Multi Agent System to Optimize Comfort and Energy flows in the Built Environment

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ABSTRACT

This paper discusses the control of building energy comfort management systems led by the economic movement within the energy market resulting in different prices. This new generation of building management systems focuses on the application of multi-agent systems for autonomous flexible operation of building services systems to obtain overall improvement energy efficiency and comfort. Multi-agent systems have proven to be successful in many applications to detach the timely interdependencies between systems and applications and come to a decentralize approach. In this study a multi-agent system (MAS) is developed to control and manage building services systems. A case study on an existing building system pointed out that energy consumption is reduced of a central air conditioning unit and local heating and cooling units with help of the proposed market driven multi-agent system, while maintaining comfort within the bands of user preferences. Furthermore it can be concluded that the system adapts to the dynamic changing situation and amount of momentary available resources.

INTRODUCTION

In today's building automation, the main goal is to deliver the required comfort, but also to do this with a minimum use of energy and a minimum emission of greenhouse gases. As about 40 % of the worldwide energy consumption is directly related tot the built environment [Parry M.L., 2007], improvement of the energy performance is important to meet the environmental goals. Optimal control of the HVAC and other building systems should be able to minimize the energy consumption and still meet the required comfort goals.

The available data-acquisition, communication technology and available data-storage, opens the possibilities to develop advanced control methods. The main goals for these new control methods are: 1.Continous adaptation of demand to changing circumstances, such as change in occupation or use of a part of building. 2. Adaptation of the processes to the available (sustainable) resources. And 3. The building should be able to operate as part of a larger framework of buildings. This should lead to a sustainable environment, where buildings should be able to adapt to the actual production of windmills, bio-plants or PV-panels. The suitable technology to implement these schemes is through the use of software agents. Software agents can act as virtual representatives of local tasks within a building. Multi-agent systems form a potentially powerful framework for the implementation of distributed and delocalized control architectures [Ponci, 2010]. The agent representation leads to a decentralized control structure while also more global goals can be achieved.

Multi Agent Systems (MAS) for building control.

A MAS structure for building operation has been described by Akkermans en Ygge, [Ygge 1999], they used micro-economics for the optimal distribution of a limited amount of cooling capacity within a large building. A market oriented distribution model was used to allocate the available capacity to each part of the building. Each part of the building expresses their need for cooling through a bidding scheme. An auction allocates the capacity to each part of the building. When through external factors, solar gain or change in occupation, the need for cooling in a part of the building increases, the part of the building increases it's bidding price for cooling capacity.

CASE STUDY: INTERDEPENDING MAS -CONTROL

In this study the MAS is based on a similar market oriented approach, agents define their demand for capacity (amount of cooling or heating) in a bidding process, based on the price of the resource. The difference is that the optimization takes into account 2 commodities (heating & cooling) instead of only one, and each commodity can be supplied to either the central air handling unit (CAHU), or the individual room units (HC1&HC2). As the CAHU preconditions the air for the rooms, the central demand for heat and cooling strongly interact with the local demands. This lead to a increase of the complexity of the process. The goal is to find a good structure for the optimization of the energy flows. The presented scheme (fig.6) is a first approach based on a strategy fully based on markets, as used by Kok, Warmer and Kamphuis in the control scheme for distributed control of the electric grid (Powermatcher: multi-agent control of electricity infrastructure [Kok e.a 2005] The schema combines micro-economics theories with control theory (fig 1). [Akkermans 2004]. The control decisions (biddings) are made by each controlling agents based on information of the local operating conditions and part of the overall operating conditions. A match of demand and supply is reached through an auction where an agent acts as a broker, this agents initiates the bidding process and is a supervisor of the process.

After several iterations of this process the overall control objective are met.

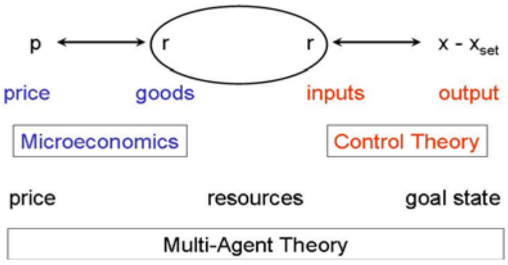


Figure 1 Conceptual scheme for the market strategy; multi-agent model combining micro-economics and control theory [Kamphuis, Warmer 2007]

The goal of this study is to find a market driven MAS approach for a multi-commodity system (heating, cooling) of a building, where price and availability of the commodities are interdependent. The MAS coordination of the energy flows in the building should give each (sub) system the possibility of autonomous actions to obtain acceptable comfort in the represented room and overall leads to an optimal use of the resources.

Local Comfort

To maintain the desired indoor climate in a room the supply of heating and cooling needs to be adjusted. To realize this with a minimum of resources, all the flows have to be continuously optimized. The used comfort model is based on the well known model of P.O. Fanger [ISO 7730. 2005]

Since the scope of the study is to focus on the optimization of MAS for energy, it is assumed that every comfort parameter can be individually changed within its defined comfort band.

In the case study the emphasis is on the interdependence between the central air handling unit and the local heating/cooling units per room.
The two rooms in the building have a different orientation, so during the day the demand for heating/cooling will shift per room. The two-room building is modeled in HAMBase [v. Schijndel, 2009] a dynamic building model implemented in SIMULINK® and uses actual climate data in the simulation. The used simulation set-up is given in figure 2.

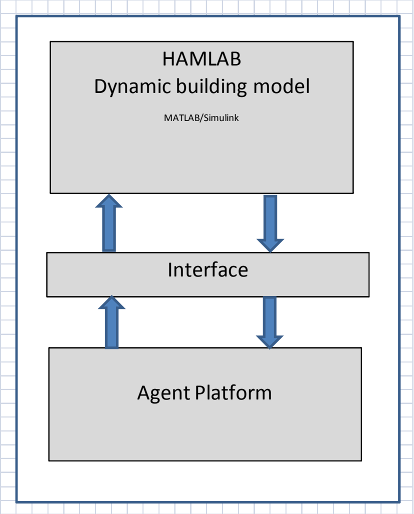


Figure 2. Simulation set up as used in the case study. The HamBase model represents the dynamics of the building, an interface is used to connect to the MAS system. [pennings 2009]

The climate control-system consist of a central air-conditioning unit who pre-conditions the air, per room it is possible to post heat/or cool the air to reach the desired comfort in the room (figure 3). The commodities (heating or cooling) used to condition the rooms have to be distribution over the central AHU and the local units HC1 and HC2.

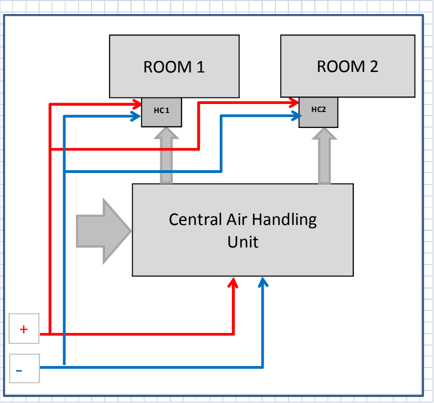


Figure 3. Central AHU and local room conditioning units.

Interdependent Resources.

The local operating agents each representing and have as task to realize the desired condition in their room. Each agent receives their needed commodity (heating or cooling) through either the central system or through the local unit in the room. The 'heating' and 'cooling' markets decides which amount of the desired commodity is supplied through the central AHU or through the individual unit in the room. Trough a bidding mechanism the optimal distribution of heating and cooling is realized. The difficulty is that a change on a local market will have effect on the central market and vice versa. This general effect is explained in figure 4 where a shift on market A leads also to a shift on Market B.

This interdependence needs an optimization algorithm to reach global optimization. The room-agents act only locally, so in order to find an optimum over more than one market an optimization service is introduced in which all the local markets participate. The optimizer is used to settle the auction on the local markets. The used structure of the MAS system is given in figure 6. For each room a comfort 'market' is introduced these comfort market compete with the central air-handling unit on a heating and cooling market.

Heating and cooling are delivered either to the central air handling unit or directly to the room through the individual units per room. The setting of the outlet temperature of the central unit is used for the calculation of the needed amount of cooling/heating by the local units. The global optimizer leads to the optimum setting of the outlet temperature of the central unit.

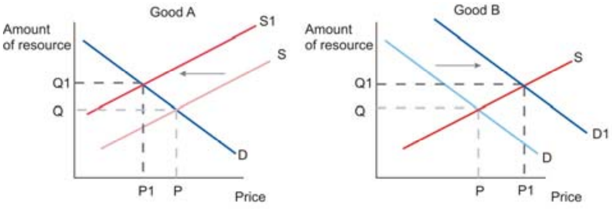


Figure 4. Interdependent markets where events in one market do have consequences in another market. The price of good A falls due to an increase in supply (S to S1). This leads to an increase in the quantity demanded (Q to Q1). As consumers increase their purchase of good A, this will also lead to an increase of good B necessary to process good A. The demand curve for good B shifts from D to D1

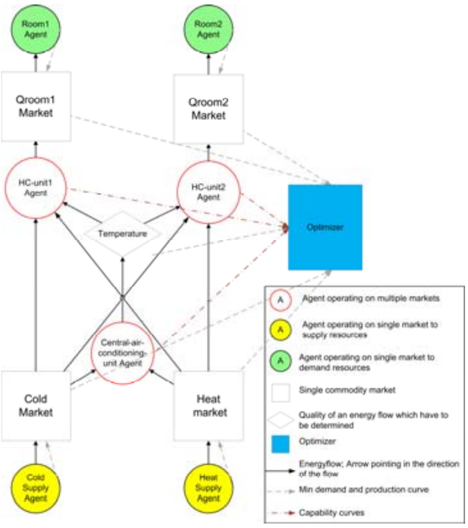
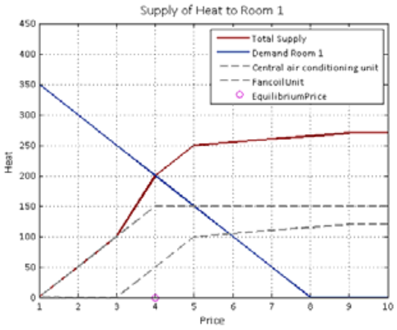
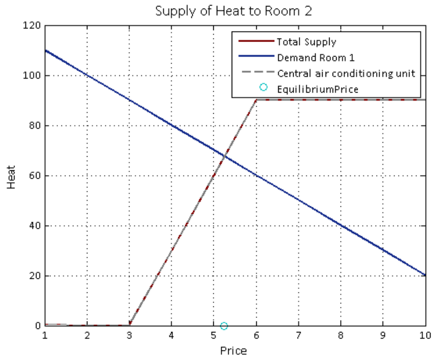


Figure 5 Scheme of used agents in the simulation [Pennings 2009]

The given configuration is simulated with the set-up given in figure 6. In figure 9 the simulation result are given. The simulation is done for a sunny day with moderate outdoor temperature (11-18°C) and a peak solar irradiance of 700 W/m^2. The top graph shows the simulated temperatures in the two rooms, the lower graphs shows the heating- (positive) and cooling- (negative) power flow to the individual and central air handling units.



(a)



(b)

Figure 6. The bidding curves (supply & demand) (a) is the compound of the central AHU and the HC1 for room 1 and (b) shows the bidding for room 2, where no additional heat of the HC2 is required.[Pennings 2009]

The curves of figure 6 show the bidding at point ○;2 in figure 7. The heat delivered by the central AHU is sufficient for room 2, while room needs additional heat from the fan coil unit HC1. At point ○;8 in figure 7, instabilities occurs. These are caused by the slow dynamic response of the building. These instabilities are related with the time-interval of the available data in the simulation. This resulted in higher temperature differences over a short time interval. In further research the stability needs further research..

From the results of figure 6 can be concluded that the interdependencies of building systems lay in the resources, related to energy flows, which they exchange. From the simulation results there can be concluded that the agents are adapting depending on the situation on the demand for energy, there can also be concluded that they find the optimal energy efficient operation strategy together. Some improvements are necessary order to reach stable operation. and comfortable by adapting the demand for energy dependent on predication of future demands.

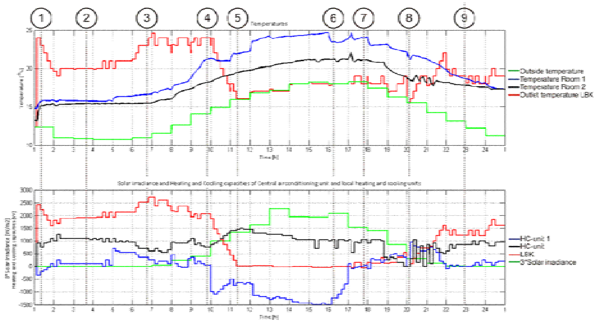


Figure 7. Results of the two room building. At ○;1the simulation started, the agents of the central and individual units start with an initial capacity 0 and need to find an optimum in heating and cooling capacity. ○;2 As expected the central AHU delivers a minimum amount of heating to both rooms. For room 1 (HC-unit 1) needs no additional heating, HC-unit 2 delivers additional heat to meet the required temperature. ○;3Both room units start to deliver extra heat. This is because the room-units have a faster response time; the central AHU is limited to a max. change of 0.1K /s. ○;4 By adjusting the tuning parameters for the bidding of the AHU range can be adapted. ○;5While room 1 needs cooling and room 2 still heating, the AHU just supplies air with outdoor conditions. ○;7The temperature of room 1 go to the minimum allowed temperature, due to the fact that the cooling load is changing into a heating load. ○;8 Oscillations occur due to slow response of the AHU. ○;9 Stable operation again.

Discussion and Conclusions

The in this paper proposed multi-agent system is based on a simple market oriented approach to determine for what price a good or service can be exchanged. Agents define their demand and production of resources and trough a adaption of their bid price for a commodity the desired goal can be achieved. The introduction of inter depended markets complicates the solution. With the introduction of a central optimization function the local operation of the agents could be maintained.

Events in one market do have effect on other markets. It is a challenge to ensure system stability in more complicated systems. The centralized algorithm for the two room building was capable of making a good tradeoff of the multiple objectives and was able to approach the optimal settings of the system without an increase of the energy efficiency. The desired thermal comfort could be realized.

In the two room simulation the desired goals: local operation of the agents; thermal comfort; and optimal energy use, could be realized, though it led to a complicated set of markets and agents. For further research a simplification of the setup is desired. A MAS system is a flexible system and with the realized simulation environment different schemes can easily be tested before applied on a real live system.

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