Proactive Management for Smart Buildings
Resource Management Strategy

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Abstract: Self-sustainability and near-zero energy consumption have already become common requirements for construction of new buildings. Apart from the existing traditional ways for improving building energy efficiency like introducing novel architectural solutions or new building materials, the role of energy management has been increasingly seen as pivotal. Nowadays buildings rely on their management systems to provide optimised energy supply solutions and meet their energy demand targets from on-site generation and storage installations. In this paper the latest developments in proactive approach in management of building resources will be presented and critically compared to the existing electrical energy efficiency methods based on reactive type of control. Simulation and cost/benefit results are used to demonstrate the performance improvements achieved by deploying the proactive management system.

1 INTRODUCTION

The term "Smart Buildings" normally refers to various control techniques used for integration of renewable energy sources to buildings, energy efficiency improvement, reduction of greenhouse emissions and application of demand side management. The results of various studies on incorporation of renewable energy technologies into buildings reveal in many cases lack of a holistic approach to investigation and optimisation of small energy supply systems. The main drawbacks are identified as an absence of analysis of end-use energy demand, lack of pre-definition of energy system structure in initial phases of building design and finally not taking advantage of more sensitive, proactive energy management schemes.

Once the energy supply mix has been determined, further advances can be achieved through resource management (Téllez, 2011), (Prodanovic, 2012). What most of the existing building energy management systems (BEMS) (ABB, 2010), (Vikon, 2009) have in common is their reactive nature of control as they mostly attempt to react on an unexpected event in order to accomplish actions to rectify the situation. Although these technologies may lead to construction of more "ecologically friendly" buildings, novel BEMS should not be limited to energy conservation measures only, but also to look for any proactive ways to improve energy performance and potentially achieve self-sustainability. Yet, recent advances in energy storage technologies, demand side management techniques, on-site CHPs, intelligent appliances along with development of sensor networks and information technology suggest that near real-time optimal dispatch of all installed resources is possible (Doukas, 2007) and (Gupta,2010).

New hierarchical methods for proactive management of multiple energy sources to meet total energy demand of a small, local scale energy system are being under investigation (Brooks, 2010). In order to propose and develop management systems capable of taking strategic decisions, all the relevant control aspects need to be considered such as prediction, scheduling and real-time control for generation and demand resources installed (including demand side management and demand dispatch). Energy storage devices and energy exchange with electricity grid play an important role in these new schemes as they add more options in management of installed energy sources by accommodating for their different dynamic properties and by compensating for any supply or demand uncertainties. To further improve the real-time energy balance, shorter intervals for the overall optimisation so that the system is in position to

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proactively manage any various dynamic uncertainties of renewable energy sources (RES, like solar radiation, wind speed), demand profiles, prices, efficiency of energy conversion subsystems etc.

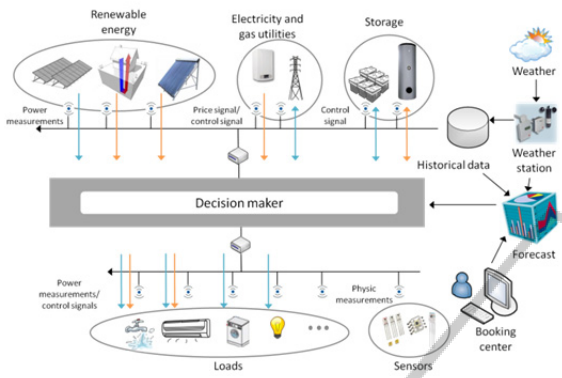


Figure 1: Building management system.

In this paper the results of the ongoing research aimed to achieve additional cost savings and performance improvements in the building resource management will be presented. The flexibility of both demand and generation will be discussed and a hierarchical control structure for prediction based proactive management will be discussed. The simulation results are used to demonstrate the system performance and assess the cost benefits of the proposed scheme.

2 ENERGY DEMAND

In order to create a representative energy demand profile for a building that can be used for demand prediction and energy management, it is necessary to consider all the specific functional details and services available. User profiling is one of the most important aspects that can be linked directly with the demand. The building occupancy and external ambient data are some of the crucial aspects. Figure 2 shows a daily profile of the hotel occupancy indicating when the clients are inside the building and when they are active. This information directly relates to the way the services are used.

In Figure 3 an aggregated daily demand profile is depicted for a hotel. The main contributors to the energy demand can be easily identified: laundry, restaurant food preparation, HVAC etc.

What is relevant for the management system is to determine what loads may be shifted in time or trimmed in power. In this way some additional load flexibility can be obtained and used for demand prediction and system optimisation.

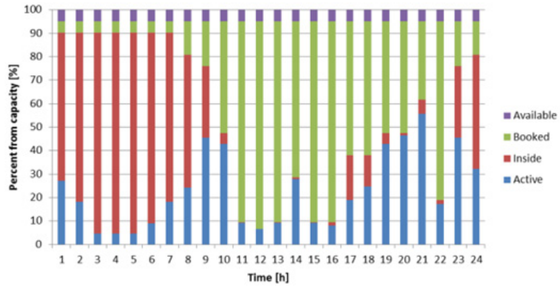


Figure 2: Guest behaviour daily profile.

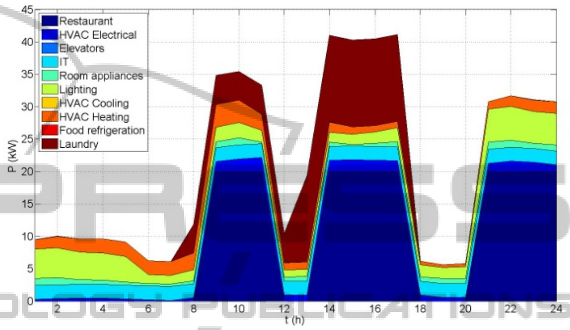


Figure 3: Aggregated profile of daily demand in summer.

3 ENERGY RESOURCES

In the past most of the buildings depended solely on the electricity grid and on-site diesel generation to provide for their energy needs. In recent years there is a significant effort to introduce concepts of energy self-sufficiency and near zero consumption in the building sector. To achieve that, more conventional and RES have been integrated to buildings.

The creation of the generation mix including the energy storage devices is a tecno-economic exercise and several references (Téllez, 2011), (Todorovic, 2011) deal with this issue. Just as an example, different energy system configurations have been compared in Figure 4 for their cost savings, self-consumption and self-sufficiency when a special “super off-peak” tariff is used (favouring nocturnal energy use and having three pricing periods).

Once the battery system is installed there are many more options for proactive energy management and cost savings. Just charging the batteries during the low pricing periods can account to about 10% of savings. Yet, the batteries provide more flexibility and can improve energy capture from intermittent resources so that the locally generated energy is neither exported (at lower prices) nor left unused.

What is relevant from the management point of view is to determine the main control parameters of the installed resources. In this way it is important to identify what resources are dispatchable, what resources are introducing the uncertainty to the system, dynamic properties etc.

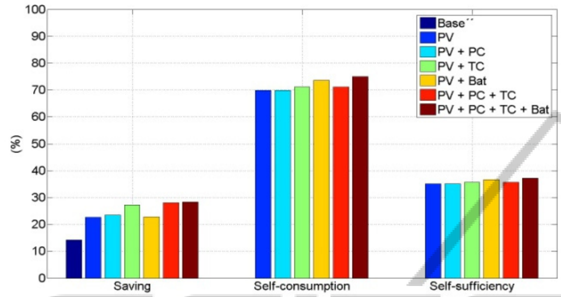


Figure 4: Cost savings, self-consumption and self-sufficiency for different generation configurations.

4 PROACTIVE MANAGEMENT

In contrast to the most of energy efficiency methods used in the building sector to achieve energy and operational cost savings (based on predefined resource scheduling and reactive actions), the proactive management uses historical and real-time data to predict the demand and then optimise in advance the commitment of all installed system resources.

4.1 Control Steps

In order to integrate a mix of diverse technologies, the dynamic properties of the installed equipment and control processes need to be taken into account. It is, therefore, important to adopt a hierarchical management structure that is the most suitable for the respective response times required. Figure 5 depicts the necessary levels for successful application of the proactive management.

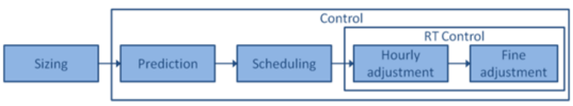


Figure 5: Hierarchical structure of management system.

In the first step (Prediction), the short-term weather forecast, user behaviour predictions, external factors, historical data and system ratings are all used to obtain one-hour estimates of the RES supply and the consumption patterns for the following day. This prediction step can be updated up to one-hour ahead to improve the accuracy of control.

An optimal plan for each hour is calculated in the next step (Scheduling) where the set-points of controllable sources are adjusted to meet the expected demand according to the RES profiles, cost, DSM and storage strategies aforementioned.

The role of the next steps (RT control) is to actively balance supply and demand by managing disturbances introduced to the system by weather conditions, prices, human behaviour etc. The demand management actions applied continuously (demand dispatch, DD) here include only an adjustment of the controllable loads. DD selects loads with scheduling and/or intensity freedom so that their modification will not affect the user comfort. For example, refrigerators, dishwashers, etc. could advance start times of their cycles or comfort temperatures could be slightly increased in air conditioning devices. Another option to provide additional balancing capacity is to reschedule the energy storage devices. Finally, the fine adjustment step includes any necessary minute based balancing requirements of the system.

By applying the four optimisation steps and taking into account the dynamic properties, the prime exploitation of the installed resources can be achieved.

4.2 Real-time Operation

The RT control is continuously making decisions for all the dispatchable energy resources in order to reduce the instantaneous mismatch between the supply and consumption. Energy imports (exports) from (to) the grid are considered in order to capture any change originated from the applied access tariffs.

The main entities in the control process are shown in Figure 6 and can be classified into one of these four different categories: on-site generation, load, storage or the grid connection. The sources are divided in dispatchable and non-dispatchable ones. Majority of the RES are considered as non-dispatchable because of their unpredictable behaviour. RES mostly present in commercial buildings are small wind turbines, photovoltaic and solar thermal systems.

On contrary, dispatchable sources can be adjusted to any control demand. Along with gas turbines, reciprocating engines, etc. small scale Combined Heat and Power (CHP) plants are frequently present to avoid any heat waste during the electricity production.

Conversely, sinks of energy comprise of controllable and non-controllable loads. Controllable load is any schedulable, curtailable, deferrable and adjustable load under some restrictions, hence it is suitable for application of DD. Lighting, HVAC systems, and some kitchen and cleaning appliances generally belong to this group. Yet, entertainment and essential personal appliances fit in the uncontrolled group.

Storage units and grid connection can be used either as sources or sinks according to system needs. Various tariffs can be applied when accessing the electricity grid for purchase or sale. Regarding storage systems, batteries and thermal tanks are frequently found in commercial buildings.

Finally, the core of the RT controller consists of a sensor network providing continuous system measurements, data base for storing and using the historical data and an intelligent decision maker to coordinate the operations.

Two most common situations the controller is subjected to are:

- Energy shortage, caused mainly by reduction of RES availability due to unpredicted weather conditions or sudden increases of demand. Typical control actions include: curtailment or postponement of controllable loads, utilization of energy storage, using additional on-site (dispatchable) generation and importing (buying) energy from the grid (in case it is more economical and faster than the aforementioned alternatives).

- Energy surplus, when more favourable weather conditions than predicted arise or when there is a demand reduction by, for example, a lower occupancy level than expected. Typical solution is to store the energy excess for future use (if possible), advancing cycles of some controllable device or exporting energy to the grid.

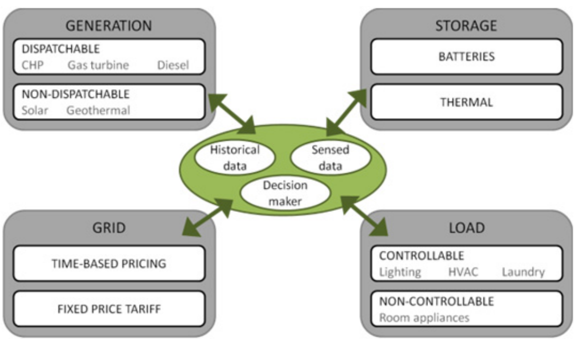


Figure 6: Information exchange in real-time.

In case a shortage or a surplus of energy remains for considerable time, a permanent change of weather or behaviour conditions should be considered.

4.3 Optimisation Problem

The dispatch decisions are continuously made by the controller. This complex task takes into consideration the stochastic nature of the parameters involved, dependence on the past and current decisions, future (scheduled) actions and multi-objective options of the optimisation problem. Favouring local renewable generation and occupant comfort maximization are also valid optimisation targets.

The decisions are made for a particular interval, but the optimisation problem also affects the successive intervals as they are not independent.

In the proactive control, the system is configured to be sensitive to any variation that may affect the demand or generation. Figure 7 shows the block diagram of how the optimised set-point levels for each unit are generated. This generation includes both, present time and future intervals depending on the predicted future scenarios.

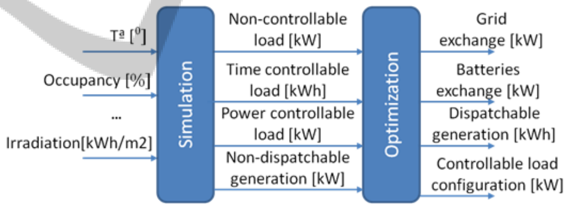


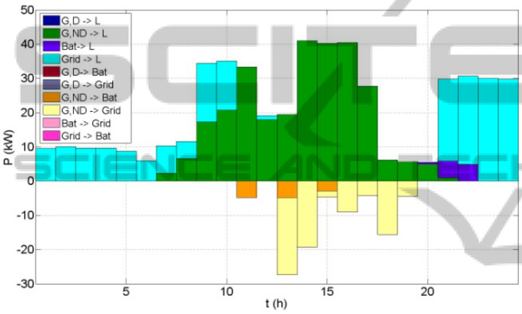
Figure 7: Generation of control actions.

4.4 Test Case

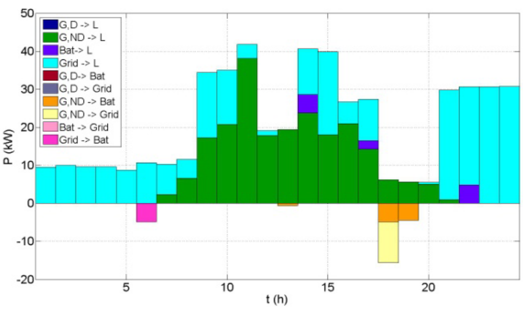
An example of the daily demand coverage of a hotel during summer months is used to show the features of proactive management. It is assumed the "super off-peak" tariff is used, favouring the night time consumption from the grid. The daily scheduler optimized the generation, storage and demand resources based on the most recent available data at midnight. The washing services were scheduled to coincide with the maximum PV generation and the lighting during these hours is permitted to operate at the maximum power. The batteries are charged from the PV generation during the daytime and they are used during the evening hours when the food preparation increased the total demand. Figure 8a shows the demand coverage in more details.

The solar irradiance forecast was then updated with more accurate data at 5.00h indicating lower than expected insolation between 12.00h and 16.00h. As a result of the updated optimization, the batteries are charged during the night time and discharged during that interval, some additional import from the grid is necessary and the washing was scheduled to finish before then. Also, the levels of lighting were reduced. The updated demand coverage is shown in Figure 8b.

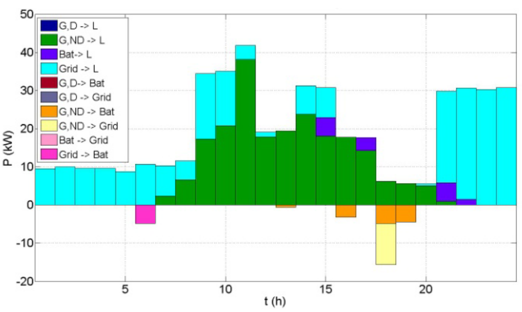
Finally, at 9.00h the demand prediction for the evening hours was once again revised, as the information about the cancellation of the dinner party booked at the restaurant was received. The reduction of the demand shown in Figure 8c allowed more accumulated battery energy to be used to cover the evening demand and reduced the purchase of energy from the grid.



a) Optimisation at = 00:00 h.



b) Optimisation at = 05:00 h.

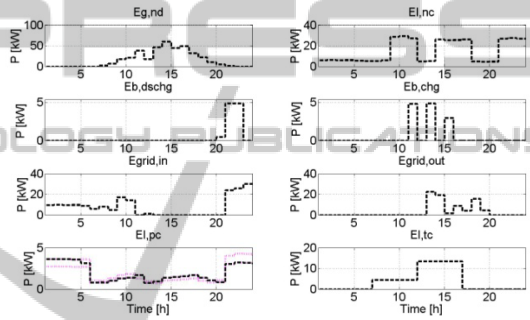


c) Optimisation at t = 09:00 h.

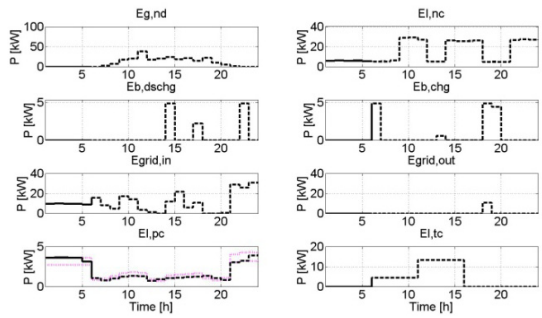
Figure 8: Updates of demand coverage according to revised scheduling.

Figure 9 shows the proactive management and the applied control updates in more details. In these diagrams on the left side the total generation is split between non-dispatchable generation *Eg,nd*, energy storage discharge *Eb,dschg*, electricity purchase *Egrid,in* and then power adjustment *El,pc*. On the right side electrical non-controllable load *El,nc*, energy storage charge *Eb,chg*, electricity export *Egrid,out* and time-shiftable load *El,tc* are shown.

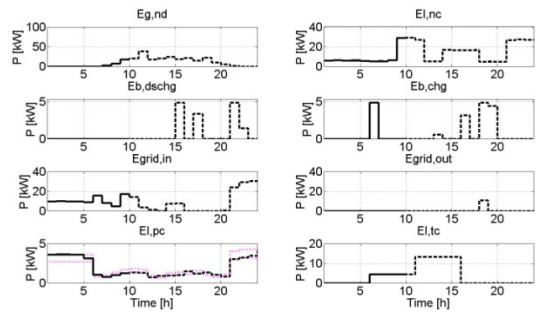
The main difference between the plots was introduced by lower than expected non-dispatchable generation *Eg,nd*. This as an effect rescheduled the times of the charging and discharging the batteries *Eb,chg* and *Eb,dschg*, the grid purchases and sales *Egrid,in* and *Egrid,out*. Also, some changes to these profiles were caused by the demand reduction in the evening hours.



a) Optimisation at = 00:00 h.



b) Optimisation at = 05:00 h.



c) Optimisation at = 09:00 h.

Figure 9: Daily evolution of main control parameters.

5 BENEFITS ANALYSIS

To demonstrate the advantages of proactive control in terms of minimising the running costs, the savings have been calculated and compared for the three different tariffs applied. As the base case for this comparison it is assumed the fixed daily schedule without any changes applied by the proactive management. In this base case the battery charge and discharge cycles are fixed and any demand variation is covered by importing/exporting the power from/to the grid. In Figure 10 the increase in running costs as a result of not applying the hourly adjustment is shown. For the single tariff case the cost saving is around 5% while for the two-tariff case and the "super off-peak" tariff the potential for the savings increase to about 9%.

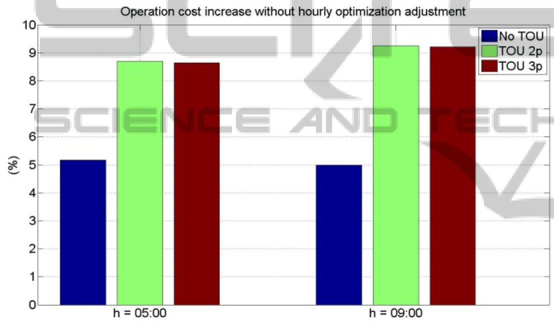


Figure 10: Increase in operational costs when proactive control updates are not applied.

The proactive management clearly demonstrates its capacity to achieve cost savings with or without the tariff discrimination system by matching the demand peaks with the available local generation. In case of the differential pricing system, the additional saving benefits are gained by the demand shifting techniques and the battery management.

6 CONCLUSIONS

This paper has discussed the operational and cost related aspects of the proactive resource management system for Smart buildings. It has been demonstrated that the proposed solution is sensitive to any unforeseen disturbance in demand, generation, access tariffs, ambient conditions, building occupancy, building services etc. and by using optimised dispatch significantly reduces operational costs.

The proposed methodology introduces a hierarchical approach to the multi-energy system design, long term resource scheduling and proactive RT response. Energy surplus and energy shortage scenarios have been both considered and with optional capacity restrictions in the system grid connection.

Simulation results and cost/benefit analysis have been used to demonstrate some of the features of the proposed proactive control.

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