# Application of Building Simulation to support ISO 50001 Energy Management: Case study of Fiumicino Airport.

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## Abstract

In this paper we describe how simulation is used to support HVAC operational strategies within the context of the CASCADE project: a comprehensive platform that integrates Fault Detection and Diagnosis (FDD) techniques into an Energy Management System (EMS) that follows ISO-50001 guidelines. The CASCADE solution is conceived as an on-line application that combines a number of data intensive services using the internet as a data exchange medium. Among these services are an ontology-driven database, FDD engines, front-end visualization software and energy management tools. The project constantly monitors HVAC data and executes FDD routines that translate to specific actions rendered by the EMS software. The project is currently being implemented in two main EU airports: Rome Fiumicino (FCO) and Milan Malpensa (MXP). The ultimate intent of this research is to explore Whole Building Performance Simulation (WBPS) as a potential service to be integrated within the overall CASCADE solution. From a facility management perspective, models are commonly used as a test-bed to assess energy conservation measures before their implementation, to provide a fault free reference for recommissioning and a baseline for measurement and verification purposes. This theoretical perspective is confronted in this paper with the practical experience and lessons learned from one of the project's demonstrator buildings.

We describe the development of a WBPS model of the Terminal 1 of FCO airport. Large open space building types such as airport terminals pose some difficulties to be reflected as building models. Additionally the CASCADE data acquisition platform provides an uncommonly fine grained and highly detailed data set of the HVAC equipment representing a challenge to be used during the calibration process. The issues encountered during the simulation and calibration stages are reported. Furthermore, old buildings such as airport terminals can actually suffer from substantial interventions that make them perform very differently from their design intent, as is the case in this demonstrator. In these circumstances, modelling strategies need to be reformulated to account for modifications and to reflect diverse operative conditions and major changeovers. In this sense, the model is also formulated as a tool to indicate a pathway for recommissioning of inefficient HVAC systems.

## 1. Introduction

Energy consumed in buildings represents between 20% and 40% of the total global energy consumption in developed countries. It is also estimated that HVAC equipment accounts for 50% of the energy consumption in buildings (Perez-Lombard et al., 2008). HVAC systems are among the more energy intensive users within buildings and also among the worst performers due to unnoticed faults, improper maintenance or wrong operational settings. HVAC inefficiencies are estimated to range between 20% and 30% (IEA, 2002). This scenario represents a huge opportunity for the implementation of Energy Conservation Measures (ECMs) where data monitoring, FDD and WBPS can play a major role. Significant effort is put in place regarding simulation to support design and analysis during the design phase of buildings. The operational efficiency and the commissioning aspects are still applications of building simulation that need to be further developed to facilitate its wider adoption.

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## 2. Case Study: Rome Airport. (FCO)

The building modelled is Terminal 1 at Fiumicino Rome Airport (Latitude 41.8° North, Longitude 12.23° East). This building was first opened in 1961 and it is an open space concourse terminal of approximately 35,000 $m^2$ of floor area. An aerial view of this building is shown in Figure 1. The building geometry and construction model was developed using Design Builder® and is shown in Figure 2. This model was then exported to Energy+ (E+). Other tools like Simergy were also used to generate the HVAC models. Further model development, calibration and results were managed straightforward using E+ tools. Broadly speaking, the building is divided in two floors: (1) the ground floor is used for arrivals. Its internal height varies from 3.3 m to 4.55 m, and (2) the first floor which is the main concourse, dedicated to departures, with an average height of 14.5 m, therefore being an space with a huge air volume to be conditioned. These spaces are used for circulation and waiting areas, including ancillary spaces for offices, commerce and restaurants. Materials, thicknesses and thermal properties of the building envelope were estimated from design information and confirmed in site visits.

### 2.1 Thermal zoning

Airport terminals are conceived as big open spaces and represent a challenge when it comes to thermal zoning, as the open areas communicate between themselves and the same air is treated by several Air Handling Units (AHUs). This layout cannot be modelled in software tools such as E+ where the maximum HVAC Air Loops per thermal zone is only one and the loop models use HVAC air loop continuity as a main assumption. Subdivision of zones mirroring air distribution equipment is also difficult, as the real equipment is often the result of successive modifications or follows an uneven layout. A solution would be to subdivide the spaces following the AHUs layout and then estimate air exchange between zones. To apply this air exchange assumption we can use: (1) Air mixing statements, (2) Cross mixing statements, (3) Zone network, (4) Air network model with CONTAM, or more complex (5) CFD models. Finally, the air exchange between zones was not modelled but air extraction in kitchens and toilet areas was considered. In further developments, some of these alternatives will be tested to quantify the model sensitivity to air exchange between zones.

### 2.2 Internal Loads

The criteria used in this model is to break down building zones according to AHU and aggregate the different loads (restoration, commercial, boarding desks, open spaces, etc.) in a global total for the zone served by the same AHU. Occupancy data was estimated based on two data sources: (1) past statistics and passengers forecast providing yearly and monthly figures (ENAC, 2011), (ENAC, 2013) and (2) daily profiles for significant days through the year using flight databases (Flightstats Inc., 2014). Flight occupancy was calculated using the Passenger Occupancy Rate (Load Factor) of 80.4 % (IATA, 2013). Occupancy times were estimated in 30′ onwards for arrivals and 90′ backwards for departures, similarly as described by Parker in the UK (Parker et al., 2011). Different profiles were used for weekdays and weekends, accounting also for significant bank holidays.

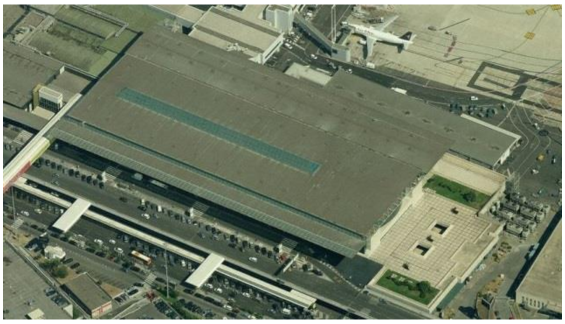

Fig. 1 – Aerial view of the FCO Terminal Airport

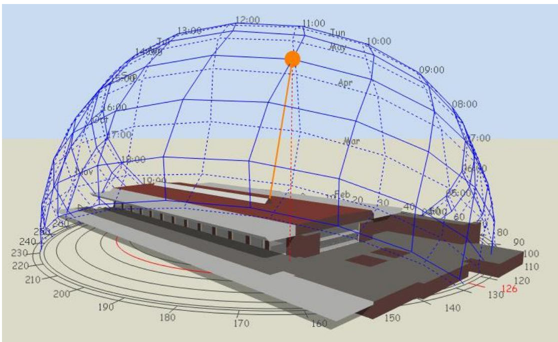

Fig. 2 – Model of the FCO Terminal Airport

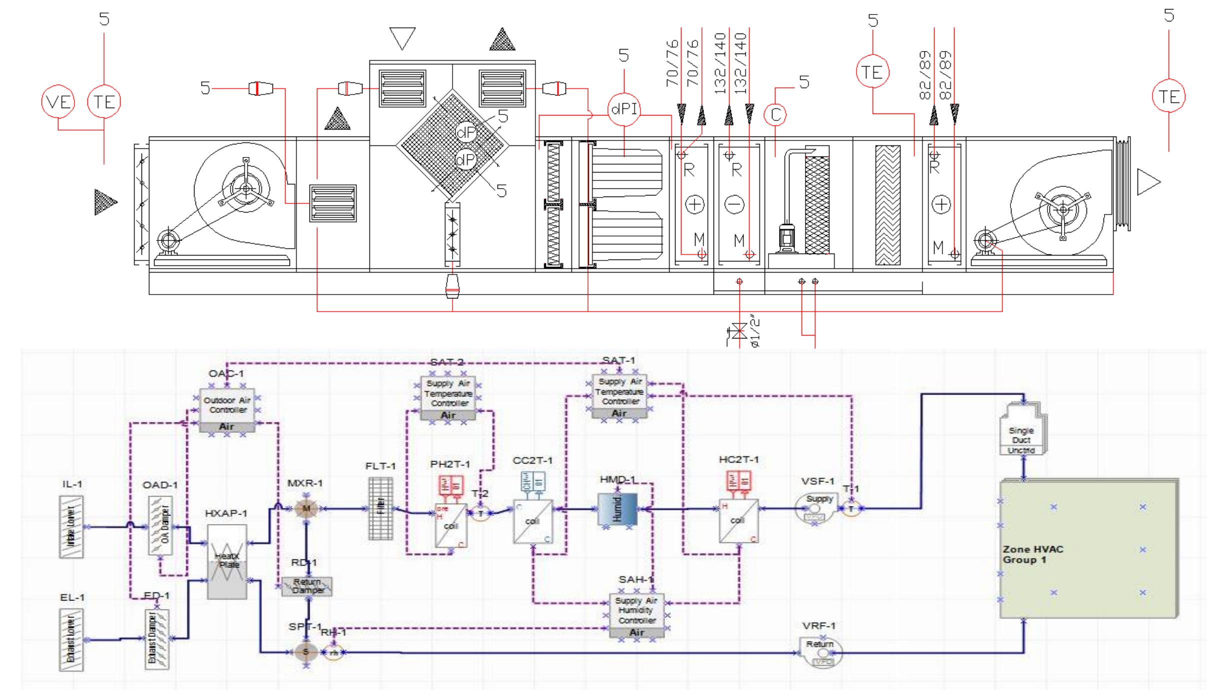


Fig. 3 – Actual (up) and modelled (down) schematic of the Air Handling Unit.

## 2.3 HVAC Model

The AHUs modelled are AHU No. 1, AHU No. 5, AHU No. 6 and AHU No. 11. These units are all serving thermal zones in the arrivals hall of the terminal at +1.00 m level (ground floor). Units show the following arrangement (see Figure 3): *Thermal Zone* → *Exhaust Fan* → *Mixing Box* → *Filters* → *PreHeating Coil* → *Cooling Coil* → *Humidifier* → *Post Heating Coil* → *Supply Fan* → *Thermal Zone* . The rest of the heating and cooling plan equipment has been idealized as district heating and cooling equipment. The AHUs are of Variable Air Volume with constant pressure setpoint.

## 2.4 HVAC Data analysis

HVAC data for calibration and analysis were retrieved using the CASCADE data acquisition platform. The data comprises more than 1060 data points along Terminal 1 systems, subsystems and components, among them: 11 AHUs, hydronic circuits, cooling towers and heat rejection groups. Data gathered included existing BMS sensored data and data gathered by additional sensors. Two AHUs were selected to install a high degree of instrumentation, these are AHU No. 1 and AHU No. 6. In these units, the additional sensors included water flow and temperature meters. Analysis of the retrieved data was performed before the calibration process and resulted in a productive activity leading to the detection of a number of faults. These divergences are summarized in Table 1. The differences between design and actual values will be taken into account in the recommissioning described in Section 4. As it can be seen in Table 1, the supply fan (nominal power 75 kW) is actually functioning below its rated power at a 60 kW to 63 kW regime. While this could be reasonable, the return fan (nominal power 55 kW) is functioning at a considerable lower power rate of 13 kW to 14 kW. This difference may be due to faulty sensors, pressure anomalies or fan problems and needs further investigation. Figure 4 shows the fans' energy consumption revealing the difference between these two fans. The Pre-Heating Coil (PHC) was not in operation during the whole period and so there was no data available to consider. The Cooling Coil (CC) data revealed that although the water temperature differences were in the range of design intent (6 °C supply and 14 °C return), the power delivered was significantly (half) lower than the rated of 556 kW. This can be due to a low air flow or to an oversized coil.

Table 1 – AHU No. 1: Components Design and Actual parameters. (a) refers to actual data, (b)

means estimated and (c) that design or generic values have been considered as input.

| AHU No. 1 Components | Variable (Units) | Design Value | Actual Value |
|---|---|---|---|
| Supply Fan | m³/h | 55,000 | N/A (c) |
| | Pa | 1,200 | N/A (c) |
| | kW | 75 | 60 to 66 (a) |
| Mixing Box Exhaust | min m³/h | 16,200 | N/A (c) |
| | max m³/h | 55,000 | N/A (c) |
| Mixing Box Recirculated | min m³/h | 0 | N/A (c) |
| | max m³/h | 38,800 | N/A (c) |
| Mixing Box Fresh Air | min m³/h | 26,000 | N/A (c) |
| | max m³/h | 64,800 | N/A (c) |
| PHC | Power (kW) | 216 | N/A (c) |
| | Temp (°C) | 80/70 | N/A (c) |
| | W.Flow (l/s) | NA | N/A (c) |
| CC | Power (kW) | 556 | 0 to 270 (a) |
| | Temp (°C) | 6/14 | 6 to 10/ 10 to 20 (a) |
| | W.Flow (l/s) | NA | 45 to 60 (a) |
| Humidifier | Pump (kW) | see footnote[1] | |
| HC | kW | 255 | 0 to 150 (a) |
| | Temp (°C) | 80/65 | 50 to 60/ 20 to 30 (a) |
| | W.Flow (l/s) | NA | 0 to 10 (a) |
| Return Fan | m³/h | 64,800 | N/A (c) |
| | Pa | 1,400 | 900(a) |
| | kW | 55 | 13 to 14 (a) |

The Heating Coil (HC) also operates at a lower energy rate than its nominal power of 255 kW, although as opposed to the Cooling Coil, the water temperature rate is quite different from the intended design, which is also confirmed by the low water flow rate. This suggests a flow problem in that component. The supply and return temperatures are much lower than expected, and the difference between them is more than 40°C in some cases, which is very high in comparison with 15°C of the design specifications. This can be due to a very high flow rate and needs further investigation. Other differences cannot be precisely investigated requiring more profound e.g., air flow rates. Some other issues are very difficult to analyse as is the case of setpoints values and mixing box operation, due to control logics hidden by BMS internal operation. These differences between design parameters and actual parameters demonstrate that calibrating detailed white box WBPS models can be an arduous experience.

1 The AHUs humidifier were disconnected thus disabled in the model

## 3. Calibration plan

The calibration process is based on previous work by Raftery (Raftery et al., 2012), and Mustafaraj (Mustafaraj et al., 2012). The calibration method used is performed by analysing and varying a set of input values iteratively to meet calibration criteria. Control version repository software and sub-hourly data gathered using the CASCADE platform were used. Input variation stands on confirmed information regarding the actual building that differs from usual default values. The information sources were: (1) design intent documents, (2) information obtained during site visits, and (3) fine grained data coming from the CASCADE platform that can be gathered at time steps as short as 5 minutes. The selection of the output variables for calibration supports the main intent of this model, which is to assist with the quantification of energy savings due to ECMs related to HVAC operation. Therefore, calibration focused on the targeted HVAC systems considering their main energy consumption variables, in this case: Supply and Return Fan Power Energy (kW); Preheating Coil Power Energy (kW); Cooling Coil Power Energy (kW); Heating Coil Power Energy (kW).

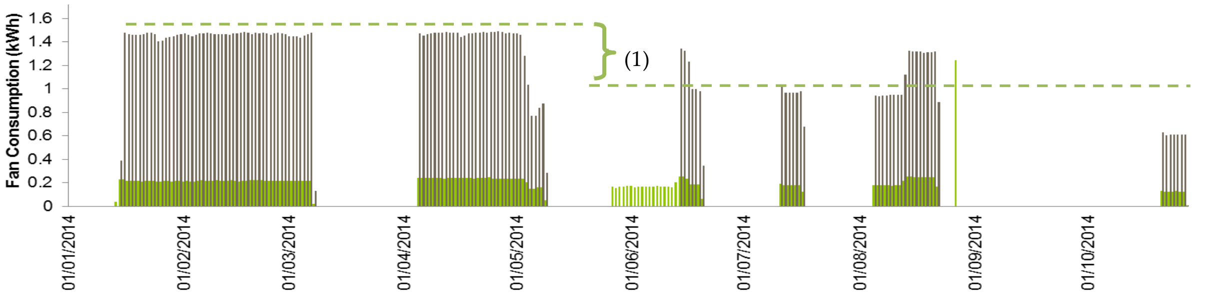


Fig. 4 – Actual AHU No. 1 Supply (Black) and return (Green) Fan Energy Daily Power Consumption for 2014. (1) Difference due to ECMs: Lower constant pressure setpoint and night setback.

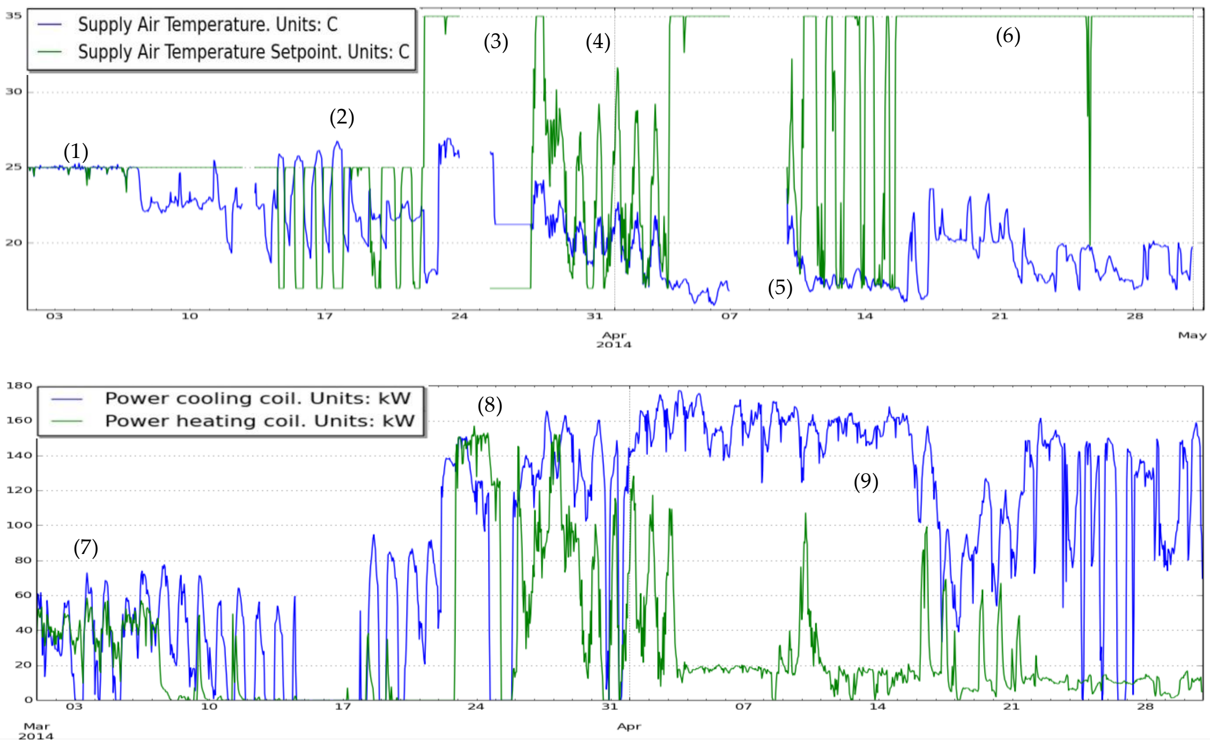


Fig. 5 – Up: Supply air temperature (blue) and setpoint (green). Down: HC (green) and CC (blue) power for March and April of 2014. (1) Shows an stable and tight control of supply air temperature. (2) Shows introduction of night setback. (3) Shows a setpoint of 35 °C that is not met. (4) In this period the setpoint varies and is not met. (5) Data gaps. (6) High setpoint value not met. (7) Simultaneous heating and cooling. (8) High spike on heating energy consumption linked with (3). (9) Shows apparently stable cooling coil in operation, residual heating energy consumption and no relationship with the setpoint for the same period.

The calibration of the fan electrical consumption was a relatively easy task due to the fans working at a constant regime. The adjustments were made to fan and fan motor efficiency parameters. For the calibration of the Heating and Cooling coils, as mentioned previously, data revealed a very different behaviour than nominal values. Different versions of the AHU using actual measured HC and CC (see Table 1) were tested but results were inconsistent with other variables such as water flow, water temperatures and setpoints. Finally, advice was given on how to solve these problems and nominal values were used for the ECMs study that follows and savings were indicated in percentages from the baseline. Other issues such as the humidifier not working were reflected in the final model as it was easy to configure by setting an availability manager to constantly off. The development of white box WBPS models encompassing large quantities of parameters to adjust is a time consuming and sometimes unproductive activity. Regarding the period of calibration, a full 8760 hour data set is needed for an accurate calibration as defined by ASHRAE guideline 14 (ASHRAE 2002). It was difficult to carry out a thorough calibration procedure as required by this guideline. The most remarkable issues detected were:

1. Numerous data gaps and incomplete 8760 h data set makes it difficult to comply with a whole year extent calibration;
2. Highly arbitrary air supply setpoint temperature. As can be seen in Figure 5, during the 2014 period, some periods show a tight control of the supply air temperature, others show very high temperatures (35 °C) and others a very unstable and probably a calculated varying setpoint. Some of the modifications are due to ad-hoc changes made by personnel;
3. Control sequences are not known. This means that the control sequences that coordinate heating and cooling coil valves can be difficult to simulate. Mixing box sequence is not known and this can result in unrealistic modelling assumptions;
4. A high difference between Supply and Return fan power consumption, which can be due to pressure or fan problems. This issue has to be confirmed further in other to recalibrate the simulation and use adequate inputs for the fans;
5. Differences between rated power and actual performance of CC and HC. This can be due to faults, e.g.: fouling, stuck valves, faulty sensors. These faults are difficult to be reproduced accurately in a simulation;
6. Simultaneous heating and cooling happening in November 2014;
7. Variable Air Volume (VAV) air loops working as Constant Air Volume (CAV).

As mentioned by Coakley (Coakley et al., 2014), calibrating WBPS models is an over-specified and undetermined problem. This statement is confirmed in this case study. A way of solving this problem would be to use component based inverse modelling or use BMS data as inputs. Nevertheless, advice was given on how to fix the known problems with the units and the model was used as a stable baseline to explore known problems regarding HVAC operation and to assess the impact of different ECMs.

# 4. AHU Recommissioning pathway

In this section, we show the recommissioning pathway proposed for the AHU No.1 based on problems encountered during the modelling phase. This sequence is based on the calculated impact of the different faults simulated, being the first the one with the most impact. A finer analysis would consider a cross scenario of the ECMs proposed where the combined effect of the different ECMs can be assessed. At the current stage, only fan consumption is reported. Further analysis will include impact on heating and cooling coils. A summary of the ECMs simulated impact is shown in Figure 6 and the same figures have been translated on per cent of energy saving with respect to the baseline. The strategies are the following:

1. Baseline (CAV)
2. VAV operation
3. 2 + Supply Air Temperature optimization
4. 3 + Night Setback thermostat
5. 3 + Night Shutdown
6. 3 + $CO_2$ - Outside Air Control

## 4.1 Constant Vs. Variable Air Volume

AHUs in FCO airport were originally designed to be of the Variable Air Volume (VAV) type. This variable flow is controlled by terminal VAV boxes at the duct ends and depends on local temperature control of the conditioned zones. The specific details of the VAV control strategy are not known. Data revealed that the fans were operating at constant electrical current (Amperes), electrical potential (Volts) and electrical power (Watts). The pressure at the ducts was also constant.

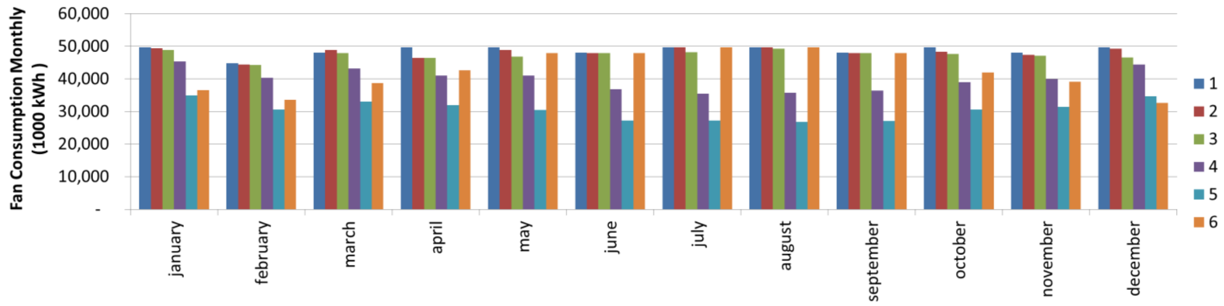


Fig. 6 – Monthly fan energy consumption for baseline (1) and the ECMs assessed

The conclusion was that the VAV boxes were not working. In order to assess the impact of bringing back the VAV boxes to a Variable Volume operation of the air loop, an initial run of the model was done and then the air flow was set to maintain 85% of the calculated airflow. This strategy (2) resulted on savings of 0% to 5% for fan consumption, and only for the months of April, May, October and November.

## 4.2 Unstable Supply Air Setpoint

Data in Figure 5 shows the air supply setpoint varying through the year. This setpoint is normally set by the operators. There is no information regarding criteria for setting up the setpoint. It can be seen that although the setpoint range has been set up in many different ways, it is very difficult for the system to meet the expected temperature. The strategy tested a wider supply air delivery threshold of 14°C for cooling and 29°C for heating. The baseline supply air setpoint has been set to a narrower range of 17°C for cooling and 22.5°C for heating, which is similar to the actual air supply temperature delivered. This strategy (3) was modelled on top of strategy 2 and demonstrated a saving of 4% to 7% on fan consumption. Again, this change was only effective for some months (April, May, July, October, November and December) and made no effect on others.

## 4.3 AHU working constantly

Data showed a constant operation of the AHUs 24 hours a day while the terminal real activity took place from 6.00 to 23.00 approximately, the remaining being the time in operation but with limited access; businesses are closed and there is a very reduced number of flights (normally only one or two). Some strategies were tested to understand the potential for savings of a night setback. A further investigation will use optimization techniques to establish an optimum start-stop time in combination with a supply setpoint temperature. The model reveals it is of high value to convey the thermal lag effects of the building and the dynamic loads. The impact of this ECM can be clearly assessed in Figure 4, where the real implementation of this setback can be clearly seen from May 2014 resulting in a 33% reduction of fan energy consumption. Two scenarios have been simulated adding to strategy 3. The first one (4) implements a night setback temperature deadband of 14°C to 29°C of the conditioned zone from 23.00 to 05.00. This rendered a reduction of 10% to 30% on fan energy consumption and was more effective in summer than winter. The second scenario (5) implements a total shutdown of the fans for the same period at night, reflecting what has been implemented in the real building. This last strategy yielded a 30% to 45% reduction of fan energy consumption. Again, this strategy was more effective for the cooling season.

## 4.4 Outside Air Rate optimization

Design intent documents show that the AHUs were calculated to attend two requirements: (1) Air per person, and (2) Air per area. These are very different ways of establishing an optimal Outside Air renovation air. For (1) to be successful, a $CO_2$ sensor must be installed in the terminal and control sequence of the mixing box accordingly. The current Outside Control in the building is not known and controlled by the operator. In the actual simulation the baseline Outside Air is set to 1 ACH. The air renovation was set to meet 8 l/person, and a limit of 1000 ppm $CO_2/m^3$. This strategy was revealed to be very successful in winter periods were AHU works at the minimum recirculated air (30%), although it is very sensitive to an unknown parameter as occupation and has to be used with caution.

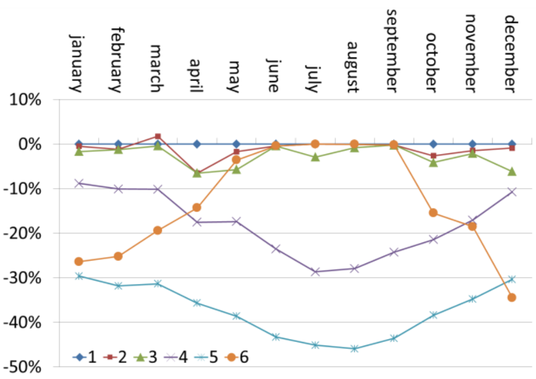


Fig. 7 – ECMs savings in percentage from the baseline.

## 5. Conclusions

In this research, a practical implementation of building simulation has been described. Whole Building Performance models can help final users to assess energy conservation measures before their implementation and this aspect of simulation is revealed by the ability of the model to simulate changes on operative conditions. Building models of large and open spaces represent a time intensive task. The model development and calibration process were revealed to be a useful way to discover problems of HVAC operation, despite calibration being difficult to achieve sometimes. The model was used to produce a sequenced recommissioning process. However, cross model configuration effects and cumulative effects need to be accounted for in potential variations of the savings estimates. The model developed demonstrates the usefulness of simulation in the implementation of the five ECMs selected: Variable air volume, Night Setback operation, optimized supply air temperature and $CO_2$ controlled Air Renovation. Simulation showed a substantial reduction in fan energy consumption of up to more than 40% in summer months. Further monitoring will verify the validity of the percentages estimated.

## 6. Acknowledgements

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