DECISION SUPPORT SYSTEM FOR DISTRIBUTED ENERGY RESOURCES AND EFFICIENT UTILISATION OF ENERGY IN BUILDINGS

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ABSTRACT

Deregulation of energy sectors provides challenges and opportunities alike for operators of public buildings. Exposure to energy prices and CO_2 emissions restrictions create incentives to adopt more energy-efficient technologies. Yet, market and technological uncertainties necessitate decision support for risk management. We present a decision support system (DSS) being developed for integrated management of energy efficient buildings. This tool intends to provide decision support for building operators to help them meet their needs in a more efficient, less costly, and less CO_2 intensive manner.

This paper gives an overview of the strategic DSS module and focuses how the operation DSS module has been conceived starting from mathematical formulation and ending with a validation exercise in a laboratory building.

INTRODUCTION

In Europe, buildings account for 40% of the overall energy consumption in the European Union and 36% of the CO_2 emissions [1]. Buildings have, on one hand, various types of uses and occupancies, e.g. residential, commercial, tertiary or industrial, and, on the other hand, a variety of energy infrastructures, types of electrical and thermal generators and storage devices and final emitters. These infrastructures are designed to meet the building energy demand: e.g., heating, cooling, ventilation, small power, lighting, and other loads linked with the process developed in the building.

From an energy management point of view, different stakeholders take decisions during the life cycle of a building. The building manager is responsible for the investment decisions on new infrastructures within the building and may also choose among different types of energy supply contracts. The building services operator is the person responsible for operating the building's infrastructure. In this paper, a DSS (Decision Support System) is presented. This tool will integrate interdisciplinary knowledge based on the state-of-the-art for managers and/or operators of public buildings by providing management of conflicting goals such as cost minimisation, meeting energy efficiency and CO_2 emission reduction requirements as well as risk management. The proposed DSS will enable these stakeholders to improve building energy efficiency in the most cost-effective manner based on their tolerance for comfort and risk.

DECISION SUPPORT SYSTEM (DSS)

The DSS tool is composed of two modules (Strategic and Operational) that can be run on its own. The DSS strategic module is based on a set of high-level operational constraints, and the DSS operational module is based on a given set of installed technologies. They can also be run together by using the operational module for load and operation scenarios generation, giving a set of scenarios, and then analysing the best long-term decision with the strategic module. Preliminary results for test sites indicate that energy consumption might be reduced by 10% as a result of the operational optimisation.

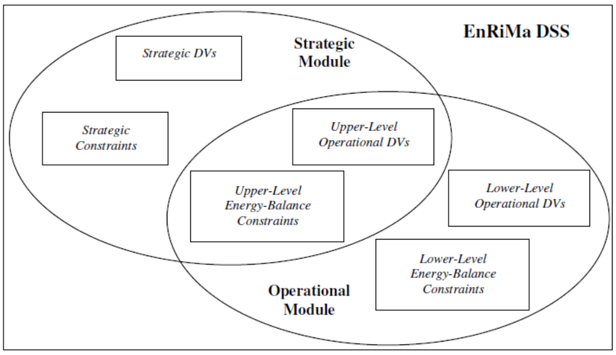

Figure 1 DSS operational and strategic modules´ interaction.

Nomenclature

t : Short-term time period index

Δt : Length of operational decisions-making period (s)

$ZoneTemp_t$: Zone temperature (°C)

$SATemp_t$: Supply air temperature (°C)

$f_{t,a}$: Supply air flow rate (m^3/s)

$ExtTemp_t$: External temperature (°C)

ρ_a : Air density (kg/m^3).

ρ_w : Water density (kg/m^3).

C_a : Specific air capacity (kJ/kgK)

C_w : Specific water capacity (kJ/kgK)

V_z : Volume of the zone (m^3)

G_w : Wall thickness (m)

U_w : Thermal conductivity of the wall (W/m.K)

A_w : Area of Wall (m^2)

$SolarGain_{t-1}$: Solar gain (kW).

$IntLoad_{t-1}$: Internal load (kW).

$D3$: Factor that takes in account air infiltration and other factors such as measurement error.

$\Delta\upsilon_t$: Mean logarithmic temperature difference according to DIN EN 442 1 (°C).

n : Parameter of radiator characteristics (unitless).

ξ : Mean nominal heat transfer capacity of radiators (kW)

$\%$: Proportion of external air(unitless).

$LowLimitTemp$: Lower limit of the required zone temperature (°C).

$HighLimitTemp$: Upper limit of the required zone temperature (°C).

S_wTemp : Supply water temperature (°C).

R_wTemp : return water temperature (°C).

$f_{t,w}$: Water flow rate in radiators (m^3/s).

D_trad : Heat output from radiator (kW)

D_t : Boiler heat demand (kW)

$CP_{t,NG,RTG}$: Energy price of natural gas (€/kWh)

η_{boiler} : Boiler thermal efficiency (unitless)

The DSS will be linked with the existing ICT to control each site's energy sub-systems, thereby facilitating the operators' short-term operational problem, which means real-time on-site generation dispatch, off-site energy purchases from different energy sources, and open positions in energy markets. The DSS will also enable long-term strategic planning to the building manager aiming at the improvement of energy efficiency, in particular the analysis of refurbishments of on-site energy systems as requirement of the forthcoming EU CO_2 emissions reduction targets.

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DSS OPERATIONAL MODULE

Currently the DSS (Decision Support System) operational module being developed is focused on a tool for the optimal operation of building HVAC systems.
The output of this tool is a set of room set point temperatures for a given time interval of our choice.
This tool has been developed for buildings with a HVAC system based on water to air, air to air or conventional radiators systems only. It is limited to HVAC systems with a centralized control via BEMS (Building Energy Management System). This enables the automatisation of a room set point temperature schedule. The main HVAC parameters must be monitored and stored by the BEMS.

The following figure shows the main HVAC loads, heat exchanges between the room and the surrounding environment as well as the different HVAC equipment that are taken into account.

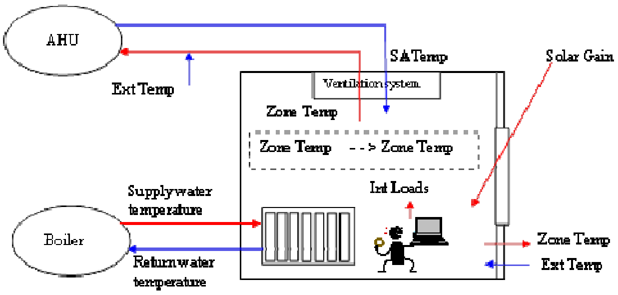

Figure 2 Typical energy loads, heat exchanges and HVAC equipment

The operational module consists of three levels of equations that determine the behavior of a HVAC system.
Firstly, an equation that determines the evolution of the zone temperature (level 1), which depends on external ambient conditions (temperature, irradiation, etc.), the building fabric and its heat gains or losses and the temperature and flow rate of the supplied air.

Secondly, the equations that describe the regulation and control of the HVAC system (level 2), for instance, how to determine the AHU supply air flow and temperature for a given room set point temperature.

Finally, equations that calculate the thermal energy supplied (level 3) by each of the heating or cooling generators (boilers, heat pumps…) and final elements (fan coil units, radiators…)

The equations used in the operational module have been extracted from published papers [3] for HVAC systems based on water to air systems and [4] for conventional radiators systems.

UCL (University College London), CET (Center for Energy and Innovative Technologies) and Tecnalia R&I have defined the equations behind the operational module, which are being tested in a laboratory test facility (KUBIK [5]) and in two real buildings, Pinkafeld, a campus office building in Burgenland (Austria) and FASAD, a community center in Asturias (Spain).

Calibration of the operational module

The first example presents the results of a calibration exercise carried out with real data obtained from KUBIK test facility.

The aim of this exercise is to determine the error (D3) obtained by the model when estimating the zone temperature described in the previous section as level 1

$$ZoneTemp_t = \frac{\left(\begin{array}{l} f_{t,a} \cdot \rho \cdot C_a \cdot SATemp_t + \frac{U_w \cdot A_w}{G_w} \cdot ExtTemp_{t-1} + \frac{C_z \cdot \rho_a \cdot V_z}{\Delta t} \cdot ZoneTemp_{t-1} \\ + D_t rad + SolarGain_{t-1} + IntLoad_{t-1} \end{array} \right)}{f_{t,a} \cdot \rho \cdot C_a + \frac{U_w \cdot A_w}{G_w} + \frac{C_z \cdot \rho_a \cdot V_z}{\Delta t}} + D3$$

Equation (1)

Several scenarios were reproduced in KUBIK. However, for the purpose of the exercise of calibrating level 1 equation (1 **Equation** (1)), only the scenario with no HVAC has been analysed.

The exercise consisted on testing the equation with data obtained from the BEMS ($ZoneTemp_t$, $SATemp_t$, $f_{t,a}$ and $ExtTemp_t$) and other parameters such as $C_a, \rho_a, V_z, G_w, U_w, A_w$ which are constants or building characteristics. Since there is no occupation and all lighting has been turned off during the tests, there are no internal gains. The solar gain term is included in D3 and obtained from multilinear regression analysis.

(1)**¡Error! No se encuentra el origen de la referencia.** Becomes (2) for the scenarios with no HVAC:

$$ZoneTemp_t = \frac{\left(\frac{U_w \cdot A_w}{G_w} \cdot ExtTemp_{t-1} + \frac{C_z \cdot \rho_a \cdot V_z}{\Delta t} \cdot ZoneTemp_{t-1} \right)}{\frac{U_w \cdot A_w}{G_w} + \frac{C_z \cdot \rho_a \cdot V_z}{\Delta t}} + D3'$$

Equation (2)

The main conclusion extracted from this exercise is that the zone temperature cannot be estimated just with (2). D3´ varies from 5ºC until 15ºC, and it cannot be considered an offset. D3´is reduced during daytime, this means that irradiation plays an important role and it cannot be neglected. Therefore a different approach needs to be taken in order to match the zone temperature.

Then, multilinear regression analysis is applied to D3´as a function of external temperature and irradiation.

Figure 3 shows the external temperature (blue), irradiation (red) and actual zone temperature (purple) during the test days. The tests were run from 17/11/2012(7pm) to 19/11/2012(6pm) and 25/11/2012(7pm) to 27/11/2012(6pm).

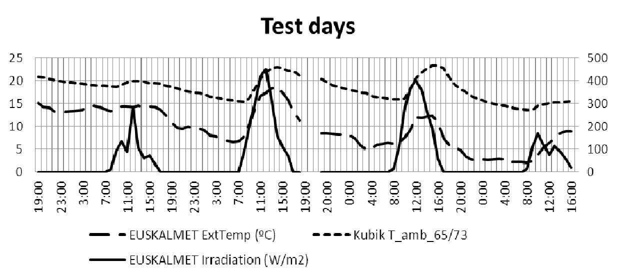

Figure 3 External temperature, Irradiation and actual zone temperature during test days.

The two first test days are used to estimate the regression coefficients. The other two test days have been used to estimate whether the regression analysis can be used to estimate the zone temperature.

Figure 4 shows the estimated zone temperature (purple), the actual zone temperature and the error. The estimated zone temperature adjusts better to the actual zone temperature. D3´seems flatter than in the previous analysis and shows a value under 5ºC.

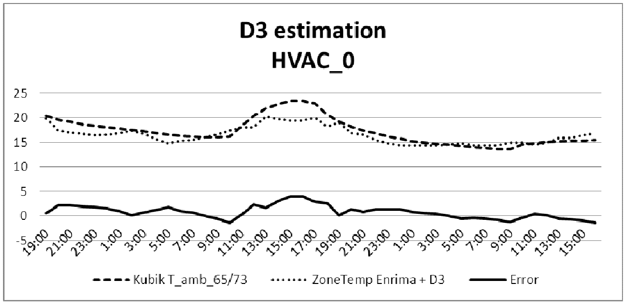

Figure 4 Zone temperature estimated by Equation and multilinear regression analysis (two test days)

The regression analysis shows a multilinear correlation coefficient of 0.83, and Student's t-distribution values between 5 and 20.

Potential energy savings

The exercise carried out for a simulated building (recreation of FASAD building located in el Siero, near Oviedo, Asturias) is based on a simple prototype using a Matlab optimization solver. The model has been developed for a conventional radiator system and HVAC.

The equations implemented in addition to (1) are the following:

$$SATemp_t = \%ExtTemp_{t-1} + \frac{(100 - \%)}{100} ZoneTemp_{t-1}$$

Equation (3)

$$LowLimitTe\,mp \le ZoneTemp_t \le HighLimitT\,emp$$

Equation (4)

$$D_t rad = \xi\,\Delta t \left(\frac{S_w Temp - R_w Temp_t}{\ln\left(\dfrac{S_w Temp - ZoneTemp_t}{R_w Temp_t - ZoneTemp_t}\right)} \cdot \frac{1}{\Delta \upsilon_t} \right)^n$$

Equation (5)

$$D_t rad = \Delta t \cdot \mathrm{f}_{\mathrm{t,w}} \cdot \mathrm{C}_{\mathrm{w}}\ (S_w Temp - R_w Temp_t)$$

Equation (6)

$$D_t = \Delta t \cdot \mathrm{f}_{\mathrm{t,w}} \cdot \mathrm{C}_{\mathrm{w}}\ (S_w Temp - R_w Temp_{t-1})$$

Equation (7)

(3) Models the supply air temperature in a mechanical ventilation system. (4), established the upper and lower limits of the room set point temperatures, (5) and (6) model the radiators energy demand and (7) models the boiler energy demand.

Based on these equations, an optimization function is developed in order to minimize the energy bill.

$$\min \sum_{\mathrm{t} \in \mathrm{To}} CP_{t,NG,RTG} \cdot D_t \cdot \eta_{boiler}$$

Equation (8)

The particular simulated building fabric and HVAC parameters have been used for this exercise.

Three scenarios were analysed. Figure 5 shows the results for the third scenario.
Scenario A contemplates a scenario where no optimization exercise has been done. Therefore, room set point temperature remain constant: 23,5ºC during working hours and 20,5ºC during non-working hours.

Scenario B, similarly to scenario A, no optimization has been done and room set point temperatures remain constant: 22ºC during working hours and 19ºC during non-working hours.

Scenario C is a scenario where as a result of the optimization exercise the room set point temperature is dynamic.

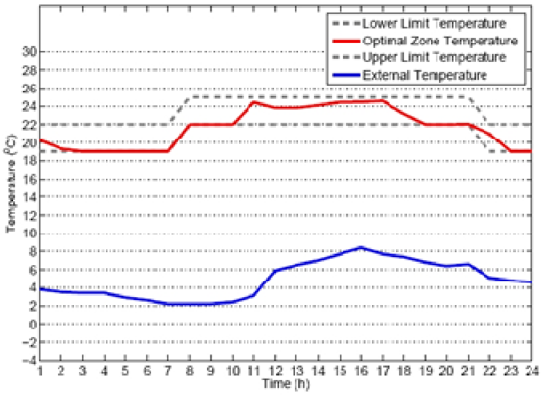

Figure 5 Dynamic room set point temperatures for FASAD exercise.

The analysis of the results show that scenario C saves 22% and 2 % of the energy consumption when compared with scenarios A and B respectively. The total daily gas consumption in scenario C is 544kWh.

CONCLUSIONS

An overview of the DSS operational and strategic modules has been presented.

The level 1 equation behind the operation module has been described and the calibration exercise based on empirical data has been presented for a scenario with no HVAC.

The accurate estimation of zone temperature is a fundamental key of the DSS operational module in order to calculate the optimal next day room set point temperatures.

The further steps in relation with this are the calibrations of other scenarios which include constant air supply temperature and variable air supply temperature scenarios.

Additional, the potential savings achieved with the DSS operational module have been presented.

REFERENCES

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[2] http://www.enrima-project.eu/

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