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BUILDING SIMULATION IMPROVEMENT ENERGY MANAGEMENT SYSTEM

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ABSTRACT

Development of new technologies and methodologies regarding building performance, building simulation and building energy management systems improvement is commonly found in the scientific literature. Furthermore a large group of simulation software applications has become available for a diversity of building performance assessments over the last years. Additionally a great number of modern buildings are provided with Energy Management and Control Systems which supervise and collect operating data from different energy components. However, these buildings energy management systems are generally recording operational data without being further processed and analyzed, in order to identify possible energy-saving measures. In this context the combination of both dynamic thermal simulation models and buildings energy management systems in the operational stage would allow for improved energy efficiency and significant energy savings in all types of buildings. This paper describes an assessment of the simulation model for an existing office building sited in Belgium. Although several improvement measurements were analyzed it should be noticed that the simulation run with a minimal fresh air valve aperture and increasing the CO_2 control set point up to values allowed by the European standards shows a reduction of more than fifty percent of energy consumption while the comfort condition are guarantee. The results demonstrate the added value of dynamic thermal simulation models in the operational phase of a building.

INTRODUTION

A large group of simulation software applications has become available for a diversity of building performance assessments over the last years. Additionally a great number of modern buildings are provided with Energy Management and Control Systems (EMCS) which supervise and collect operating data from different components of heating, ventilating and air conditioning (HVAC) systems. However, these buildings energy management systems (BEMS) are generally recording operational data of a building without being further processed and analyzed, in order to identify possible energy-saving measures. There is no continuity to the process of building performance assessment through the building lifecycle [1].

As a result of the increase of energy intensity and energy consumption indexes, the European Commission released the directive 2002/91 concerning the building´s energy efficiency. Alongside with the directive 2006/32, which concerns the energy end use efficiency at the energy services, the European Commission has set a suitable environment for the systematization of the energy management procedure in energy-consuming buildings such as hospitals, hotels, and office buildings [2]. Nowadays the development of new technologies and methodologies regarding building performance, building simulation and building energy management systems improvement is commonly found in the scientific literature. Hereafter a selection of the relating papers up to date is presented.

Within ESP-r (simulation tool) a control system was implemented by Clarke et al, [3]. The authors describe the development and testing of a prototype simulation-assisted controller, in which a detailed simulation program is embedded in real-time control decision making. An intelligent decision support model using rule sets based on a typical building energy management system was presented by Doukas et al in [2]. The model, which used a knowledge-based expert system to control the building’s operational data, carry out diagnosis of internal conditions and optimize building’s energy operation.

Mahdavi illustrates how computational modelling may be applied to enrich the informational repertoire of building systems operation control by inclusion of a larger set of indoor environmental performance indicators [4]. While Mathews and

Botha, [5] investigate the possibility of using dynamic integrated simulations for improved thermal management of HVAC systems in buildings. In the same way, dynamic models as well as self-tuning HVAC component models were developed and validated against measured data from an existing HVAC system by Nassif et al in [6]. Taylor et al, describes an evaluation of the building in terms of measured thermal comfort and energy use [7]. TRNsys models were developed to investigate the effect of changes to the control system on the energy use and thermal comfort provided by the building.

The challenges that the building simulation discipline faces in becoming a daily instrument in the design and operation of buildings, new forms of ubiquitous, remote, collaborative and pervasive simulation and other trends and manifestations are discussed by Godfried in [8]. O'Sullivan in [1], discusses combining such a building product model with a building management system and other tools and technologies to create a framework for monitoring, analyzing and controlling a building throughout its building lifecycle based on a set of performance metrics. Additionally Radhi in [9] observed that the search for optimization measures can be identified in a two-part sequence: measures already identified and proposed measures based on the result of energy analysis.

A substantial contribution in the analyzed topic was made by means of the Annex 40. As was observed by Visier et. al, in [10], Commissioning consists of clarifying building system performance requirements set by the owner, auditing different judgments and actions by the commissioning related parties in order to realize the performance, writing necessary and sufficient documentation, and verifying that the system enables proper operation and maintenance through functional performance testing. Accordingly the authors refers that getting tools to detect new occurring faults is important but it is even more important to commission the buildings to avoid initial faults. A project so called Annex 40 on "Commissioning of Building HVAC Systems for Improved Energy Performances" was launched for the period 2001-2004. The objective of the Annex was to develop, validate and document tools for commissioning of buildings and building services.

In this context the combination of both dynamic thermal simulation models and buildings energy management systems in the operational stage would allow for improved energy efficiency and significant energy savings in all types of buildings. This paper describes an assessment of the simulation model for an existing office building sited in Belgium and demonstrates the added value of dynamic thermal simulation models in the operational phase of a building.

BUILDING DESCRIPTION

The approach is implemented for an office building representative of practice in the region, from the design, construction as well as operation aspects. The infrastructure of the institution consists of several edifices sited in Brussels. In this paper the analysis was only in one building focused. Figure 1 shows a representation and a sky view of the buildings.

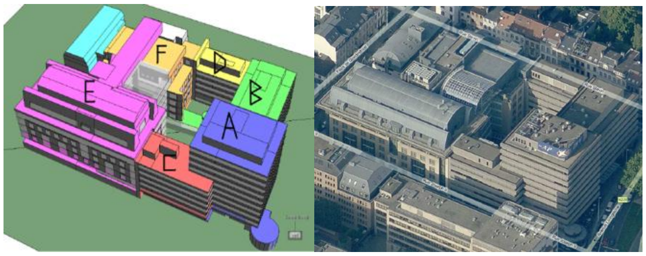


Figure 1. Representation and sky view of the office buildings

Four of the buildings are the older ones built around the year 1970. The two other buildings were constructed in 1994. The analysis was carried out in one of the buildings constructed in 1994. The condition of the chosen building was favourable due to the use of modern technique of construction, good insulation and even doubles glass plus double skin façade.

An analysis of the normalized heat consumption between years 2005 and 2007 shows an increasing trend. The normalized heat consumption increases 8% along this period. The value of this indicator for the office buildings reaches 96 kWh/m^2/year, which is fairly lower than the standard for Building Office, (150 kWh/m^2/year) [11]. During this period (2005-2007) the electricity consumption increases by 12%. It should be noticed that during this period an increase of the use of computer and informatics devices took place in the company. The normalized specific consumption of electricity for the building was of 271 kWh/m^2/year. This value if significantly larger than the standard value for this kind of buildings, 144 kWh/m^2/year [11].

Since the building and its services are too complex to model all, two models, one for the building and another for the HVAC system were modelled separately.

MODEL THEORETICAL ASSESSMENT

Following a synthetic summary of the building model extracted from the TRNsys manual [13] is presented. The Multizone Building modelling, type56 and TRNBuild model the thermal behaviour of a building divided into different thermal zones. The building model consist of a non-geometrical balance model with one air node per zone, representing the thermal capacity of the zone air volume and capacities which are closely connected with the air node. Thus the node capacity is a separate input in addition to the zone volume. On one hand, the Convective Heat Flux to the Air Node Q_i (W) is defined as:

$$Q_i = Q_{surf,i} + Q_{\inf,i} + Q_{vent,i} + Q_{g,c,i} + Q_{cp\lg,i} \quad (1)$$

Where $Q_{surf,i}$ (W) is the surface gain (total convection to air from all surfaces within zone), $Q_{inf,i}$ (W) is the infiltration gains,

$Q_{vent,i}$ (W) is the ventilation gains (air flow from a user defined source), $Q_{g,c,i}$ (W) is the internal convective gains (by people, equipment, illumination, etc) and $Q_{cplg,i}$ (W) is the gains due to (convective) air flow from zone *i* or boundary condition

On the other hand the Radiative Heat Flows to the Walls and Windows $Q_{r,w,i}$ (W) is defined by equation (2).

$$Q_{r,w,i} = Q_{g,r,w,i} + Q_{sol,w,i} + Q_{long,w,i} + Q_{wal-gain} \qquad (2)$$

With $Q_{r,w,i}$ (W) the radiative gains for the wall surface temperature node, $Q_{g,r,w,i}$ (W) the radiative zone internal gains received by wall, $Q_{sol,w,i}$ (W) the solar gains through zone windows received by walls, $Q_{long,w,i}$ (W) the longwave radiation exchange between this wall and all other walls and windows and $Q_{wall-gain}$ (W) the user specified heat flow to the wall or window surface.

Furthermore, in this component, in order to allow the user to describe cross ventilation or a ventilation circle several zones a coupling convention can be defined. The coupling statement allows the definition of an air mass flow that a zone receives from another zone, considered as a heat flow from or to the air node.

This description is a very simplified representation of the building model of type56. This component allows that heating and cooling system can be used as a separate equipment components, they can be coupled to the zones as either internal convective gains or ventilation gains. A more comprehensive description of the model can be found in TRNsys manual [13].

Simulation of ventilated double skin façade.

The ventilated double façade has not been modelled as a specific model for the double skin, but as another thermal zone included in the building model. Consequently, a similar theoretical approach previously explained was appropriate to model this characteristic of the building. Saelens presented a comparative study of several approaches for model double skin façade [14]. The author study the following model with different degree of complexity: i) single zone (SZ); ii) single zone with separation of radiation and convection (SZRC); iii) linear temperature gradient (AL); iv) exponential temperature gradient (AE); v) cell centred finite volume (NUM). The author reported that most of the case studied presents good accuracy with respect to the statistical deviation of air temperature variation. Although it was concluded that SZRC, which is the TRNsys model, have an acceptable fit. For SZRC, the statistical deviation of air temperature variation was only 1.58.

In addition, attention should be pay to the movable shading device. In a ventilated double façade, the shading device can be placed in various positions. On one hand it can be modelled as an internal shading device associated to an external window if it is against the external glass façade. On the other hand if it is against the internal glass façade, it can be modelled as an internal shading device associated to an internal window. Moreover it can be located in the middle of the cavity or in some place between the two glass façade; in that case an internal shading device associated to a fictive internal window should be modelled.

A shading device can be pulled down or rolled up according to any value: sunshine level, inside temperature, solar radiation or anything else. Like real controllers, the TRNsys controller models use operational hysteresis to stability. It avoids shading devices to keep going up and down all the time as soon as the control value varies a little bit. The shading device reduces the incoming solar radiation on the glazing area of the window by means of a specified shading factor. This factor is defined as the ratio of non transparency area of the shading device to the whole glazing area.

External Shading influence.

External Shading influence is modelled by mean of the angular heights of obstructions seen from an arbitrary opening and output numbers that describe the time dependent shading of the opening. For each opening following parameters should be defined: the slope, the azimuth, a series of absolute surface angles: angles for which obstruction heights will later be provided as well as several subsequent angular height of an arbitrary obstruction as seen from the centre of an aperture while looking in the direction of one of the provided surface azimuth angles.

A vertical opening has a viewing angle of 180 degrees and a horizontal opening has a view angle of 360 degrees. Since it is less evident what the viewing angle for an arbitrarily sloped opening is, all openings are defined as having a 360 degree view angle while the plane containing the opening would be considered an obstruction shading the opening. Surface angles (α) are defined in an absolute co-ordinate system (as opposed to relative to the opening) and for each one, an angular obstruction height θ is required.

BUILDING MODEL ASSESSMENT

As was mentioned before the buildings and its services are excessively complex to model the whole building. For that reason only one building was chosen to be modelled taking into account that it has BEMS. The building consists of 8 floors, but only 4 floors were modelled. In the study case, floors 2 to 5 consisting of 26 zones were modelled. General data concerning the building are as follows.

Zoning per floor:

- landscaped Office (including small data room)
- Double skin zone for each orientation + 1 extra for the double skin towards the atrium (makes 5)
- For the 4 floors: staircase as 1 zone, sanitary blocks as 1 zone, (modelled as 1 zone adjacent to all office zones).

A floor plan view of the building is shown in Figure 2. For all orientation the wall have double-skin window.

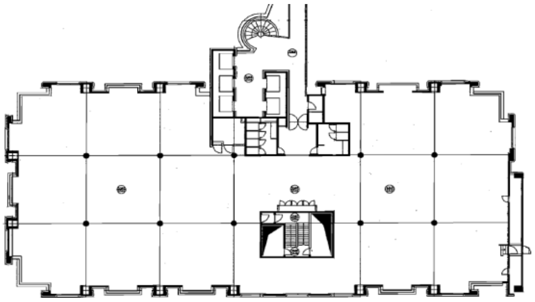
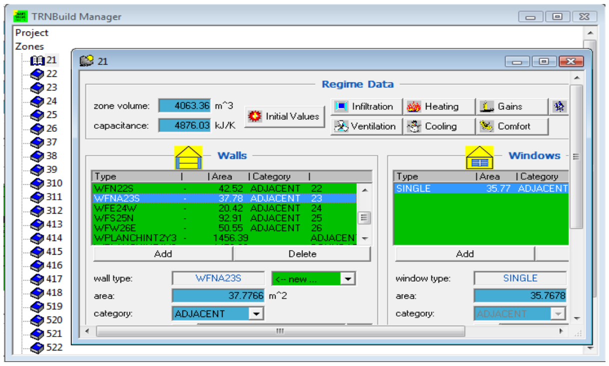


Figure 2. Floor plan view of the building

These floors are ventilated by ventilation groups KG6 and KG7 and the sanitary extraction group. The atrium was not modelled as a zone, but as a boundary condition for each floor with a fixed temperature profile. The solar protection has a regulation per façade. Boundary conditions between restaurant and floor 2: adiabatic (identical) was defined. Similar definition for floor 5 towards floor 6 was made.

In TRNsys, the Zone window contains all information describing a thermal zone of the building. The data describing a zone can be divided into four main parts: a) the required Regimen data, b) the Walls of the zone, c) the Windows of the zone and d) optional equipment data and operating specifications including Infiltration, Ventilation, Cooling, Heating, Gains and Comfort. As shown in Figure 3, the information about Walls within a zone can be defined. Here a name for each wall type, the solar absorptance, and the convective heat transfer coefficient was specified.



zone volume: 4063.36 m^3

capacitance: 4876.03 kJ/K

Type		Area	Category	
WFN22S	-	42.52	ADJACENT	22
WFNA23S	-	37.78	ADJACENT	23
WFE24W	-	20.42	ADJACENT	24
WFS25N	-	92.91	ADJACENT	25
WFW26E	-	50.55	ADJACENT	26
WPLANCHINT2Y3	-	1456.39		ADJACEN

wall type: WFNA23S <-- new ...

area: 37.7766 m^2

category: ADJACENT

Type	Area	Category
SINGLE	35.77	ADJACENT

window type: SINGLE

area: 35.7678

category: ADJACENT

Figure 3. Information about Walls within a zone

From the building plans, the geometry and the orientation were determined. For the 26 zones, from the second until five floors, geometry and wall data for the office building were available. The volume of air within the zone, the total thermal capacitance of zone air plus any mass not considered as walls, the initial temperature of the zone air, the initial relative humidity of the zone air and humidity model, were defined in the regimen data.

To model the buffer effect of humidity within a zone, the more detailed moisture capacitance model has been used. This model describes a separate humidity buffer divided into a surface and a deep storage portion. Each buffer is defined by three parameters: the exchange coefficient of the surface buffer storage, the exchange coefficient of the deep buffer surface and the deep buffer storage. See the main TRNsys Reference Manual [12] for a detailed description of this model.

Two kinds of Windows have been defined. On one hand single glass windows have been used in each adjacent walls facing from offices zone to double skin zones. On the other hand double glass windows were used in each external wall of the double skin zones. A significant different exist in the Overall Heat Transfer Coefficient, (U values), of both kind of windows, 5.68 W/m^{2}K for the case of single glass windows and 1.27 W/m^{2}K for the case of double glass windows.

Modeling the Double façade.

Several approaches to model the ventilated double façade can be found in the literature. In Reference [14] Saelens gives an overview of multiple skin façade models developed during the last years. One of the difficulties simulating a ventilated double façade is explained, among other things, by the complex heat exchange process around the shading device due to the absorption of the solar radiation (by the shading device) and to the cavity ventilation [15].

The double skin model in TRNsys building model is an approximation and its parameters will have to be defined in such way that the approximation is as precise as possible for the most crucial outputs (Air temperature in the cavity and Surface temperature). This is done by defining windows as boundaries of the zones and using the single zone with separation of radiation and convection model for the cavity [16].

Certainly the cavity can be modelled by 2 or more zones for further detailed, but the more the cavity is subdivided the longer is the TRNsys simulation time [15]. In the case analysed building with none less than 40 windows with double skin, a total of 20 double façade zones have been defined. If these zones were subdivided the simulation time will increase significantly. Figure 4 shows a real view of the windows and the allocation of shading device in the office building

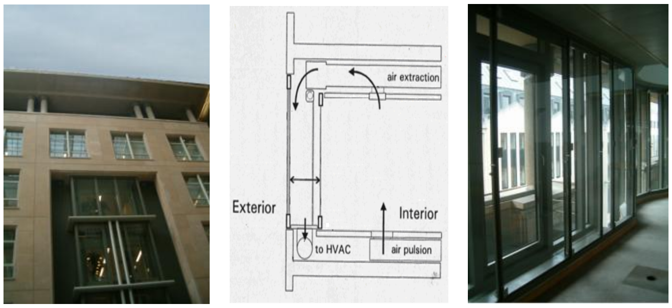


Figure 4. View of the windows of the building.

Accordingly, in every floor, the modelling approach of each double skin zone was conducted assuming only one zone for each orientation independently of the amount of windows in the wall. Internal shading device were defined for each double glazed window. The control of the shading device was carried out by using three criteria.

The shading device is pulled down if the external daylight luminance is larger than 10000 lumens. In addition, it is considered that the solar angle on horizontal surface should be between 90° and 25°, while the solar angle on the wall surface should be larger than 30°. In order to guarantee the stability of the model typical controller components which operate with hysteresis mechanism were used. The expression used to calculate the daylight luminance as a function of the luminous efficacy, was extracted from Wright et. al, in Reference [17].

Input data information.

As was mentioned previously, the heating and cooling systems were modelled externally to the TYPE 56 component. The ventilation of the offices zone, for instance, Zone Z21, Z37, Z413 and Z519 is covered by two supply air flows, the Central flow and the Periphery. In addition an infiltration rate flow was defined for each zone. In the double façade zones a coupling procedure was used to model the return air flow of the Periphery ventilation inlet across the double façade.

Internal gains (including persons, lighting, electrical devices, etc.) were defined as input, since this information was available from the BMS data base. The occupation schedule was defined by using the information of an energy audit previously carried out in the building [12].

We used the global measured electrical consumption to model the consumption of the computers, lighting and other electrical equipment. It should be notice that there were not data from all the year. Average values for those months without information (winter) were used. The average values were calculated for each hour and making distinction between weekdays and weekend. Once all the details of the building model were defined in type 56, it was coupled with the systems model. As can be seen in Figure 5, in the integrated model all the input were defined, for instance, weather data, internal gain, internal shading device controller, ventilation air flow etc.

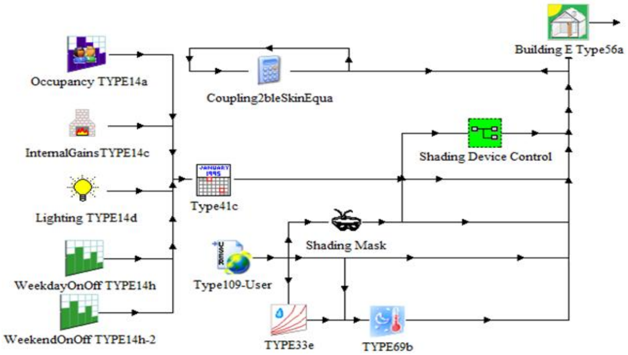


Figure 5. Section of building model in TRNsys.

By means of a shading mask component taking into account the difference of each floor in all orientation, the external shading influence was considered. The beam radiation calculation is made by deciding whether the sun is obstructed by an object at any given time. The diffuse fraction calculation is made by integrating the shading effects seen by the window and dividing by the view factor from the opening where there are no shading objects present.

A section of the global building-system model is presented in Figure 6. The pink line represents the air network treating by the climatic group KG6 unit. The green boxes are TRNsys macros that contain a part of the system model. It can be seen that the air starts from the KG6 system then goes in TRANSIT IN Central which contains the supply pipes to the building. The return pipes are placed in TRANSIT OUT Central macro box. Then the air goes in the return and the cycle can go on. The building office are compose by an inner sector supplied by the KG6 unit and an outer sector supplied by the KG7 unit. The orange line represents the air network treating by the KG7 unit. A detailed description of the integrated model can be found in Reference [12].

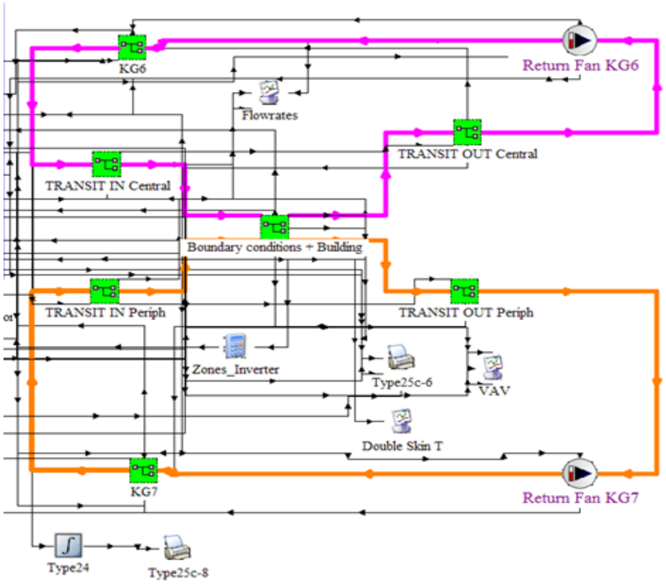


Figure 6. Integration between system and building models

MEASURMENT CAMPAING

Temperature measurements.

The measurements were carried out in two steps. Temperature, relative humidity and absolute humidity in the offices zones were measured during more than two months in the summer, from July 31th to October 10th 2008, while the CO_2 concentration was measured in floor three during three weeks, from May 28th to June 16th 2009. As shown in Figure 7, for each floor average values were calculated and cumulative curves were constructed. It can be seen clearly that temperature values of floor four are most of the time the largest amount, while the lower value of temperature take place in floor three.

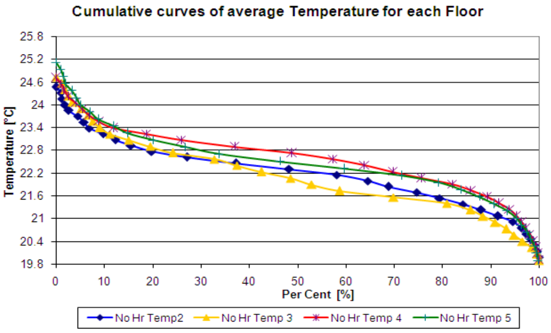


Figure 7. Hourly average temperature for each floor.

Two typical profiles were clearly identified for weekdays and weekend. The graphic in figure 8, shows the weekday profiles. As can be seen during the weekday from 8:00 hour to 18:00 hour the temperature values remain around 22.5 °C.

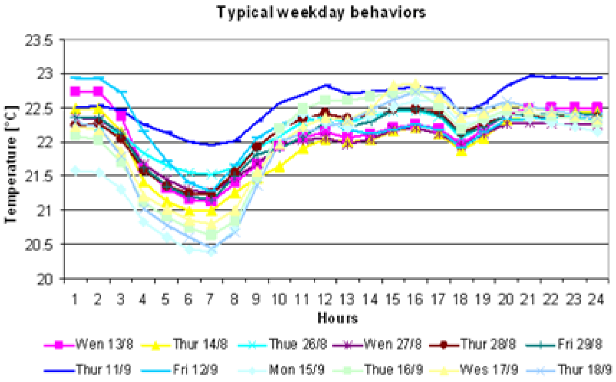


Figure 8. Temperature Profiles in office zone for weekday.

Concentration of CO_2 measurement.

Hence, a complete definition of indoor air quality categories is difficult, for practical applications can be applied four categories of indoor air quality (IAQ), for instance, (High, Medium, Moderated and Low indoor air quality). Current research and practice would suggest that IAQ could be categorized by CO_2 concentration, as can be found in European Standard, (EN 13779: 2008) [11]. Consequently, the CO_2 concentration was measured in floor three during three weeks, from May 28th to June 16th. The logger was placed in the centre of the floors in a suitable position. Data were logged every 5 minutes. Figure 9 shows the behaviour of the CO_2 concentration during one week.

It can be seen that for the whole period, during the nights, as well as, the weekends, (6/13/2009 and 6/14/2009), the value of CO_2 concentration remain almost constant around 400 ppm. During the weekday the concentration of CO_2 increase progressively during the day up to 725 ppm and diminishing during the night.

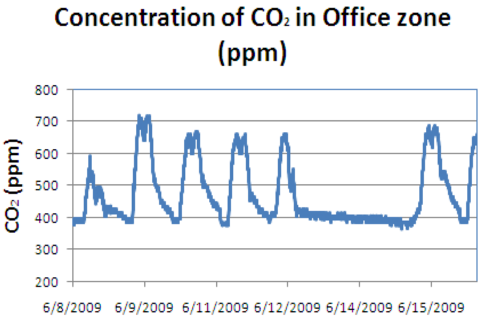


Figure 9. Concentration of CO_2, office zone, (one week).

The concentration presents an oscillatory behaviour keeping value between 400 ppm and 725 ppm. It should be notice that the maximum value of 725 ppm is significantly lower than the IAQ European standard of CO_2 concentration in non residential buildings, for instance, 1200 ppm for low indoor air quality.

ECONOMIC CONSIDERATIONS

To estimate the economic feasibility of the measurement, as well as, to evaluate the influence of the double skin façade the annual benefits have been calculated. The annual benefits consist of the financial value of the saved heat and the financial value of the saved electricity. Therefore the annual benefits can be seen as the primary energy that has been saved by means of the modification of the system, compared to the installation consumption before to the modification. Two major modifications are presented:

- The changes in the set point of the CO_2 control relating with the aperture of the fresh air valve
- The use or not of the double façade in the building.

In order to estimate the primary energy saved, the annual fuel cost is calculated. In this paper we use the methodology presented by De Paepe in references [18] to calculate the annual fuel cost. Accordingly, the annual fuel cost can be defined as the annual amount of fuel burned in the boiler F multiplied by the financial value of the fuel V_F per unit in which F is considered.

Where the amount of fuel can easily be calculated using manufacturer's data (efficiencies, etc.) and an estimate of the annual operating time, the financial value of the fuel is much harder to define. As was observed in Reference [18], in a liberalised energy market, fuel prices are not fixed but must be agreed upon by both parties. Usually, the larger the volume of fuel bought, the lower is the price per unit of volume one has to pay. In the present analysis, for simplicity, the fuel price is assumed as a means. The annual cost (C_H), representing the value of the demanded heat, is then:

$$C_H = FV_F \tag{3}$$

Where F the annual amount of fuel burned in the boiler (in kWh) and V_F the value of the fuel as explained before (in €/kWh). In the current case the pre-Heat, the post-Heat, the Fan consumption, as well as, other components of the thermal system were considered. The hot water production is ensured by a Redamax boiler of 730 kW, with a seasonal output of 85% of efficiency.

In a similar way, we can calculate the annual electricity cost (C_E) by means of the following expression:

$$C_E = EV_E \tag{4}$$

Where E is the annual electricity demanded (in kWh) and V_E is the value of the electricity (€/kWh). It should be noted that cold production in the building is ensured for an Electric Chiller of 625 kW with a performance coefficient of 3.97 at 100 % load

In this case, the value of the benefits is the avoided cost for producing the amount of heat with the boiler and the financial value of the avoided electricity consumption. Market prices for electricity, gas and fuel oil are key parameters for the economic analysis of the thermal system. Additionally we have considered conversion factors, in kWh, for the primary energy used [12]. These values are assumptions for the market prices, which do not include transport costs, grid costs, taxes, levies, etc. They are included for calculations, but strongly depend on the thermal system type and size [18].

The assumed values are:

- Electricity during the day: 0.1063 €/kWh
- Electricity during the night: 0.0664 €/kWh
- Gas: 0.03113 €/kWh
- Primary energy conversion factor for Electricity: 2.5
- Primary energy conversion factor for Gas: 1.1

To compare the impact of different measurement with a similar base of analysis the fuel energy saving ratio (FESR) have been calculated. The fuel energy saving ratio, also called Percent of Fuel Saving (S) measures the extent of fuel savings directly [19], it is given by the following expression:

$$FESR = 1 - \frac{F_I}{F_B} \tag{5}$$

Where F_I is the total amount of fuel consumed after the modification in (kWh) and F_B is the total amount of fuel consumed before the modification in (kWh).

RESULTS AND DISCUSSIONS

Model Calibration.

The first step of the calibration is to define which part of the model should be calibrated, as well as, the inputs given to this segment of the model and the output we want compare to the reality. Then we have to define the parameters that should be adapted so that the simulation matches as well as possible the measurements we made.

Figure 10 shows a comparison between the supply temperature found by simulation of the KG7 and the one given by the BEMS system. As can be seen there is an acceptable accuracy. The BEMS curve confirm that there is a kind of offset made by the BEMS because the supply temperature reaches 29°C although the maximum supply temperature defined in the BEMS and in the simulation was 27°C.

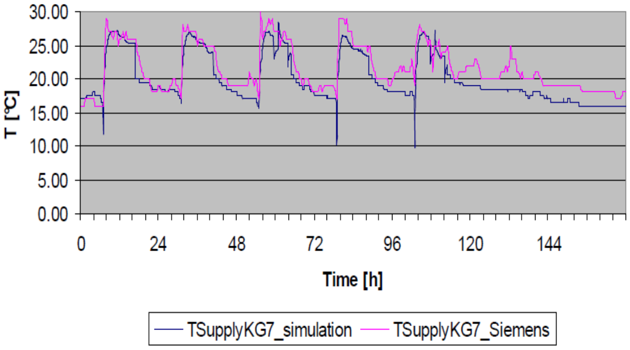


Figure 10. Supply temperature of simulation and BEMS.

Improvement measurement

Although several improvement measurements were analyzed the following samples demonstrate the viability of the present approach. The first improvement measurement focused in the free cooling system consist of reduce the use of cold fresh air in order to decrease the heating consumption. Reducing the amount of fresh air is permitted because the CO_2 concentration is never greater than 725 ppm in the office as shown in Figure 9. According to European standards we can increase the CO_2 set point up to 1000 ppm. Table 1 shows the KG7 air handling unit simulation results for the aforementioned conditions.

Table 1. KG7 air handling unit: 20% fresh air valve opening

Component	**Consumption (kWh)**	**Primary energy (kWh)**	**Cost (€)**
Supply Fan	5719	14297	607
Return Fan	4605	11514	489
Pre-Heat	110796	121875	3449
Cool	6284	15710	668
Humidifier	267	669	28
Post-Heat	101819	112001	3169

The supply air set point was changed and a CO_2 concentration control with a minimum fresh air valve opening of 20 % was aided. The results of a simulation with 20% of the fresh air valve opening and a CO_2 control with a set point of 800 ppm shows a reduction of more than 27 % of energy consumption. Table 2 shows the KG6 and KG7 air handling units' simulation results for several operation conditions. Further detailed of the uncertainties analysis are presented in the following section

Table 2. KG7 air handling unit simulation results

Case: (Fresh air opening [%], CO_2 [ppm])	**Total Cost [€]**	**Primary Energy [MWh]**	**Saving [€] (%)**	**Standard Deviation [%]**
Reference, Opening (30%)	17257	566	-	-
20% Opening, 800 ppm CO_2	12505	409	4752 (27%)	5.9
10% Opening, 800 ppm CO_2	11344	370	5913 (34%)	5.6
5% Opening, 800 ppm CO_2	10766	350	6491 (38%)	5.6
20% Opening, 1000 ppm CO_2	10048	325	7209 (42%)	8.7
10% Opening, 1000 ppm CO_2	8909	285	8348 (49%)	8.8
5% Opening, 1000 ppm CO_2	8373	266	8884 (53%)	9.2

The results of a simulation run with 5% of the fresh air valve opening and a CO_2 control with a set point of 1000 ppm shows a reduction of more than 50 % of energy consumption while the comfort condition are guarantee. It should be noticed that the uncertainty analysis denotes that this operation condition presents the higher value of standard deviation. The graph in Figure 11 shows the comparison between our CO_2 model in blue and the measured CO_2 concentration in red.

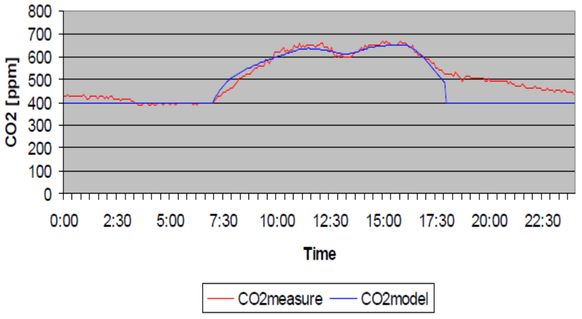


Figure11. CO_2 concentration of the model and measured

Evaluation of double skin influence

In order to evaluate the influence of the double skin façade in the ventilation gain of the building, two major scenarios in the building model were compared. In the first scenario, the building model was tested considering the double skin working. It means that the return air flow of the periphery ventilation supplied was carried out across the double façade. On the other hand in the second scenario the building model was tested considering that the double skin does not work. It means that the return air flow of the periphery ventilation supplied was not carried out across the double façade. The comparison was carried out by using the sum of the Ventilation gain in the office zone, (Z21, Z37, Z413 and Z519). Figure 12 represents the monthly primary energy demanded for the heating system, (ventilation gains) in office zones during winter.

The graphic shows that during winter the primary energy consumption will increase if the double skin were not working. Since during winter the building is demanding heat from the system, this result denotes that the use of the double façade contribute to the save energy.

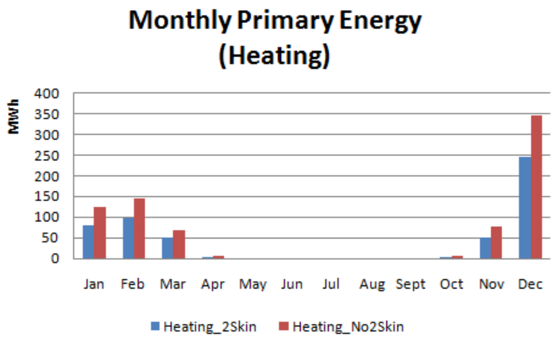


Figure 12. Primary energy demand in office zones (winter).

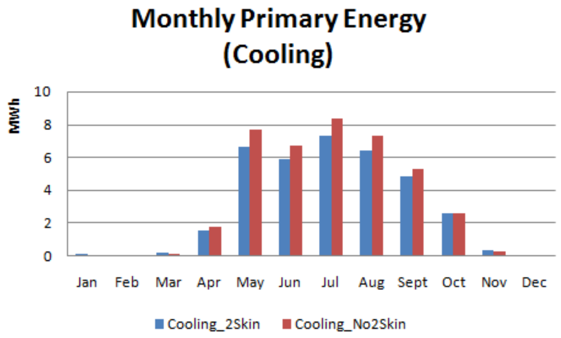


Figure 13. Primary energy demand in office zones (summer).

Furthermore, as can be seen in Figure 13, during summer, the double façade have also an important role in the save of energy. The graphic reflects that during summer the primary energy consumption decrease when the double skin is working. Accordingly, Figure 14 represents the contribution of the double façade in the save of energy. The graphs reflects that it is saved up to ten percent of energy as a result of the use of double skin during summer, as well as, thirty one percent of energy saved during winter.

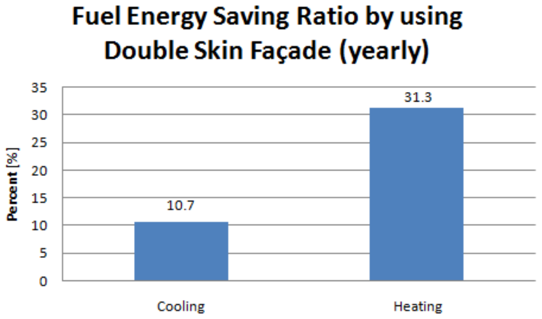


Figure 14. Reduction of primary energy consumption

UNCERTAINTY AND SENSITIVITY ANALYSIS

Parameters and assumptions of any model are subject to changes and uncertainties. If parameters are uncertain, statistical analysis can give information concerning the uncertainties of the results. Uncertainty analysis defines the variation or uncertainty in the output variable of the model due to the variations of the input. The determination of the uncertainty analysis is straightforward. The standard deviation is estimated by Eq. 6:

$$\hat{\sigma} = \left[\sum_{i=1}^{N}\frac{(y_i-\mu(y))^2}{N-1}\right]^{1/2} \qquad (6)$$

Where y is the output, μ the expected average value of y, i the sample and N is the number of samples.

The standardized regression coefficients (SRC) were applied to determine the sensitivity of primary energy demand (PED). As was observed by Breesch in Reference [20], when the input parameters x_j are independent, the SRC provide a measure of variable importance since SRC measures the effect of the variation of an input parameter x_j with a fixed fraction of its standard deviation on the variation of the output Y, while all other input parameters equalize their expected value. Regression techniques allow the evaluation of sensitivity of individual model inputs, taking into account the simultaneous impact of other model inputs on the result.

In this study, a factorial analysis I^k, i.e. 2^2, with 2 factors at two levels (low and high) was carried out. An experimental design consisting of the combinations of parameters which were varied in the levels at which they were set was conducted. In addition the factorial experiment allows for estimation of experimental error since the variability on the response variable as a result of all possible combinations of these levels across all such factors can be analyzed. The outcomes of the uncertainty analysis can be found in Table 2. Consequently, for each operation conditions (cases) the SRCs were applied to determine the sensitivity of Primary energy demand and consequently the influence in the total annual operation cost of the thermal system.

The statistical model upon which the analysis of screening designs is based expresses the response variable $\hat{y}_i$ as a linear function of: the experimental factors, interactions between the factors, and an error term, which can be expressed as:

$$\hat{y}_i = b_0 + \sum_{i=1}^{k} b_i x_i + \varepsilon \qquad (7)$$

The experimental error ε is typically assumed to follow a normal distribution with a mean of 0 and a standard deviation equal to σ.

As was reported in [21], all the input parameters in a building simulation can be assumed to be normally distributed. The levels selected for each parameter correspond to [μ-2σ; μ+2σ], where μ and σ are respectively the average and the standard deviation. This means a parameters is included in this interval with a probability of 0.98. Distribution on the input parameters has been estimated from data in the literature and standard. The uncertainty on the CO_2 concentrations in the control system is assumed the average accuracy of the CO_2 concentration logger, used in the monitoring of the building management system [22]. A variation of 5% for the CO_2 concentration set point is assumed.

Additionally, the airflow through an envelope opening is derived from the relationship between the pressure and the velocity along a streamline, i.e. Bernoulli equation written as the orifice equation. It should be noticed that, in this expression, the discharge coefficient play an important role. A compressive analysis of the characteristics of night ventilation opening can be found in Reference [20]. Flourentzou et. al, measured the discharge coefficient in a real naturally ventilated office building and concluded a discharge coefficient of 0.6 ± 0.1 [23]. The uncertainty value of 0.1 represents 16 % of variation with respect to the average value of 0.6 for a sharp-edged opening. Consequently in this study a variation of 16 % for the opening is assumed.

Commonly, in order to simplify the interpretation of screening designs, the model is expressed in terms of "effects". For the response surface designs the "Pareto Charts" displays each of the estimated effects in decreasing order of magnitude.

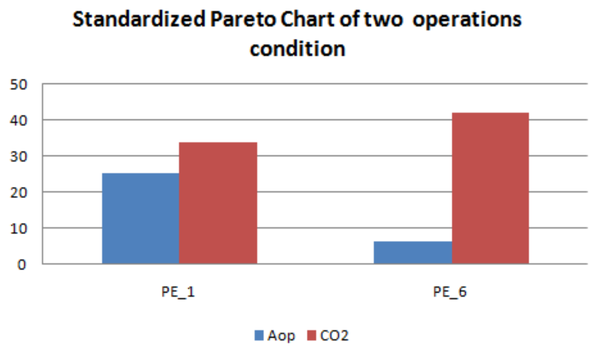


Figure 15. Estimated effects of two operations condition

Figure 15 displays the estimated effects for two different operations condition, (PE_1: Opening of 20%, 800 ppm CO_2 and PE_6: Opening of 5%, 1000 ppm CO_2). The length of each bar is proportional to the standardized effect, which is the estimated effect divided by its standard error. It can be seen that when a small value of fresh air opening is used, the effect of the CO_2 concentration set point has more statistical significance.

CONCLUSION

An improvement measurement focused in the free cooling system, consisting on the reduction of the use of fresh air in order to decrease the heating and cooling consumption was presented. The fresh air valve opening was changed and a CO_2 concentration control was aided. The results of a simulation run with 5% of the fresh air valve opening and a CO_2 control with a set point of 1000 ppm shows a reduction of more than 50 % of energy consumption. Significant benefits resulted when applying the proposed improvement measurement since the total annual cost of the primary energy demand is reduced from 17257 € till 8373 €.

Additionally the influence of the double skin façade in the ventilation gain of the building was analyzed. The result show that the building primary energy consumption without the double skin façade operating would rice up to 812 MWh in a year base. In contrast, as a result of the double skin façade operation the building primary energy consumption is only 566 MWh in a year base. The previous value represents a 30 % of reduction of the primary energy consumption. The results highlight the significance of the use of the double skin façade in the primary energy consumption of the thermal system.

The present paper demonstrated the high potential of dynamic thermal simulation and building energy management system analysis for calibrating and determining energy efficiency improvement. As well as, how important can be regulation improvement on thermal systems in terms of annual energy savings and, as a consequence, of pollutant and CO_2 emission reduction.

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