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ENERGY CONSUMPTION OPTIMIZATION OF A SMALL SPANISH AIRPORT

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ABSTRACT

To have a proper energy management in buildings, it is necessary to evaluate its HVAC system.

To properly compare operating strategies and solve possible problems, one needs to reproduce the building and its HVAC system behavior under real life conditions (building materials, cooling, heating and ventilation demands, meteorological conditions, etc.). For this reason we developed a simulation model of the entire system (building and HVAC) to provide this information.

This paper explains the energy audit we made in a small Spanish airport: data collection, thermographic inspection, TRNSYS simulation and on-field measurements to validate the model.

INTRODUCTION

In 1998 INTA (National Institute of Aerospatial Technology, Spain) and AENA (Public Business Entity that manages, coordinates, operates, maintains and administrates Spanish public civil airports) signed a framework program in order to optimize the energy consumption in some Spanish airports by means of renewable energy, combined heat-power production and improvement of the current energy systems.

Under this framework program, we studied how to minimize the fuel and electricity consumption of a small Spanish Airport optimizing the HVAC system and detecting "bad habits" in the use of the building.

First, we collected data about the building structure, its climatic conditions, its use, its HVAC system and its actual energy consumption.

Then, we made a thermographic inspection to find out possible thermal losses due to bad insulation or defects in the building structure.

Finally, we used the software program TRNSYS 15 to simulate the building thermal performances and its HVAC system behavior.

In this work we will show:

a) The problems/issues we found out inspecting the building, such as massive air infiltration, wrong conditioning due to bad maintenance and faults in the functioning of the HVAC system, "bad habits" in the use of the building due to the misunderstanding of the causes and consequences of these habits;

b) How we simulated the thermal behavior of the building, calculating the heating/cooling needs to achieve a comfortable temperature;

c) How we simulated the HVAC system of the building, finding out errors in the original design and final construction of the HVAC system;

d) Some solutions we proposed to optimize and correct the HVAC system; such as increasing the power of the boilers, reducing unnecessary infiltration and ventilation; balancing the hydraulic water loop of the HVAC system, changing the setting point of the rooms temperatures, reducing the hours of functioning of the HVAC system, etc.

e) Some predicted results compared to real on-site measured values.

f) Future strategies that should be simulated and studied, such as temperature reset control, VSD pumps, supply fan static pressure control, demand control ventilation, etc.

As this work is still in act, partials results obtained in applying some of the solutions proposed indicate a great reduction in energy consumption, especially fuel consumption.

This study is a first-of-a-kind for us and will constitute a platform to develop new studies in optimizing the energy consumption in other buildings.

DATA COLLECTION

As a first step, we started collecting the following data:

- General data of the airport such as location; year of construction; visual inspection of the building, its HVAC system and its maintenance; plans; etc.

- Data of energy consumption such as electricity and gas invoices
- Building details and thermal properties of the material employed in the construction
- Detailed description of the HVAC system

Energy Consumption

The *fuel consumption* is referred to the storage tank: when empty it is filled again (and an invoice is made), so we could just know the fuel consumed during a certain period. Moreover, we couldn't distinguish clearly between the fuel used in the kitchen and the fuel used heating the building.

The electricity consumption is stated in an invoice referred to a global monthly electricity consumption of the airport, so it was difficult to find out how much electricity had been spent just for Air Conditioning.

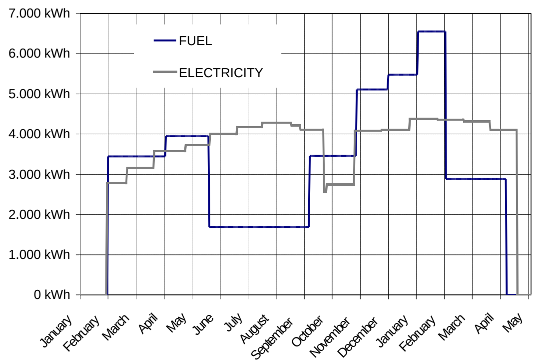

Figure 1 Mean daily consumption of Electricity and Fuel (both as kWh)

In Figure 1 it is possible to see the mean daily consumption of Electricity and Fuel that could be estimated from the invoices. It can be seen that the electricity consumption seems to rise during the summer because of the Air Conditioning while the fuel consumption seems to diminish. In summer there is fuel consumption even if the HVAC system boilers are switched off, as the kitchen is always open.

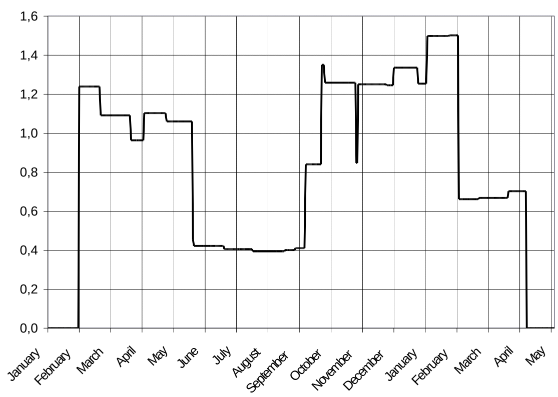

Figure 2 Electricity/Fuel ratio (adimensional)

In Figure 2 it is shown the ratio between Electricity and Fuel consumption. This ratio drops heavily during the summer, as the boilers are switched off and the AC is switched on. These conditions make a combined heat and power production difficult.

Building Description

In Figure 3 it is shown an aerial view of the airport. The building has three floors: an underground floor used for maintenance, a ground floor where the passengers enter and leave, and a first floor that hosts the personnel offices, a restaurant and the VIP lounge.

Figure 3 Aerial view of the Airport

The underground floor is not conditioned; it's built of concrete and all its parts in contact with the ground (floor and walls) are not insulated.

The floors above the ground are made of a metallic framework filled of sandwich panels whose main composition is polyurethane. The roof is a standard roof terrace system. Inside the building there are few separation walls, most of them are lightweight walls. This means that the building has a low global thermal inertia and heats up and cools down in a very short time. Each floor has a total surface of 3.200 m^2.

According to the Spanish Building Regulation (NBE-CT-79) the building is suitable for the climatic conditions of its environment.

HVAC description

The main elements of the HVAC system are:

- A chiller
- Two boilers
- 16 Air Handling Units (AHUs)
- A hot water loop
- A cold water loop
- 10 pumps
- Fan coils of 4 pipes in every office

A simple scheme of the hot and cold water loop can be seen in Figure 5 and Figure 6. The Hot Water

Loop and the Cold Water Loop feed directly the AHUs and the fan coils.

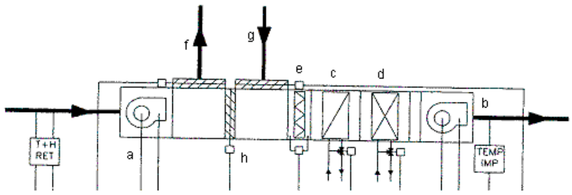

Figure 4 Typical Air Handling Unit

A typical AHU used in the HVAC system can be seen in Figure 4. The Free Cooling section is not present in all the AHUs, just in the main ones.

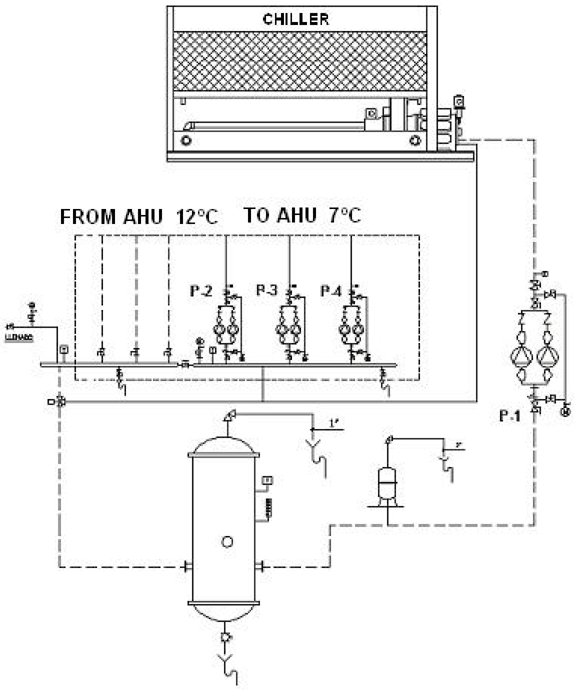

Figure 5 Scheme of the Cold Water Loop

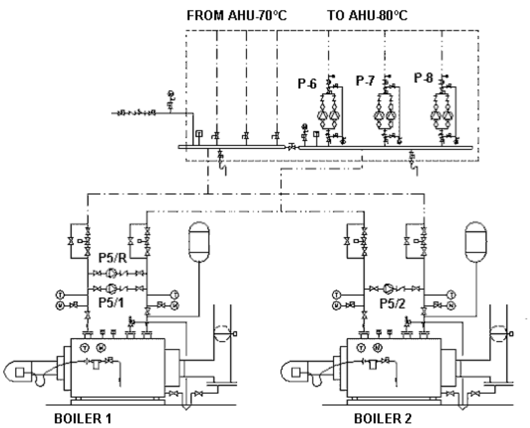

Figure 6 Scheme of the Hot Water Loop

THERMOGRAPHIC INSPECTION

The aim of the thermographic inspection was identifying possible losses of energy due to bad insulation, bad construction, faulty materials, etc.

The inspection took place during the second week of June 2001, that is, during a not very hot period. The building (81m x 38m x 9m) was divided into five representative areas: West, East, Land, Air and Roof. Each area was divided into subareas in order to obtain a more detailed analysis. We tried where possible to inspect areas that were shaded in order to avoid solar reflections. We used a meteorological station to keep track in every moment of the weather conditions needed to correct the thermographic images. We measured the distance of the area to inspect from the thermographic camera. We used several thermocouples in every area inspected, inside and outside the building. The areas inspected were also normally photographed.

As the new airport was built in 1999 using good building materials and good means of construction, we expected to find a good thermal behaviour, and so it was!

During the measurement, the differences between the inside and outside temperatures were small, varying from about 1.5ºC in the West side to about 12ºC in the East side (about 8ºC for the others sides).

In Figure 7, Figure 8 and Figure 9 it is possible to observe the results for the West Side/Outside. The analysis showed that the sandwich panels temperature was quite homogenous, with no important losses of energy. The glazings of the windows were more difficult to analyse because of solar reflections. Anyway, no important energy loss was observed. The metallic frame of the windows was perhaps the most critical part.

Figure 7 Visual picture of the West side/Outside

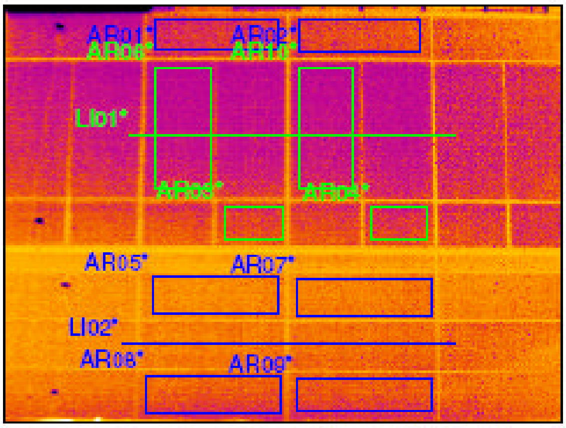

Figure 8 Infrared picture of the West side/Outside

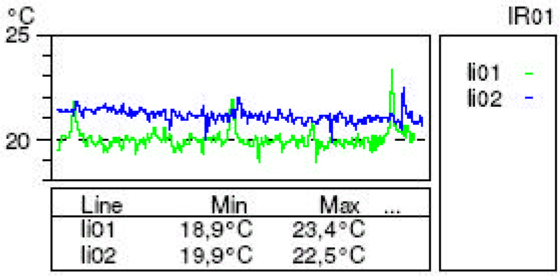

Figure 9 Temperatures from Figure 8

In Figure 10, Figure 11 and Figure 12 it is possible to observe the results for the Land Side/Outside.

Figure 10 Visual picture of the Land side/Outside

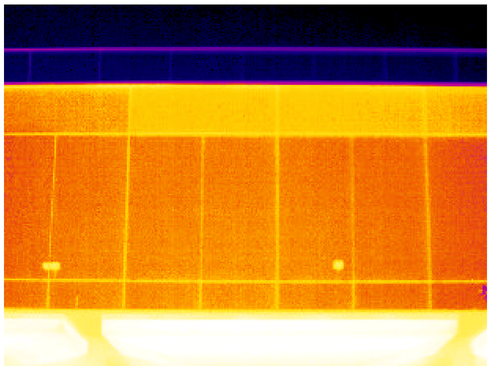

Figure 11 Infrared picture of the Land side/Top/Outside

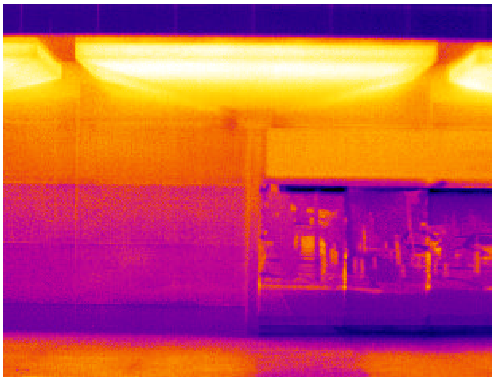

Figure 12 Infrared picture of the Land side/Bottom/Outside

The analysis showed that there were not any important thermal losses due to faulty materials, faulty construction or faulty insulation.

FIRST TRNSYS SIMULATION

TRNSYS is a transient systems simulation program with a modular structure. It recognizes a system description language in which the user specifies the components that constitute the system and the manner in which they are connected. The TRNSYS library includes many of the components commonly found in thermal and electrical energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. TRNSYS is well suited to detailed analyses of any system whose behaviour is dependent on the passage of time. Main applications include: solar systems (solar thermal and photovoltaic systems), low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells.

To run a first "simple" simulation, we gathered the following information:

- *Detailed description of the building*: geometric details and building elements. To do so, two auxiliary programs were used: SimCAD for the geometric description of the building and Prebid for the TRNSYS component description.

- *Meteorological data*: We used one year of meteorological data from the National Institute of Meteorology (solar radiation, humidity and dry bulb temperature).
- *Use of the building*: People entering and leaving, working hours, scheduled lighting, etc.
- *Auxiliary data*: we used a program called *Sombrero* to calculate the shades over the building. Using the meteorological data we calculated the temperature of the ground.

With these data it was possible to calculate the sensible energy demand during a year, that is the energy required for cooling and heating in order to keep a certain temperature inside the building.

This first simulation showed that the airport was consuming much more energy then needed.

The main problem of the simulation was quantifying the outside air infiltration. The airport is located in a windy place and there are people entering and leaving all the time. There are double doors, but not distant enough to have one open while the other is shut: the double doors open at the same time. The exterior walls of the airport are made of sandwich panels fitted on a metallic framework; many of them are not properly fitted so they cause an air leakage, especially in windy conditions.

We simulated the effect of this air infiltration: we started calculating the energy consumption with an initial air infiltration and then we observed the increase in the energy consumption as the air infiltration increased, as in Figure 13. The x-axis represents the air change of infiltration: 100% means 1 air change per hour. The y-axis represents a relative energy consumption, cooling and/or heating for keeping a certain temperature. For example, with an air change of infiltration of 50% the energy consumption would be a half compared to an air change of infiltration of 100%. The trend is almost linear and thus we can say that double air change of infiltration means double energy consumption.

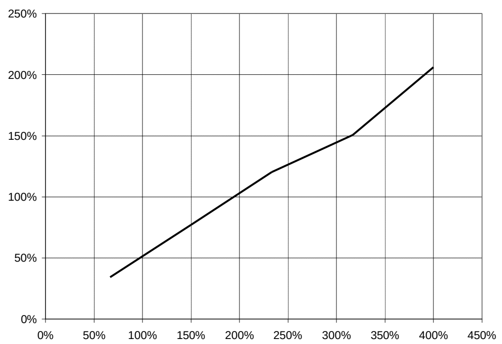

Figure 13 Increase in the energy consumption as the air infiltration increases

When especially cold, the airport used to leave the heating switched on 24 hours a day, even during the night when closed. As the building thermal inertia is so small, we thought it was not necessary.

FIRST PROPOSED SOLUTION AND RESULTS

We first suggested paying attention to the air infiltration, avoiding bad habits like leaving the outside doors open, and sealing where possible. We also suggested not keeping the heating on the whole day, but just during the working time, that is from early in the morning until late in the evening.

Accordingly to the airport, the energy consumption, especially the fuel consumption, **diminished to a half**.

SECOND TRNSYS SIMULATION

In this second simulation, we tried to simulate the behaviour of the whole HVAC system. We introduced in the simulation the following elements:

- A chiller
- Two boilers
- Air Handling Units
- Pipes for water supply of the AHU
- Pumps and fans
- A control system for the management of all these elements

All these elements were simulated as close as possible to the main characteristics of the real ones used in the HVAC system of the airport.

Summer

In Figure 14 it is possible to see the behaviour of an AHU in a “not very hot” day. In the graph it is plotted the outside temperature (*Line 1*), the inside temperature (*Line 2*), the air temperature at the outtake of the AHU (*Line 3*), and the percentage of opening of the 3-way valve that controls the flow of cold water through the AHU (*Line 4*).

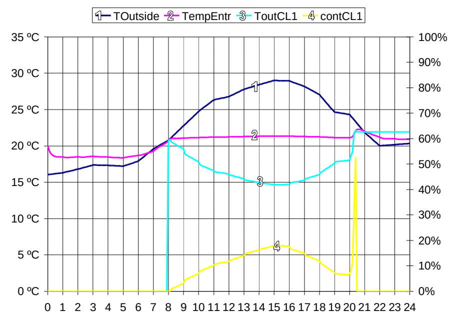

Figure 14 Behaviour of an AHU in a “not very hot” day

The data plotted in this graph are TRNSYS calculated.

It can be seen that for a "not very hot" day, the HVAC system performs fine, keeping the room temperature control set to 22ºC.

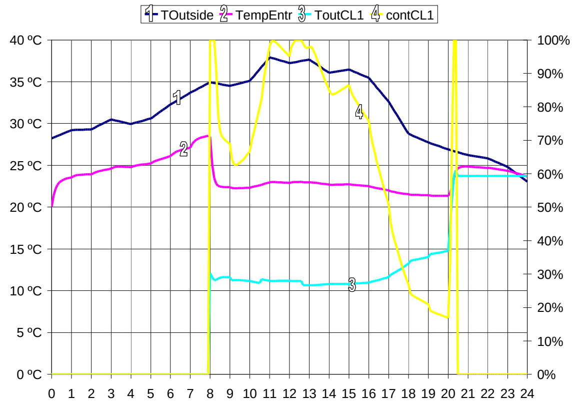

Figure 15 Behaviour of the same AHU in a "hot" day

In Figure 15 it is possible to see the behaviour of the same AHU in a "hot" day. Now the AHU has a peak during the start and another peak during the hottest hours of the day. The last peak is due to the switching off of the chiller 10 minutes before the switching off of the HVAC system. For the "hot" day the AHU has some problems keeping the set room temperature to 22ºC.

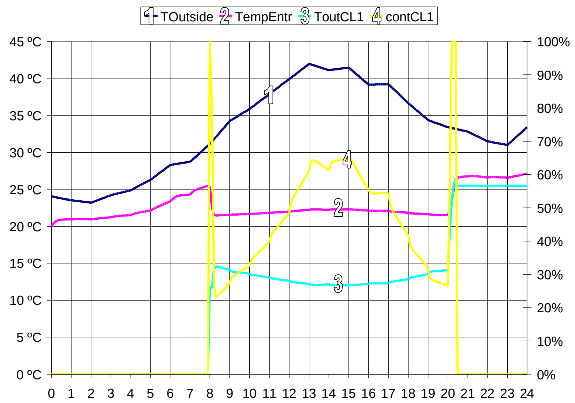

Figure 16 Behaviour of the same AHU in a "very hot" day and half Infiltration

In Figure 16 it is possible to see the behaviour of the same AHU in a "very hot" day, but with half infiltration. Now the AHU has no problems in keeping the set room temperature, even during the hottest hours of the day. Thus, it's clear how much is important to keep as low as possible the outside air infiltration.

Winter

In Figure 17 it is possible to see the behaviour of an AHU in a "very cold" day and in Figure 18 the primary loop water temperature at the inlet and outlet of the boilers.

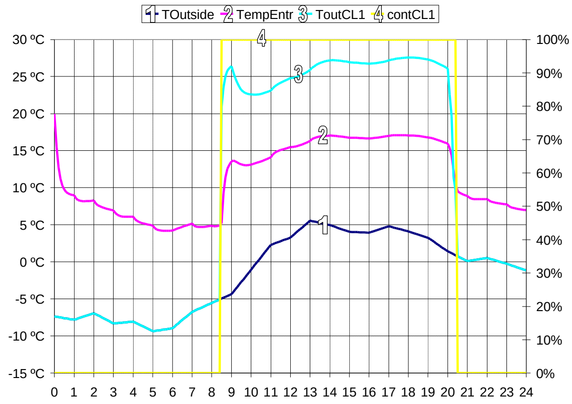

Figure 17 Behaviour of the same AHU in a "very cold" day

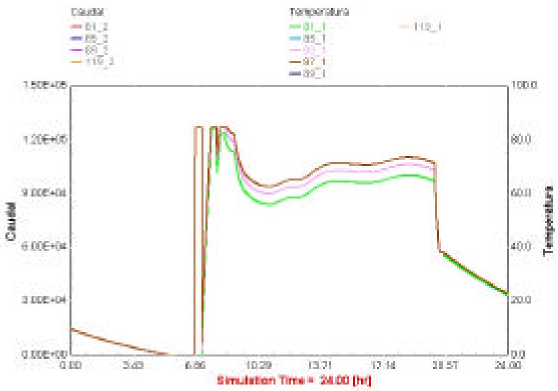

Figure 18 Primary Loop Water Temperatures in a "very cold" day

The set room temperature is 20ºC and the HVAC system can't keep it anytime. Even the boilers outlet water temperature is below 80ºC.

Maybe this problem could be solved raising the heating power of the boilers, reducing the outside air infiltration, raising the heating power in the AHUs, leaving the HVAC system switched on 24 hours a day, etc.

People in charge of the functioning of the HVAC system choose the strategy of keeping it switched on 24 hours a day, but with low improvements as showed in Figure 19.

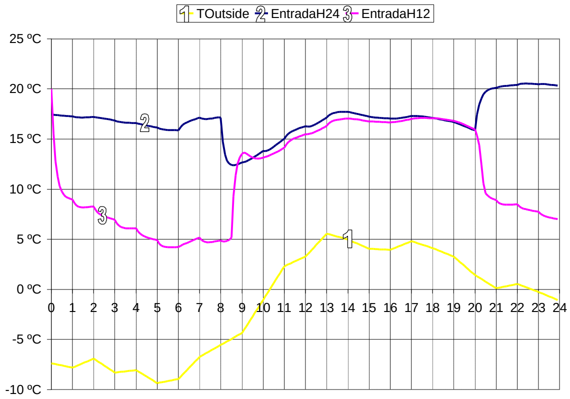

Figure 19 Behaviour of the same AHU in a "very cold" day during 12 and 24 hours functioning

In Figure 20 we simulated the same "very cold" day doubling the boilers heating power. Now the AHU achieves the set room temperature, but in a long time. Doubling the boilers heating power meant just a 13% rise in the consumption.

In Figure 21 we kept the original boilers power, but reduced to a half the outside air infiltration. The AHU achieve the set room temperature even in a shorter time compared to double boilers power, thus stating once again the importance of keeping as low as possible the infiltration. The fuel consumption only reduced a 5% as the boilers still works almost 100% of their capacity.

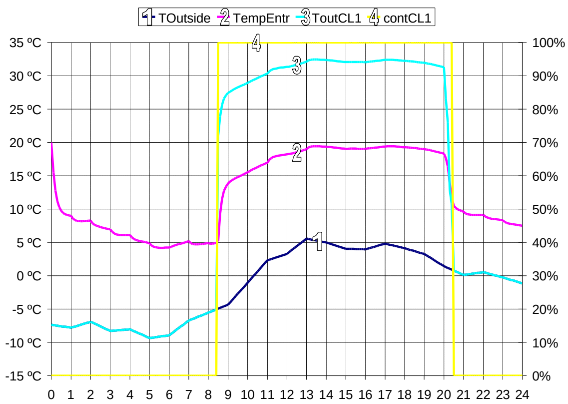

Figure 20 Behaviour of the same AHU in a "very cold" day and double boilers heating power

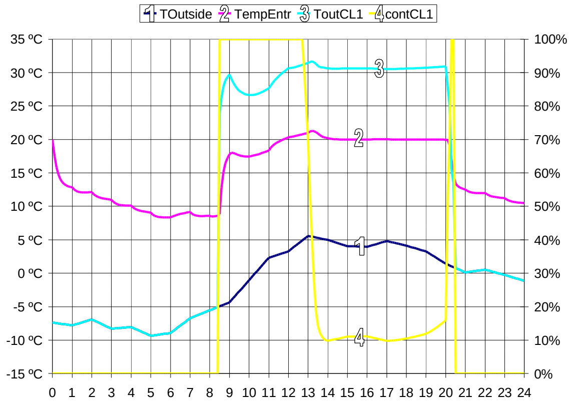

Figure 21 Behaviour of the same AHU in a "very cold" day and half infiltration

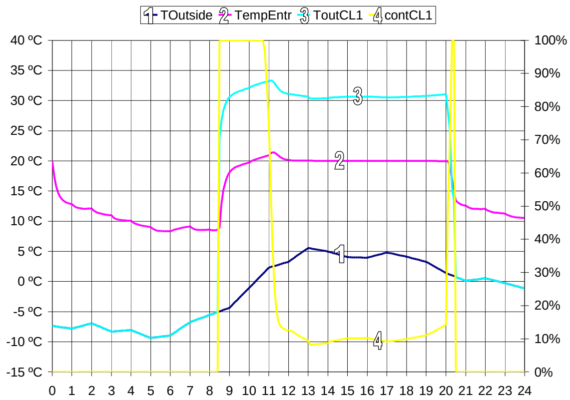

Figure 22 Behaviour of the same AHU in a "very cold" day, half infiltration and double boilers heating power

In Figure 22 we combined both half infiltration and double boilers heating power. Now the AHU performs fine keeping the set room temperature. The fuel consumption reduced a 3%. If we increased the heating power of the AHU, we would obtain an even better behaviour, as the set room temperature would be achieved in a very short time, as seen in Figure 23.

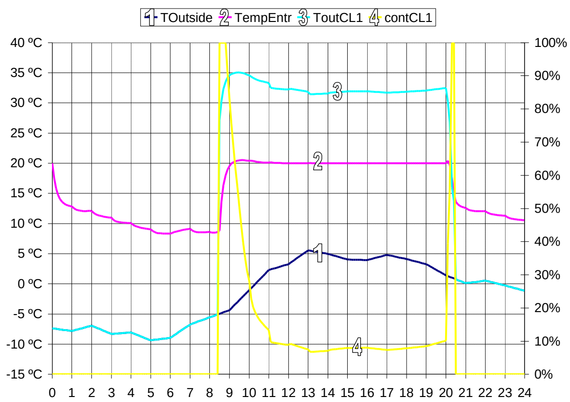

Figure 23 Same as in Figure 22, but more heating power in the AHU

ON FIELD MEASUREMENTS

During the whole 3rd week of February 2005 we went to the Valladolid's airport to perform some measurements in order to validate our TRNSYS calculation. We measured:

- Water flows and temperatures in the primary and secondary loops
- Water flows and temperatures in some AHUs
- Air flows and temperatures in some AHUs
- Various Room temperatures
- Various CO_2 concentrations
- Outside meteorological conditions (temperature, wind, humidity, pressure, solar radiation)
- Fuel consumption

The comparison between some data of the TRNSYS simulation and the on-field measurements can be seen in the following figures.

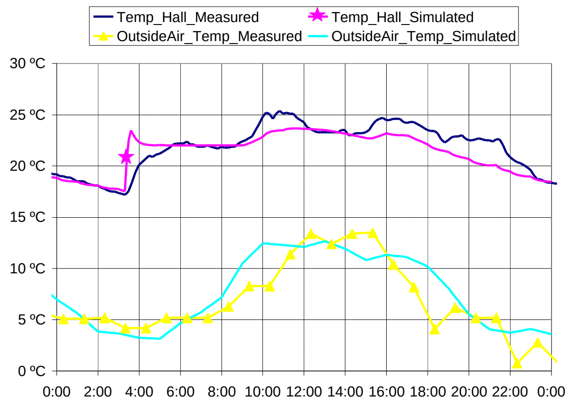

Figure 24 Outside air temperature and Entrance Hall temperature of the Airport (measured and simulated)

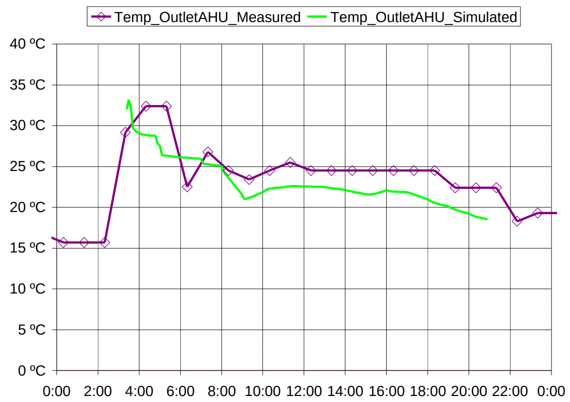

Figure 25

In Figure 24 it is possible to see the outside air temperature (measured and simulated) and the temperature of the Entrance Hall of the Airport (measured and simulated). We chose to monitor the Hall of Entrance as it is the biggest zone of the airport; other zones were also measured but not so thoroughly.

In Figure 25 it is possible to see the air temperature at the outlet of the biggest AHU that is conditioning the Entrance Hall.

It is possible to observe that the predicted (simulated) temperatures fit very well the measured temperatures.

We also compared the measured fuel consumption with the TRNSYS estimated fuel consumption and the difference is less than 10%.

FUTURE STUDIES

Developping this model we are aware that it is possible to simulate and therefore study many strategies more, such as temperature reset control, VSD pumps, supply fan static pressure control, demand control ventilation, etc.

CONCLUSION

With the thermographic inspection we could not find any relevant fault in the building construction and we thought that most of energy loss should be due to outside air infiltration.

With the TRNSYS simulation we found out how much is important the air infiltration. We also found that the boilers could be undersized as well as some AHUs.

Preventing the HVAC system to be switched on 24 hours a day together with a significant outside air infiltration, reduced the energy consumption (especially fuel consumption) to almost a half, according to the fuel invoices.

The on-field measurements revealed that the TRNSYS simulations performs very well and can be a useful tool to optimise the whole HVAC system.

ACKNOWLEDGMENT

I would like to thank AENA for letting us carrying such a study in an airport and my ex-colleague Gastón Sanglier who carried the thermographic inspection.

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