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Author:
Christian Johansson, Fredrik Wernstedt, Paul Davidsson

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COMBINED HEAT & POWER GENERATION USING SMART HEAT GRID

Christian Johansson[1], Fredrik Wernstedt[2] and Paul Davidsson[1, 3]

1 Blekinge Institute of Technology, 371 79 Karlskrona, Sweden

2 NODA Intelligent Systems AB, Drottninggatan 5, 374 35 Karlshamn, Sweden

3 Malmö University, 205 06 Malmö, Sweden

christian.johansson@bth.se, fredrik.wernstedt@noda.se and paul.davidsson@mah.se

ABSTRACT

Combined heat and power (CHP) generation is often used when building new district heating production. CHP makes it possible to simultaneously produce electricity and heat, thus maximizing the energy efficiency of the primary fuel. The heat is used in the connected district heating system while the electricity is sold on the local power market. In a CHP plant it is not possible to separate the physical process of producing heat and electricity, which may cause suboptimal behaviour when high spot prices for power do not coincide with high heat load demand.

This paper presents the design and implementation of a system which makes it possible to control the heat load demand in a district heating network in order to optimize the CHP production. By using artificial intelligence technology in order to automate the run-time coordination of the thermal inertia in a large amount of buildings, it is possible to achieve the same operational benefits as using a large storage tank, albeit at a substantially less investment and operational cost.

The system continuously considers the climate in each participating building in order to dynamically ensure that only the best suited buildings at any given time are actively participating in load control. Based on the dynamic indoor climate in each individual building the system automatically controls and coordinates the charging and discharging of the buildings thermal buffer without affecting the quality of service.

This paper describes the overall function of the system and presents an algorithm for coordinating the thermal buffer of a large amount of buildings in relation to heat load demand and spot price projections. Operational data from a small district heating system in Sweden is used in order to evaluate the financial and environmental impact of using this technology. The results show substantial benefits of performing such load control during times of high spot price volatility.

Keywords: smart heat grid, combined heat and power, district heating, optimization, load control

NONMENCLATURE

Abbreviation	
DHS	District Heating systems
CHP	Combined Heat and Power
DSM	Demand Side Management
QoS	Quality of Service
Symbols	
T	Temperature [K]
H	Heat load [W]
b	Operational boundary
x	Heat load matrix block
c	Spot price array block
Subscript	
m	number of rows in matrix
n	number of columns in matrix

1. INTRODUCTION

In a district heating system (DHS) one or several production units distribute heated water or steam throughout a pipe network. Buildings are connected to this network either directly or by heat exchangers. This delivered heat can then be used for a multitude of purposes within the building, e.g. radiator subsystems, hot tap water or heating of ventilation air. The basic concept with centralized production units is normally environmentally and financially sound, since such facilities can easier incorporate large scale energy efficiency schemes. District heating is most common in northern and eastern parts of Europe including Russia and other former Soviet countries, although the concept is utilized around the world and is gaining an increasing acceptance on markets throughout Asia and North America [1].

Any type of production can be used in a DHS, as long as it is able to heat the water to the desired level. This flexibility allows a wide range of different production solutions, such as industrial waste heat, geothermal heat, biomass, fossil fuel boilers and nuclear powered heating. In many DHS a cogeneration plant is also added to the system. This provides the possibility to produce electrical power in parallel with the heat production. Such combined heat and power (CHP) systems typically have a very high level of energy efficiency compared to stand-alone thermal production plants [2]. In a CHP plant water is heated to steam, which is then led into a turbine which in turn transforms the kinetic energy to electricity in a generator. The steam is then cooled by transferring its heat to the return water in the district heating system, which in turn is distributed throughout the DHS.

The electricity produced by the generator is normally sold on the power market. In northern Europe the power market is run by Nord Pool Spot, which was the world's first market for trading power. Nord Pool Spot provides a market for buying and selling power in Sweden, Finland, Denmark and Norway as well as in Estonia, Germany and Great Britain. In 2010 the total power traded through Nord Pool Spot amounted to 310 TWh, which correlates to a monetary value of about EUR 18 billion [3]. Since the power market is deregulated it is subject to basic market characteristics such as the balance between supply and demand. Since energy in the form of electricity is by nature quite hard to store, the electricity has to be made available at the same time as there is a need for it. And since both this demand and the available supply vary throughout the day, the price for electricity will obviously also vary throughout the day. On Nord Pool Spot power is traded based on hourly market prices. These spot prices are traded one day in advance, and are then published on the same day at 14.00 CET as a set of 24 spot prices, each correlating to an hour the following day. There is also an intraday market at Nord Pool Spot. The intraday market acts as a balancing tool between supply and demand in real time. Prices on the day-ahead market can vary quite a lot during a 24 hour period, and situations where the highest spot price for the day is twice that of the lowest is not uncommon. At the intraday market prices can be even more volatile.

These price changes obviously make it financially sound for the individual energy companies to try and match their production with the highest spot prices. In a DHS/CHP system the physical act of producing electricity cannot be separated in time from heat production. However, if the heat can be stored in preparation for the heat load demand, it is possible to optimize the CHP process in relation to power spot prices. By using large heat water storage tanks it is possible to do this, by charging the storage tanks while the power spot prices are high respectively discharging them when the heat load demand rises in the buildings. However, such storage tanks are expensive to build and maintain, and their operational characteristics are inflexible. This paper presents an alternative way to manage heat production in relation to the spot price market. By using its thermal inertia it is possible to charge and discharge a building with slight amounts of heat energy without affecting the perceived indoor climate [4,5]. If this behaviour is coordinated among a sufficiently large group of buildings the amount of energy controlled is comparable to any storage tank, albeit at a much lower installation and maintenance cost. Such a system also has the added benefit of having a more flexible operational behaviour than a storage tank, since the heat load changes in an individual building are only limited in time by the speed of the connecting valve.

Controlling the heat load in buildings is known as demand side management (DSM) and can be implemented either by passive tools, e.g. design of price lists, or by active tools such as direct load control [6,7]. The heat load demand in a building is basically related to two different driving forces; a) the heating demand and b) the hot tap water demand. The heating demand closely follows the changes in outdoor temperature while the tap water demand is caused by social behaviour. Although social behaviour does display predictable patterns from a macroscopic point of view, the tap water usage cannot be used in relation to heat load control, since the tap water system needs a continuous heat load level in order to avoid Legionella growth. Also the tap water system is subject to direct feedback regarding quality of service (QoS) if the heat load is changed, e.g. a person taking a shower will instantaneously identify a drop in the tap water temperature. The heat balance of the building itself however, is a physical process characterised by a more slow-moving nature. If the heat load for the heating system is removed it will normally take several hours before any person in the building will notice any change [5]. This process is even more inert when only a subset of the heat load is manipulated.

Normally the heating control system of a building will control the forward temperature in the radiator system based solely on the outdoor temperature. Active load control basically equates to temporarily diverting from this. This is done by controlling the heat load demand, and thus the forward temperature in the radiator system, based on some other control signal.

The scheme presented in this paper is initiated by a system wide heat load analysis which is synchronized with spot price projections. Active load control is then performed in order to implement the calculated heat load demand strategy while maintaining sufficient levels of QoS.

The paper starts off by introducing related and previous work concerning the subject. In section three heat load storage and load control in buildings is discussed in more detail. Section four details an optimization model for correlating spot price and heat load demand. Section five describes how the load control system is designed while the process of evaluating its behaviour is described in section six. The results are presented in section seven, while section eight discusses the system and the results.

The paper is finalized in section eight and nine with conclusions and future work.

2. RELATED WORK

The basic prerequisite ability to use the thermal mass of buildings as heat storage facilities has been thoroughly investigated in previous work. It has been shown that substantial amounts of energy can be saved in relation to both heating and cooling demand, even just by considering passive use of a buildings thermal mass during the architectural design phase [8,9]. By actively using the thermal inertia within building structures it is possible to equate this to the operational behaviour of large storage tanks [5].

Such active load control has been studied in relation to building thermal mass, where the validity of the concept is proved through practical experimentation. Such operational load control systems have been evaluated since the eighties [10]. This early system used the electricity network in order to communicate load control commands to each building. This was a one-way communication set-up which prevented the system from considering aspects relating to QoS, which meant that the system was controlled without any feedback from the individual buildings. It is not until the last decade that technological progress in relation to communication and processing has become sufficiently adaptable and reasonably priced to warrant any large scale installations [11]. In particular the development of inexpensive and robust infrastructures for communication has been a pivotal aspect of this development, and previous work has shown how different levels of available communication affect the efficiency of active load control in operational settings [12]. Although the realization that reliable two-way communication was of outmost importance is evident even in the earlier works [13].

The concept of DSM quality filters was proposed in a previous paper as a way of managing the relation between energy companies increasing demand for environmentally and financially optimized operational planning and customer's demand of robust and continuous QoS [14]. Maintaining a sufficient level of QoS is paramount for any load control scheme. System wide active load control is dependent on the coordination of heat load demand in a large group of buildings, and normally the end-customers occupying these buildings are not sympathetic to overly volatile heat deliveries.

3. LOAD CONTROL IN BUILDINGS

Normally the control system in a building will manage the heating by continuously measuring the outdoor temperature and adjusting the temperature of the secondary heat system accordingly. In most cases this control is performed by some sort of PI or PID feedback mechanism [15]. In order to perform active load control in the building this normal control has to be overridden during each load control instance. This is normally done by offsetting the outdoor temperature signal to some degree, either by predefined internal processes in the existing control system software, or by external manipulation of the signal from the outdoor temperature sensor. Many existing control systems attenuate the signal from the outdoor temperature sensor, in order to avoid volatility in the resulting control signal due to rapid changes in outdoor temperature. Such attenuation should preferably be minimized in systems aimed at performing active load control, since they cause the system to react slower than is necessary.

The QoS needs to be maintained at all times in each individual building participating in the load control scheme. One obvious solution for this is to use indoor temperature sensors which give continuous feedback to the system. Many solutions for such temperature measurements exist, and lately solutions based on wireless technology have also become more widely available. The main problem with wired solutions in this regard in the cost of installing such systems, since the temperature sensors need to be deployed throughout the building. Wireless solutions are cheaper in this regard but suffer from other problems, mainly related to connectivity and power usage. Especially power usage is crucial, since most wireless solutions use batteries, although continuous progress is being made in this regard [16]. A basic problem when using indoor temperature measurements as a control signal is that they are very susceptible to social behaviour. Installing a number of such sensors in the same building and then using an average value reduces the influence of such stochastic behaviour. Although even such a value is not optimal as a direct control signal, since an individual load control instance should be able to stop long before a temperature drop is measured among a group of physical sensors.

The time constant of a building is often used to describe the thermal inertia of a building. This value can be view as the heat capacity of the building in relation to its specific heat loss. The time constant describes what happens with the indoor temperature when no heat load is input into the building, and the temperature consequently starts to drop. The time constant is expressed in hours, and might vary from just a few hours to several hundreds of hours. Most normal multi-apartment buildings in Sweden have time constants between 50-200 hours.

The time constant is a good starting point for evaluating the ability of a building to perform active load control, although it is too simple to use for heat loss analysis in real time control. Active load control involves short term charging and discharging of the thermal buffer within the building. In order to model such thermal behaviour an energy balance model is often used. Within this project we use a system of two differential equations in order to express the change in indoor temperature and building structure temperature in relation to the outdoor temperature. Such models are based on the basic heat load balance within a building on the fundamental form shown in equation 1.

$$\Delta T_{indoor} = H_{input} - H_{output}$$

(eq. 1)

where H_{input} is the total heat load supplied into the building, H_{output} is the combined heat losses and ΔT_{indoor} is the indoor temperature difference this will lead to. Such heat load balance models are the prevalent method of describing the thermal dynamics of building structures. These models can be made sufficiently complex and might include several more variables than just one indoor temperature and one building structure temperature [17].

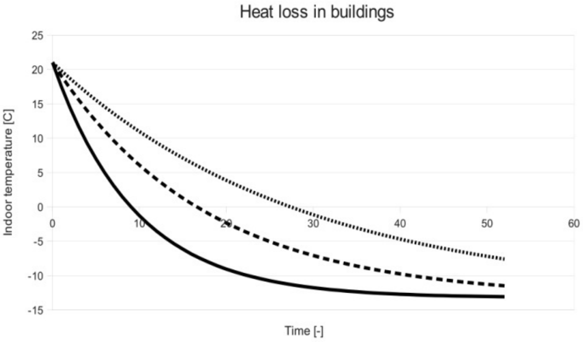

Figure 1 Heat loss in buildings with three different time constants. 80 hours (continuous), 150 hours (dashed) and 250 hours (dotted). The time scale is in nine hour increments.

Figure 1 shows the heat loss in three different buildings. The values are calculated by the energy balance model used in this study. As each time step is about nine hours the time interval spans about twenty days. Figure 2 shows data generated by the energy balance model compared to actual measurement data from a real building. The building in question is a very large school building with a considerable time constant of about 380 hours. During one weekend the building heating system suffered a total breakdown, which enabled us to measure the temperature drop during the time it took to repair the heating system [18]. The repair time is slightly less than 36 hours, which is the time span shown in Figure 2. Since this is only a small part of the time constant of the building the graph does not display the full logarithmic behaviour present in the previous figure.

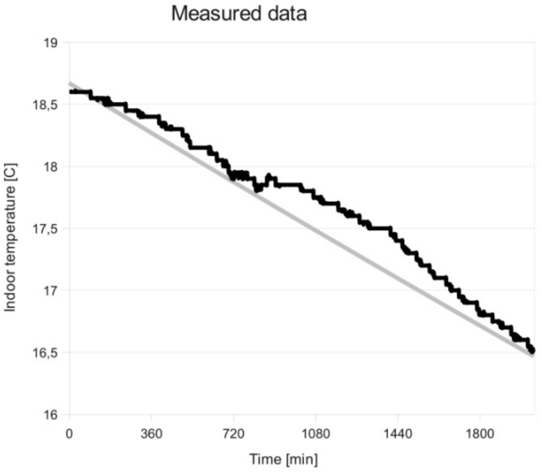

Figure 2 Measured data compared to the energy balance model

In order to ensure sufficient levels of QoS the proposed systems uses the combination of an energy balance model and physical indoor temperature sensors. Having access to actual measured temperature data is invaluable in order to gain acceptance for active load control among building owners and residents.

4. HEAT LOAD SYNCHRONIZATION

In order to synchronize future heat load and spot price peaks, it is necessary to have projections of both these values. The spot prices on the Nord Pool Spot power market is published one day ahead so this data is freely available. A heat load projection can be modelled based on weather forecasts. Since the projection is short term, in this case one day ahead, and the only variable used is outdoor temperature the weather forecasts are sufficiently accurate. The heat load projections are then arranged in accordance with the spot price, in this case an array of 24 values correlating to system wide heat load demand for each hour the coming day. The idea is then to rearrange the heat load array so that it matches the spot price array as closely as system constraints allow. If the heat load demand is discretizised and represented in a matrix, this process can be formalized in the following optimization model.

$$\max \sum_{i=0}^{m} \sum_{j=0}^{n} f(x_{i,j}) * c_j$$

(eq. 2)

$$\textit{subject to}$$

$$f(x) = \begin{cases} 1 \; if \; x_{i,j} \neq 0 \\ 0 \; if \; x_{i,j} = 0 \end{cases}$$

(eq. 3)

$$if \; f(x_{i+1,j}) = 0 \; then \; f(x_{i,j}) = 0$$

(eq. 4)

$$b_{upper} \geq \sum_{i=0}^{m} f(x_{i,j})$$
(eq. 5)

$$b_{lower} \leq \sum_{i=0}^{m} f(x_{i,j})$$
(eq. 6)

$$\sum_{i=0}^{m} f(x_{i,j}) \leq \sum_{i=0}^{m} f\left(x_{i,j-1}\right) + b_{dynamic}$$
(eq. 7)

$$\sum_{i=0}^{m} f(x_{i,j}) \geq \sum_{i=0}^{m} f\left(x_{i,j-1}\right) - b_{dynamic}$$
(eq. 8)

The cost function in Equation 2 maximises the total earnings of the sold electricity. The amount of electricity is constant, since the total heat demand is constant. The heat load data for each hour is discretizised heat load blocks and added into an m by n matrix, where m is the theoretical maximum amount of heat load in the system. The value of n is 24, i.e. one column for each hour during the period. Equation 3 quantifies the existence of heat load blocks in each section of the matrix. Equation 4 stipulates that a heat load block must either have another block under itself or be at the bottom itself. This basically means that the heat load must be connected and start at zero. Equations 5 and 6 set the maximum and minimum boundaries for the production during the entire time span. Equation 7 and 8 set the dynamic boundaries between each time step, i.e. they control how much the production can shift between each hour. It should be noted that all the boundaries relate to the system wide total, i.e. a combination of all available production units and operational load control ability.

The chosen block size affects the computational performance required to solve the optimization problem, since the amount of blocks equals the amount of rows in the heat block matrix. During this study a block size was chosen according to equation 9.

$$size_{block} = heatload_{max}/10$$
(eq. 9)

Obviously any number can be chosen instead of 10, but the higher the number the higher the computational load. Also there is no point in having a much smaller block size, since a real time operational load control system will not be able to implement such a solution exactly anyway. Figure 3 shows a simple example solution to the described optimization problem. Matrix A is the reference heat load, i.e. the starting point for the optimization, while Matrix B, C and D are three solutions with different dynamic boundaries.

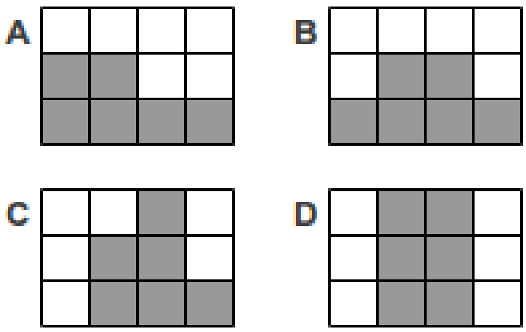

Figure 3 Example solutions with reference (A), dynamic bound = 1 (B), dynamic bound = 2 (C) and dynamic bound = 3 (D)

In the example from Figure 3 four time steps are used, which correlate to spot prices of 5, 7, 10 and 4 in that order. The maximum boundary is three, and the minimum boundary is zero in all solutions. The dynamic boundary is one for solution B, two for solution C and three for solution D. The earnings for each matrix is 38 for the reference case, 43 for solution B, 48 for solution B and 51 for solution D.

5. MARKET BASED HEAT LOAD ALLOCATION USING AGENT TECHNOLOGY

When the system has found the solution to the heat load synchronization it must also enforce this in the DHS the following day. This is implemented by active load control, in which the system uses the thermal inertia of buildings in order to manage the heat load demand in order to approach the heat load synchronization scheme. We use a market based allocation system in which an auction-like process distributes load control among the participating buildings. Such an auction process is based on the idea that a mechanism of supply and demand is self-regulating. Our system uses agent technology in order to manage and operate this auction process. An agent is a stand-alone software system which is capable of flexible and autonomous action, and observes and acts upon its environment and directs its activity towards achieving some goal [19]. Agent technology provides a framework for structuring computer applications around autonomous and communicative components. In our case these components consist of the individual buildings as well as the production units. Agents are often used in complex and unpredictable environments, where available data is distributed. Since an operational DHS display such characteristics agent technology provide a convenient framework for implementing active load control. Figure 4 shows the basic communication architecture for such an agent based auction process.

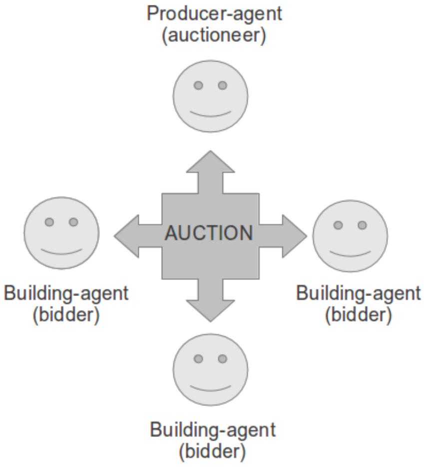

Figure 4 Communication architecture of agent based auction

By using the difference between the actual indoor temperature and the acceptable indoor temperature boundaries the system can represent a form of currency. If a building has a large difference between the actual indoor temperature and the temperature boundaries it will have large thermal buffer which can be controlled, i.e. the building will have large amount of available currency. However, if the building indoor temperature is close to the limit where the temperature change might be noticeable, the building will have a small amount of available currency. This currency is then used by the building agents in order to buy load control by the production agents through an auction process. The more load control an individual building agent buys, the more it will charge/discharge its thermal buffer, thus in the process becoming poorer and therefore not being able to compete in the auction rounds. Thus the building agent will stop performing load control and the indoor temperature will slowly return to the original position, which in turn increases the agent's ability to start bidding at the auction again. Based on this behaviour the overall system will be self-regulating in regards to QoS while finding an optimized heat load allocation, since the system will have an automatic correlation between a buildings ability to perform load control and its inclination to do so. This type of agent system has been described in detail previous work [7,14].

6. EXPERIMENTAL SETUP

The reference data for this project has been collected in the DHS at Gothenburg Landvetter Airport in Sweden. The system has about thirty buildings served by the production units. These buildings range from large hangars and arrival halls to smaller buildings containing guard facilities and restaurants. The data was collected during the full month of January in 2011.

The spot prices are accessed from the Nord Pool Spot webpage, and encompass data from the same time period, i.e. the month of January 2011. The prices are expressed in SEK but have been converted to EUR and USD for the evaluation of this study. The exchange rate used is 1 EUR = 9.17 SEK and 1 USD = 7.04 SEK.

In order to evaluate the performance of the system we used the DHEMOS simulation tool. DHEMOS is a simulation model framework for district heating systems, combining the models for production, distribution and consumption into one tool [20]. DHEMOS was originally part of the ongoing research at Blekinge Institute of Technology, but is now run as an open source project. The underlying simulation models used in DHEMOS are described in previous work [21].

The heat load reference matrix and spot price array are built based on the collected data. The optimization problem is then solved, which results in a new heat load matrix. This heat load scheme is then simulated in DHEMOS in order to evaluate the affects this would have on QoS among the consumers and other components within the DHS. Only the 20 largest buildings where used for active load control during this study.

The optimization calculation is done using Octave 3.2.4. The DHEMOS simulations have been run on a Linux/Ubuntu 11.10 computer with Intel Core i5 CPU with 4 GB of RAM.

7. RESULTS

The data affecting the simulation, i.e. spot price data and outdoor temperature, obviously changes every day. The data presented in this section is based on a representative period of twenty-four hours. Figure 5 shows the heat load demand in the DHS before and after the synchronization process. It should be noted that the total heat load demand during the day is left constant.

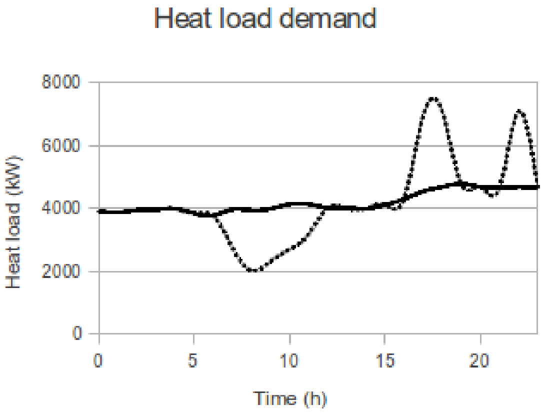

Figure 5 Heat load demand in the DHS, showing reference (continuous) and optimized (dotted)

It is clearly visible where the high and low spot prices triggering the synchronization are occurring. The system tries to move as much heat load demand as the boundary values will allow, from hours with low spot prices to hours with high spot prices. Figure 6 shows the indoor temperature changes in an individual building as the load control mechanism enforces the heat load scheme in the DHS.

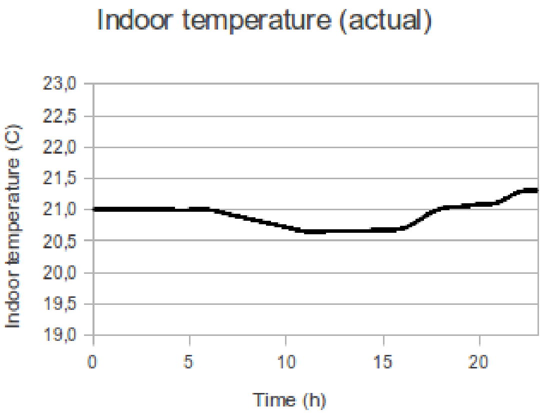

Figure 6 The indoor temperature in a building during load control

The starting point for the indoor temperature is 21C, which the existing control system in the building will be able to uphold if there is no load control being performed. As the load control is enforced the temperature starts to drop slightly, while slightly increasing during the later parts of the day. Even if the heat load is roughly halved during several hours when the first load control is done, the indoor temperature is only slightly affected. The same is true during the later heat load peaks when the spot price is high during the evening. Figure 7 shows the rate of change in the indoor temperature as the heat load demand deviates from the level required by the existing control system.

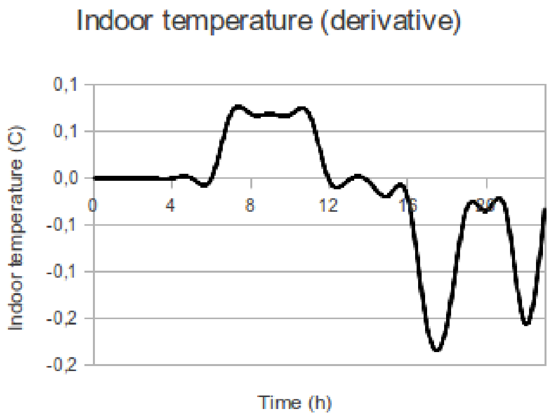

Figure 7 The change in indoor temperature throughout the day

The derivative of the indoor temperature clearly correlates with the changes in heat load input throughout the day. This is a measure of the charging and discharging of the thermal buffer within the building. It shows how the building is used to synchronize the spot prices, and is essentially a horizontal mirror image of the heat load demand. Figure 8 shows the QoS level of the building agent throughout the day.

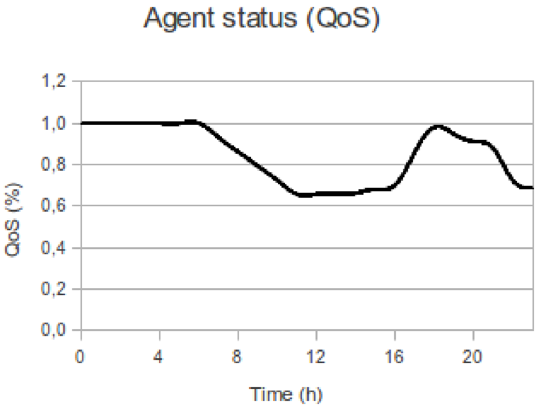

Figure 8 Agent status as expressed in QoS

The QoS in Figure 8 is expressed in percent. A full 100% indicates that the indoor temperature is 21C, which is what the existing control system is trying to uphold. Any deviation from this value will result in a decrease of QoS. In this study the indoor temperature was allowed to deviate up to 1C from the wanted indoor temperature, i.e. in an interval between 20C and 22C. The QoS level will approach zero as the temperature approaches these limits. The QoS is the currency which the building agent uses to engage in the auction process. In Figure 8 it is clearly visible that the agent's funds decreases as it engages and wins load control through the auction. Conversely, as the agent refrains from auctions the funds increase as the indoor temperature slowly returns to the original state.

Table 1 shows the financial results in relation to the presented data. The slight discrepancy when comparing percentage is due to rounding of the monetary values.

Table 1 Financial results

Description	**EUR**	**USD**
Earnings (ref)	2850,66	3713,15
Earnings (solution)	2952,49	3845,78
Difference	101,83	132,64
Difference in percent	3.59%	3.57%

There exists different ways to implement active load control in DHS. The system we use in real-time implementations cost approximately 1000 EUR (1302,56 USD) per building agent, which gives a repayment time of 196,41 days based on the figures presented in Table 1 in relation to the twenty buildings used for load control. Counting a heat season of about six months, this equates to a repayment of the investment by little more than one year.

8. DISCUSSION

The main object with many production plants, especially those using biomass or other low quality energy carriers for fuel, is to maintain an even production level throughout the day. Such production units will get smaller dynamic bounds, but they are still able to respond to general heat load fluctuations in the system. The synchronization strategy presented in this paper functions by creating artificial heat load peaks during hours with high spot prices in order to maximize the sale of generated power. This might not be advantageous to the end customer if the district heating price is partly priced according to different levels of heat load- or flow usage. Although it should be noted that the load control system is a general tool for managing the heat load demand and it might be used for evening out peak loads just as well as creating or moving them. In this regard it functions similar to a heat water storage tank, and it is hard to generalize since each DHS is different from the next.

The daily spot price spread, i.e. the difference between the highest and lowest hourly spot prices during the day, is the most important factor when evaluating the earnings. A larger spread will obviously lead to higher earnings. This can be compared to the function of daily trading on stock markets, where the difference between bought and sold price during short periods of time influence the potential earning. This is especially apparent when trading on the intraday power market, when there is no prior knowledge of the price. Just like stock market day trading financial instruments can be used to evaluate price projections, either by technical or fundamental price analysis. However, the application of such techniques in relation to active load control is beyond the scope of this paper.

Normally, when optimizing in relation to current spot prices on the power market, large storage tanks are used. Another alternative is to use the distribution network in itself as a storage device. Using the thermal inertia of buildings as proposed in this paper, is just an extension of this established control philosophy. One crucial difference is the ability to adjust to sudden changes when using heat load demand in buildings. Load control in a building can react as quickly as the valves on the heat exchanger can move, while a storage tank requires much longer pre-heating and charging strategies. In practice this is like comparing seconds to hours. This is especially important in relation to intraday power markets, in which the energy company has no prior knowledge of the electricity price. The financial gain in such markets is also potentially larger since they tend to be more volatile and thus resulting in larger spreads.

There is also another, quite important, difference between using the thermal buffer of buildings instead of storage tanks, and this is the installation and maintenance costs involved. The price for a storage tank is heavily dependent on the current price of steel. The total installation cost is more or less linear with the steel price for storage tanks up to about 50 MW, after which it increases even more since the added physical constraints of such large tanks require increased dimensions. A storage tank with a heat load of about 50 MW costs about 3 million EUR (3,9 million USD) while a corresponding system using active load control will cost approximately 1 million EUR (1,3 million USD). The maintenance cost is also substantially lower.

Another solution for spot price optimization is to increase the pressure head throughout the DHS, which enables the possibility of lower return temperatures in the primary flow network. Since this result in a higher temperature gradient in the production turbine, it is possible to get a higher output from the power generation. However, having excessively high pressure heads is expensive, and might also introduce other problems in relation to component behaviour. Performing load control, on the other hand, helps lower the primary return temperature without requiring higher pressure heads [22]. By coordinating this behaviour among a larger group of buildings it is possible to achieve a lowered temperature on average also.

During this study we have used simulation to evaluate the behaviour of the load control system. However, the products used to implement such systems exist on the market today, and have been extensively evaluated in previous work. This makes it possible for us to draw conclusions about the system limits in regards to the operational managing of heat load demand, which enables us to set realistic boundaries for the synchronization problem.

A basic problem with solutions such as the one proposed in this paper, is that if all parties active on the market used them it would obviously affect the outcome of the trading. In practice this is not a problem, since CHP represents a very small part of all power being traded on the open markets. In Sweden more than eighty percent of all power is produced by hydro power or nuclear power, while wind power, CHP and other marginal production types make up for the rest.

9. CONCLUSIONS

In this paper we have presented a model for finding an optimized synchronization between heat load demand and spot prices when using CHP. This is then implemented through active load control by using the thermal inertia within individual buildings. The model takes into account the specific boundary conditions present for individual production unit configurations in relation to operational limits of load control in individual buildings. This is done by using a market based auction process as a mediating interface between the buildings and the production units. Agent technology is used in order to implement this auction process. Each building is assigned an individual agent, which will try to maximize the load control while maintaining a sufficient level of QoS.

The results show clear financial incentives for implementing this type of technology, having a repayment time of less than two heating seasons. At the same time it is concluded that it is possible to achieve this without jeopardizing the QoS among the participating buildings.

The financial benefits of this technology are dependent on the spread of the spot prices, in relation to the boundary conditions in the system. But since this spread is normally quite large, even systems with tight dynamic boundaries will experience improved earnings.

10. FUTURE WORK

Based on the flexibility of the agent based load control solution it is likely that the type of solution presented in this paper is appropriate for managing synchronization in relation to intraday power markets. Since the spot prices are not known in advance it places even more focus on high flexibility and the ability to quickly adjust the power production. A distinguishing factor of such intraday markets is their tendency to be very volatile with highly fluctuating prices, much more so than the normal day-ahead power markets. However, such an environment does place additional demands on the ability to evaluate projections of heat load demand as well as spot prices. Hence, further investigation and incorporation of such techniques in the present model should be a primary goal in the near future.

Another interesting venue is to further develop the optimization model in order to use dynamical sizing of the heat blocks. This would enable a closer correlation with individual consumers or groups of consumers, and would make possible a direct mathematical derivation between the entity instigating load control (i.e. the energy company) and the entity performing the load control (i.e. the building). It would also enable a route for quantifying the contribution of individual buildings when performing load control, in turn enabling a way to compensate building owners for letting the energy company use their resources.

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