Demand Side Management in Smart Buildings Using KNX/EIB

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Abstract. This paper aims to present the development, design and analysis of a control scheme named Thermal Model Predictive Control for Demand Side Management Cooling Strategies. The control is implemented on a building in Athens whose thermal model is derived using the Finite Difference Calculation Method. The development and testing of the thermal model is implemented on-line while the predictive controller for cooling strategies is analysed through simulation results. The advantages of the scheme are described, including the ability of the predictive controller to consult the users for energy and cost savings during the peak demand, in an acceptable way by them regarding the thermal comfort issue. Smart Grids and Smart Microgrids can communicate with this controller for increasing their efficiency.

Keywords: Demand Side Management, SCADA, Smart Buildings, KNX/EIB.

1 Introduction

Demand Side Management (DSM) is a measure taken by electric utilities to influence the amount or timing of customers' energy demand, in order to utilize scarce electric supply resources more efficiently. According to IEA Demand Side Management working group, the term "demand response" refers to a set of strategies which can be used in competitive electricity markets to increase the participation of the demand side in setting prices and clearing the market [1]. The net effect of the demand response is to ease system constraints and to generate security and economic benefits for the market as a whole. As far as the thermal comfort is concerned in order to reach the desired indoor temperature and humidity, the heating/cooling demand should be regulated thus satisfying a DSM strategy. In the framework of this paper "Thermal Model Predictive Controller" is developed implementing super cooling strategies, through which a building or a building part is pre-cooled during low peak periods achieving peak shaving in an acceptable way by the users regarding the thermal comfort issue during summer.

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2 Buildings Description

DSM strategies have been considered in several buildings in Athens and in Kassel. A building in Athens, Greece, has been chosen for implementing the Thermal Model Predictive Controller for DSM actions. It is called Georgiadis building, it is named after its owner, it is located in Gerakas city and the KNX/EIB technology has been installed in it, where EIB stands for European Installation Bus. A DVD Club is situated at the basement of the building. Furthermore, a bookshop and a shop which sells desalination plants are situated in the ground floor. Finally, an apartment with an attic is in the first floor. The bookshop has been chosen as the place to accommodate the experiments of this paper due to the owner‟s special interest to save energy in this building part. The Georgiadis building is depicted in the following Figure 1, where the DSM strategies have been considered.

Fig. 1. Georgiadis Building in Gerakas of Athens in Greece

The Thermal Model Predictive Controller is developed on a PC at the first stage. This development requires a communication system in order to acquire all the needed data and measurements from the building and to process them in on-line mode. The controller should be economically attractive and for this reason the following requirements have to be defined:

- Only existing on the market system components are applied; no special designs and developments.
- Basis for the design is a „normal" building part (bookshop) and no any „super installation". Research results should be able to be transferred economically into a product.

These requirements are achieved by concatenation of different networks that exist in modern buildings (Figure 2) [2]. However, today they exist in parallel without any concatenation among each other.

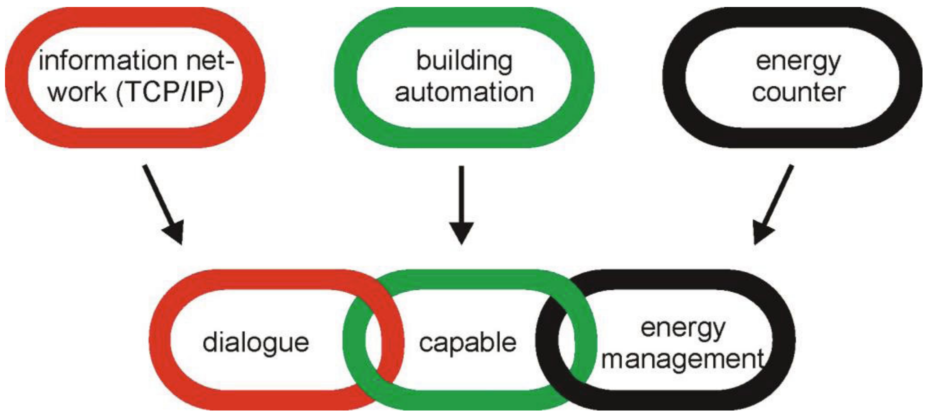

Fig. 2. Chain of different networks to obtain Thermal Model Predictive Controller

The realization of the communication process between the Thermal Model Predictive Controller, the building and the user are very important for the acceptance on behalf of the latter and the function of the system. Especially, the remote monitoring and control through Intranet even more via Internet is one of the goals of this thesis. At this point, we should take into consideration the fact that almost all building users have access to a PC that is linked to an Intranet or the Internet which consists of an ideal communication interface for building automation, as well. Therefore, building automation is linked to the information network TCP/IP. Here the building automation is based on KNX/EIB technology, where EIB stands for European Installation Bus.

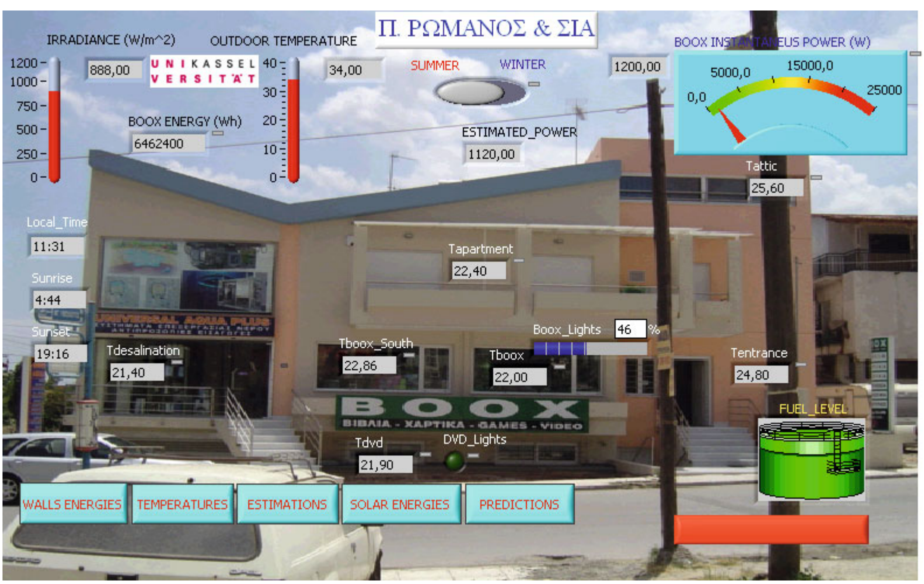

Fig. 3. The SCADA main window page

The following Figure 3 depicts the main window of the SCADA, where all indoor and ambient temperatures are monitored as well as the energy consumption and the power of the bookshop. The local time and the solar irradiance on a horizontal surface are also presented on it. With the option “WALLS ENERGIES”, Inflow, Outflow and Stored Energies of the bookshop are viewed, while the predicted indoor temperature and the measured temperature of the bookshop are shown when the “PREDICTIONS” key is chosen.

The absorbed solar radiation by the surface of the outer north wall and the windows, which are also located to the north and by the roof part made of glass are depicted when the tab “SOLAR ENERGIES” is pressed, while the estimated instantaneous power and the measured one are shown by choosing “ESTIMATIONS”. Finally, a graphical view of all temperatures is presented by pressing “TEMPERATURES”.

3 Concept

The aim of a DSM strategy is the reduction of the peak demand. Taking into account the fact that the peak demand is mainly caused by the operation of air-conditioning units during summer, the DSM cooling strategy intends to reduce the consumption of these units during the peak periods. However, this reduction should not be against the thermal comfort. This means that the indoor temperature and the humidity should not be increased more than a specified limit, so that the users still feel comfortable in it. The Thermal Model Predictive Controller is based on the Thermal Model, which is used for the prediction of the indoor temperature during pre-cooling and DSM phases. In addition, it calculates the heat fluxes of the walls and the Inflow, Outflow and Stored energies of the examined room. The Thermal Model plays a significant role in order to define the duration of the pre-cooling phase. The pre-cooling period is independent from the indoor temperature reduction [2].

The TMPC-DSM controller operates in three phases every day. The period in which the TMPC-DSM controller pre-cools a room is called Pre-cooling period or Pre- cooling phase, while the period in which the TMPC-DSM controller acts to air- conditioning units during the peak demand is called DSM phase. Moreover, the period in which the TMPC-DSM controller does not operate or act to air-conditioning units and only receives information from the Power Predictor is called Inactive phase. The TMPC-DSM controller can communicate with the operator of a Smart Grid or a Smart Microgrid for maximizing end-use efficiency.

4 Absorbed Solar Radiation

An Anisotropic Solar Radiation diffuse model based on the Hay-Davies-Klucher- Riendl (HDKR) model is applied to the bookshop of the examined building [3]. The HDKR model estimates the absorbed beam, diffuse and ground reflected solar radiation by the surface of the outer wall, the windows and a part of the roof of the bookshop, which is made by glass. The following Figure 4 depicts the measured Solar Incident Radiation on a horizontal surface by the ISET-Sensor–monocrystalline pyranometer and the absorbed radiation by the surface of the northern wall, the windows and the roof glazing in the bookshop from 18/9/2005 until 25/9/2005.

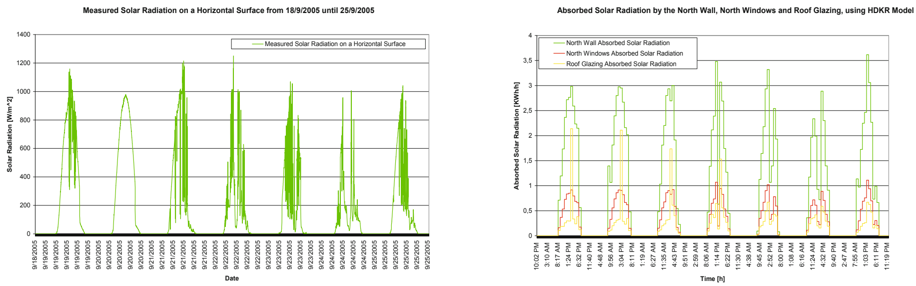

Fig. 4. Measured Solar Radiation on a Horizontal Surface (left) and the absorbed radiation by the surface of the northern wall, the windows and the roof glazing in the bookshop (right) from 18/9/2005 until 25/9/2005

5 Thermal Model

The Dynamic Thermal Model of the Bookshop is developed based on the Finite Difference Calculation (FDC) Method [4]. Inflow Energy is considered to be the energy resulting from the heat flux due to the difference between the indoor temperature and the surface temperature of the inner wall. The internal heat sources with the rates of heat transfer from the air-conditioning units leave the shop, interact to the indoor and inner surfaces temperatures and are therefore assumed as Inflow Energies.

Respectively, Outflow Energy is the thermal energy due to the difference between the surface temperature of the outer wall and the ambient temperature. The solar radiation is applied onto the surface of the outer northern wall part and is also considered as Outflow Energy.

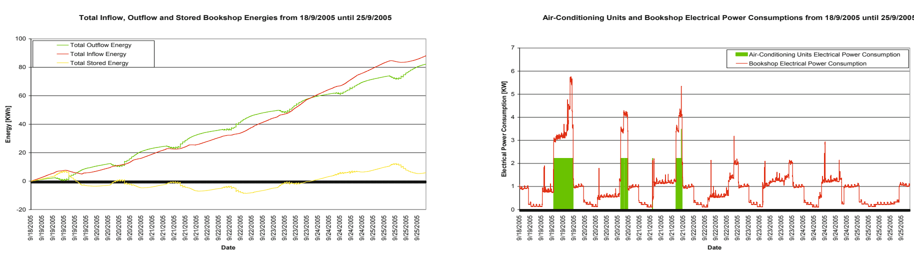

Fig. 5. Total Inflow, Outflow and Stored Energies of the Bookshop (left) with the electrical power consumption of the air-conditioning units in comparison with the bookshop electrical power consumption (right) from 18/9/2005 until 25/9/2005

The Total Inflow, Outflow and Stored Energies of the Bookshop with the electrical power consumption of the air-conditioning units in comparison with the bookshop electrical power consumption are depicted in Figure 5. Figure 5 verifies the fact that the thermal model is based on the energy balance equation. Obviously, the peak demand is mainly caused by the operation of the air-conditioning units during summer, it occurs at 19:00 and its duration is 2 hours, which is the prediction horizon of the DSM phase.

6 Analysis

The pre-cooling period is 26 minutes at maximum [2]. Therefore, the prediction horizon of the pre-cooling phase is also 26 minutes and is reduced by 47 seconds at every sample. The maximum desired predicted indoor temperature is defined to Tin_max = 27^{O}C. Figure 6 depicts the predicted indoor temperatures, using the TMPC-DSM controller, during the Pre-cooling and DSM phases in comparison with the predicted and measured indoor temperatures on 19th, 20th and 21st September 2005. Three different cases are investigated respectively these days, when the bookshop is opened during afternoon. The predicted indoor temperatures are obtained by using the Finite Difference Calculation Method.

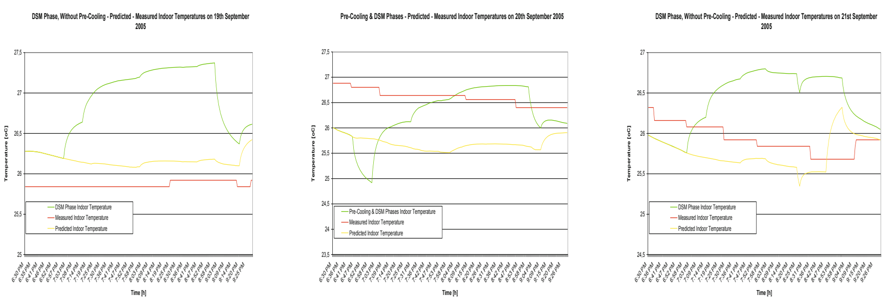

Fig. 6. Predicted indoor temperature during the Pre-cooling and DSM phases in comparison with the predicted and measured indoor temperatures on 19th (left), 20th (center) and 21st (right) September 2005

More specifically, Figure 6 (left) illustrates that the SCADA suggests the user to accept the indoor temperature which reaches 27,5^{O}C on 19th September. The SCADA informs the user that if the indoor temperature is decreased to 27^{O}C during the peak demand for that day, then an additional electric energy consumption of 1,67 KWh will occur. That will cost him €0,12 due to the increased operation of the air- conditioning units during the Pre-cooling and DSM phases. It is assumed that the user accepts this increase of the indoor temperature in our simulation results. If he does not accept it, the Thermal Model Predictive Controller

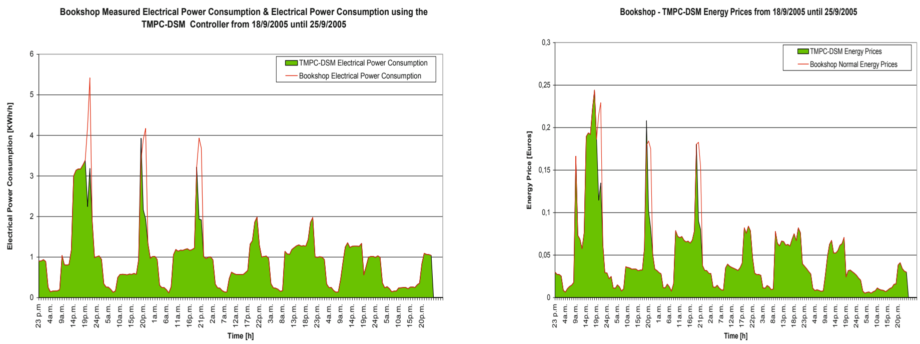

Fig. 7. Measured and prices of electrical power consumption of the bookshop in comparison with that from applying the DSM cooling strategy

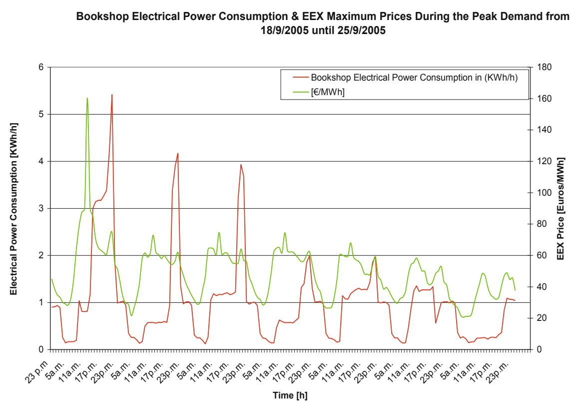

Fig. 8. Measured electrical power consumption of the bookshop and EEX prices where the maximum ones occur during the peak demand

will be deactivated and the indoor temperature will be regulated by the KNX/EIB thermostat. In this case, the SCADA will inform him about the economic benefits from applying the DSM cooling strategy.

Furthermore, according to the indoor temperature prediction during the peak period, the Pre-cooling Phase is needed only on 20th September as it is shown in Figure 6 (center). Both, the Pre-cooling and DSM optimization algorithms are applied for that day. Finally, Figure 6 (right) depicts that the predicted indoor temperature reaches 27^{o}C on 21st September during the DSM phase and without the use of the Pre-cooling phase. Only the DSM optimization algorithm is applied for this day.

The analysis of Figure 7 shows that the electric energy consumption of the bookshop is 93.180 Wh with €4,94 cost from 18/9/2005 until 25/9/2005. By applying the DSM Cooling Strategy, the energy consumption is reduced to 81.810 Wh with €4,43 cost for the same period. Therefore, energy savings of 12,21% with cost savings of

10,28% are achieved by applying the DSM cooling strategy using the TMPC-DSM controller. In the case where the maximum EEX prices occur during the peak demand as it is shown in Figure 8, the following Figure 9 depicts the cost profile of the energy consumption of the bookshop with the maximum prices duri ng the electric peak demand and the prices which will be derived if the DSM cooling strategy is applied from 18/9/2005 until 25/9/2005 [5]. In this case the energy savings are the same as in Figure 7; however, the cost of energy is reduced from €5,67 to €4,93 by using the TMPC-DSM controller; attaining cost savings of 13,03%.

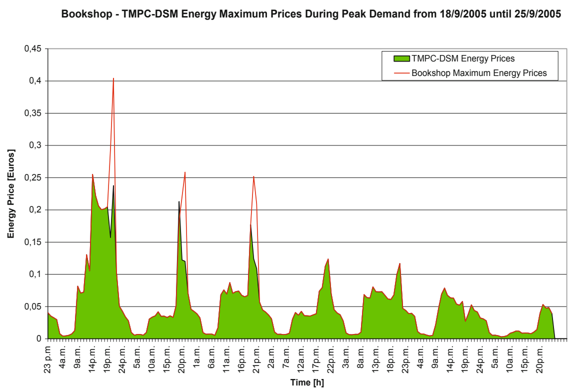

Fig. 9. Cost profile of the measured electric energy consumption of the bookshop with the maximum prices during the peak demand and the prices which will be derived if the DSM cooling strategy is applied from 18/9/2005 until 25/9/2005

Table1 illustrates the total with the daily energy and cost savings, by the application of the TMPC-DSM controller.

Table 1. Total and daily energy and cost savings using the TMPC-DSM controller

Date	Without TMPC-DSM (KWh)	TMPC-DSM (KWh)	Energy Savings (%)	Without TMPC-DSM (€)	TMPC-DSM (€)	Cost Savings (%)
19/9/2005	40,2	36	10,44	2,75	2,45	11,05
20/9/2005	24,14	20,73	14,14	1,29	1,09	15,96
21/9/2005	28,84	25,08	13,05	1,63	1,4	14,05
Total	93,18	81,81	12,21	5,67	4,93	13,03

7 Conclusions

A simplified thermal model based on FDC, assuming that there is one-dimensional conduction in x, can describe adequately the dynamics of the system. The application of Thermal Model Predictive Control for Demand Side Management Cooling Strategies proves that energy saving of 12% is feasible. The cost savings by using the TMPC-DSM controller depend on the prices of the energy during the peak periods. It is concluded that cost savings about 13% can be achieved. Smart Grids and Microgrids can communicate with the controller for increasing their efficiency.

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