooling strategy. Nevertheless, it implies the consuming energy in mechanical ventilation systems.

The energy efficiency of hybrid ventilation can be evaluated in terms of its coefficient of performance COP, defined by equation 1 as the ratio of used thermal energy and the electric energy spent in ventilation system (Pfafferott, 2003).

$$COP_{HV} = \frac{\int_{HVstart}^{HVend} m(t) C_P \left[T_{Building}(t) - T_{outside.air}(t)\right] dt}{\int_{HVstart}^{HVend} P_{electric}(t) dt} \qquad (1)$$

m: Mass flow rate of air cycled during HV
C_P: Specific heat of the air
$T_{building}$: Internal temperature of the building
$T_{outside\ air}$: Temperature of the external air
$P_{electric}$: Power of conventional cooling

The mean performance of the hybrid ventilation system during the simulated year, was calculated in 7.8 kWh_{th}/kWh_e.

Passive cooling techniques compete with mechanic cooling for energy efficient climatization strategy. An energy efficient cooling machine can present average COP of the order of 4 kWh_{th}/kWh_e. Comparing this value with the obtained COP_{HV} allows to evaluate the high level energy efficiency of the hybrid ventilation system.

Hybrid ventilation can than be considered as very interesting way of achieving good results of energy efficiency in building retrofitting. In general, hybrid ventilation can be implemented with low costs when compared with the price of a mechanical cooling machine, since it used installed systems. Nevertheless it may require the installation of extra control devices in the ventilation system, to allow the desired control strategy.

4. CONCLUSIONS

This paper presented an energy efficiency based retrofitting study, performed on a building located in the center interior of Portugal.

Although the building was recently built, it presents poor energy performance. This is due to the use of inappropriate architectural solutions, that lead to high amount building passive heating. This fact happens during the all year, with obviously high relevance in summer. As a consequence, inside thermal comfort is achieved by spending high amounts of energy to cool the building. The average energy consumption of the cooling system represents 50% of the total building energy consumption.

An annual building computational simulation was performed in order to investigate the main causes of passive heating. The computational model was than used to simulate two different retrofitting scenarios, based on passive cooling strategies.

The study demonstrates the great potential of the application of passive cooling to the building. Naturally driven free-cooling reduces the global building annual energy consumption in 7.4%.

Hybrid ventilation introduces the ability to control free-cooling. Hybrid ventilation was simulated with a control strategy based on the difference between internal en external temperature, allowing to maximize the advantage taken from free-cooling. Due to this, hybrid ventilation reduces global annual energy consumption in 10.6%

Although hybrid ventilation leads to significant energy economy, it also consumes energy since it uses the building mechanical ventilation system. Nevertheless, hybrid ventilation presents high level energy efficiency in operation, with a COP_{HV}= 7.8 kWh_{th}/kWh_e. When compared with a high efficiency chiller, with typical COP≈ 4, hybrid ventilation presents its high potential as a retrofitting technique.

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