

# **DESIGN OF AN AGENT ARCHITECTURE BASED ON THE POWERMATCHER APPROACH FOR COORDINATION OF HEATING AND COOLING IN BUILDINGS AND DOMESTIC DWELLINGS**

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## **ABSTRACT**

A lot of simultaneous processes do occur in a building. With the increase of the number of devices for heating and cooling of the building, there is a higher risk of one device counteracting the other. This leads to unnecessary loss of energy. It is becoming harder for conventional comfort control systems to satisfy the objective: 'provide thermal comfort at the lowest energy use'. Multi-agent systems for climate control can offer a number of advantages in this field because of their bottom-up modelling principle starting from the low-level primary process, in this case comfort control.

The aim of our research in the Flexergy project is to design a Multi-agent climate control system for buildings and domestic dwellings as well. In the process of obtaining this, an intermediate goal as an objective for a study was spontaneously formulated.

During the operation of a central control system for a representative office building in the Netherlands, it was observed that, due to high insulation, solar irradiance and internal heat sources, the net demand for cooling over a year is higher than for heating. As a heat pump connected to an aquifer was responsible for delivering the cooling power it was also observed that the temperature of the aquifer increased. This decreases the availability of cooling power for the building in near future.

The question was raised how a Multi-agent could help to retain the energy balance of the aquifer over a year. It was suggested that two technical possibilities to retain this balance could be exploited: first to cool the building by outdoor air during the morning hours by an air conditioning unit and second to load cold during the night with a bypass preventing warm air from entering the building.

This study describes the details of a design of a simplified Multi-agent climate control aimed at retaining the energy balance of the heat pump connected to an aquifer, exploiting the ability of the PowerMatcher to trade two or more commodities through the use of the above mentioned methods [2].

## **INTRODUCTION**

In order to achieve an acceptable indoor climate in an office or conference room, different resources are available: mechanical ventilation, heating or air conditioning unit. In the design of these systems the capacity of the resources is calculated according to a standard reference situation. This means that not all of the time the designed capacity is totally used. This leaves

room for optimization of the utilisation of the capacity in place and time. A Multi-agent market approach can be able to coordinate these energy flows to achieve global optimization and obtain decentralized control.

Other benefits of a Multi-agent approach are 1) the generic description of installations 2) plug and play behaviour of appliances 3) adaptation to the circumstances instead of predefined behaviour and 4) no need for flow diagrams. For coordination of electricity there has already been developed and tested a successful concept 'the PowerMatcher'.

The PowerMatcher is designed as a market-based control concept for supply and demand matching (SDM) in electricity network [3]. It is concerned with optimally use of the possibilities of power producing and consuming devices to alter their operation in order to increase the over-all match between power production and consumption. Each device is represented by a software agent that tries to operate the process associated with the device in an economically optimal way, so no central algorithm is needed. Furthermore the communication overhead between software agents and an auctioneer, who performs the price-forming process, is very limited. The only information that is exchanged between the agents and the agent platform are bids. These bids express to what degree an agent is willing to pay for or receive a certain amount of power. Since bids are constructed in a process of weighing the profits versus the costs, bids are a projection of the utility function of the agent. As a response the market clearing price is returned, so the agent knows how to act, start producing (resp. consuming), or wait for the next event to happen and adjust its bid. The auctioneer searches for the equilibrium price and communicates a price back whenever the price changes significantly. It has been shown that the PowerMatcher agent concept works very well for virtual power plant control [4].

The same concept can also be used for coordination of heat flows. Huberman & Clearwater [5] have claimed success with a Multi-agent system for the climate control of large buildings with many office rooms. Based on their work Ygge & Akkermans [6] proposed an alternative market design which was formulated as a quasi equation: "local information + market communication = global control".

Before describing our test case some general remarks must be mentioned. A major difference between the electricity market and heat market is the need of scheduling. Whereas electricity is almost immediately available, with heat there is time delay. Although this is not discussed in this study, one of our goals is to find a design that incorporates a solution to this problem.

Apart from controlling the thermostat or complaining about comfort, until now the user has not been part of the building comfort system control strategy in offices, the energy consequences of the user behaviour are not accounted for. In this study the user is not part of the model. However, in the building management systems the user will be the central point as not the temperature in a room but the perception of temperature by the user will be input to construct the bid that expresses the demand of the system.

Also, Multi-agent systems as a technological solution for making renewable energy solutions should be natural, easy and intuitively understandable for architects and consultants. The challenge is to design agents in such a way, that they can be implemented straightforwardly with only little configuration and always be able to work together with other agents without knowing the others technical details and intelligence.

This study is not limited to control the comfort in buildings. The PowerMatcher can also be used for domestic dwellings. It is possible to use it straightforwardly for situations where in case of a black start the demand of heat pumps of the dwellings might exceed the maximum load of the local substation.

In this paper the PowerMatcher approach is applied to the regeneration of a seasonal heat/cold reservoir (aquifer).

### THE NEED FOR AN AQUIFER BALANCE

Within the Flexergy project context it was observed that the demand for cold of a building, representative for the Netherlands, exceeds the demand for heat. As the cold is supplied by a heat pump connected to an aquifer, this results in a temperature raise of the aquifer, which deteriorates the reliability of future cold demand and has environmental consequences. The need for control of the aquifer energy balance was suggested, using Multi-agent climate control.

Table 1 contains the suppliers for heat and cold for an actual building at Utrecht. The heat pump is designed as the main supplier. District heating should only be used as a backup for days when the power needed (heat demand) is larger than the heat supplied by the heat pump. The air conditioning unit is located on the roof and offers the opportunity to load cold at hours where the outdoor temperature is still low, whereas there is also a cooling demand of the building. Such conditions generally occur during the morning and the late afternoon in autumn and spring.

|      | Main supplier | Backup           | Flexible              |
|------|---------------|------------------|-----------------------|
| Heat | Heat pump     | District heating |                       |
| Cold | Heat pump     |                  | Air conditioning unit |

*Table 1: Suppliers for the energy of the building.*

The technical design of the building will in near future incorporate a bypass from the air-conditioning unit to the heat pump, enabling the possibility of loading cool outdoor air without warm air entering the building. This offers the opportunity to load cold during the night when the outdoor temperature is low. Such operation is of course at the expense of the energy efficiency of the building, as electricity is consumed by the pumping devices. So the price of electricity, which is generally low during the night, plays an important role here.

### DESIGN OF AQUIFER BALANCE STUDY

The design for an energy balance study is shown in figure 1. Note that there are two agents controlling the same device, the heat pump.

#### Two commodities

In this design discrimination can be made between the left part in figure 1 where the trading for the heat demand of the building occurs and the right part in figure 1 where the trading of the cold demand occurs. So, there are two markets and hence two separate PowerMatcher networks for two commodities: heat and cold, which are simultaneously trading. As can be seen the “District heating agent”, the “Heatpump Heat agent”, the “Heat auctioneer” and the “Hourly Heat demand agent” balance their supply and demand by trading heat.

#### Aquifer

Two types of building blocks are visible in figure 1, the rectangular one representing an agent, the parallelogram representing input data. Only the “Dynamic Aquifer state” is also output, here the heat pump agents can write the amount of energy they have consumed (heat) or have loaded (cold). The data in the “Building Data demand” is able to secure whether there is only heat or cold demanded, thus preventing the conflicting state where both the “Heatpump Cold agent” and the “Heatpump Heat agent” offer energy. However, the design offers the

possibility to have a heat and cold demand as well. This is due to the possibility for the agents to write to the dynamic aquifer state whether the heat pump is already employed for either state. The agent's intelligence will guard that only supply will be offered when it is permitted by the value of this state (see below the explanation at figure 2).

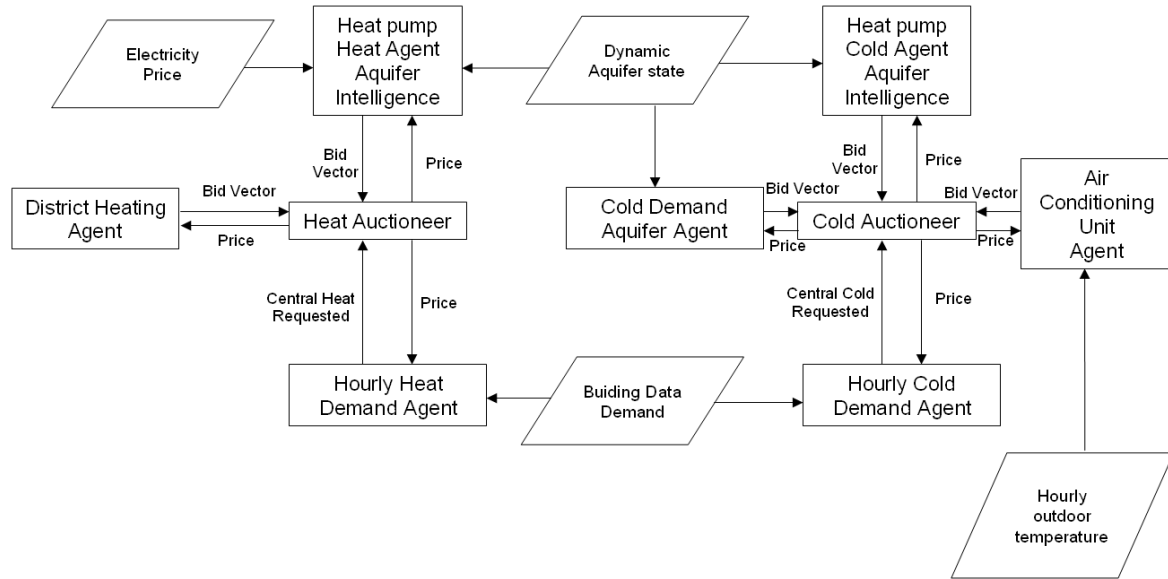


Figure 1: Design of a energy balance study for an aquifer using two commodities. The building data demand may secure whether only heat is demanded or cold and resp. in the left part allocation for heat takes place or in the right part allocation for cold takes place.

## Demand Agents

The “Hourly Cold demand agent” for the cold commodity and the “Hourly Heat demand agent” for the heat commodity are agents which accept any price for their consumption, though still preferring the supplier offering power at the lowest price. So for heat, either the “District Heating agent” or the “Heatpump Heat agent” will supply. When the aquifer needs cold, the “Heatpump Heat agent” wants to deliver and the agent simply has to adjust its bid resulting in a price that is just below the price of the “District Heating agent”.

## Supply of cold to the building and the aquifer

The most interesting part of the design is in the network for the cold commodity. The heat pump can offer cold depending on the state of the aquifer. With the knowledge of historic data in the “Dynamic Aquifer state” it can calculate how much energy it still can offer, depending on the season and the expected price developments. The price is high when it concludes there is a small amount of energy left in the aquifer in view of the expected period to the maximum exhaust level. The “Air conditioning Unit Agent” can offer cold only at times when the outdoor temperature is low; at low price. This occurs mainly in the spring and autumn during early morning hours. The aim of course is to cool the building with outdoor air, avoiding further heating of the aquifer.

To elucidate the generation of bid curves figure 2 explains some situations. It shows the expected state of the aquifer during a year as a dashed line. In situation 1 and 2 the cold well of the aquifer contains too less energy related to the expected state of energy, so it is not willing to pay for production of cold. In situation 3 there is an excess of cold, so it is willing to offer cold at even a very low price.

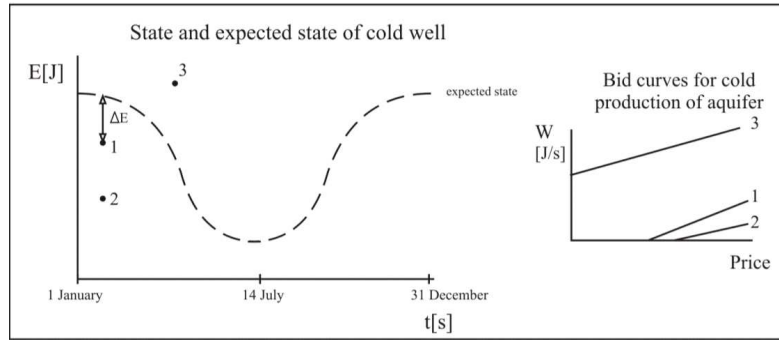


Figure 2: Generation of bid curves for discharge of the “Heat Pump Cold agent” dependent on the state and expected state of charged energy in the well.

Another way for the aquifer to retain its heat balance is introduced by an extra agent called “Cold Demand Aquifer Agent”. Outside working hours, depending on the state of the aquifer the agent may demand cold. Especially during the night when outdoor temperatures are low it will demand cold, which is physically merely transferred to the aquifer. The price for such a demand will be low. Of course only the air conditioning unit should supply this cold. The intelligence of both the “Heatpump Cold Agent” and “Cold Demand Aquifer Agent” must be tuned to prevent the system from wasting energy with the heat pump pumping cold just to bring it back to the aquifer.

### Some final remarks

For this simulation purpose it will be sufficient for the network to operate at a time schedule of one hour intervals, since the energy balance covers a year.

The “Building Data demand”, which is just a static input file, is retrieved by processing the data from the building at Utrecht. From the original data of the building, containing the original actual energy production of the heat pump and the loaded as well as the unloaded energies at the aquifer, the actual heat or cold demand of the building during one year is calculated.

The prices at which the heat pump Agents and the air conditioning unit offer their energy depend also on the price of electricity. These prices can be read from a text file “Electricity Price”, which can be generated from Dutch day-ahead electricity prices “APX prices”.

### DISCUSSION OF DESIGN OF AQUIFER BALANCE STUDY

The above design exemplifies the capability of the PowerMatcher to use two commodities in a simplified climate building control system. Two methods are possible in this design to load cold to the aquifer in order to retain the heat balance. One is possible when outdoor temperatures are low and the building has cooling demand. The other is possible at night when the outdoor temperature is low and the price of electricity is low as well.

This study might as well be extended using more commodities than just heat and cold. The heat pump e.g. buys electricity on an electricity market. So a heat pump agent trading merely on the heat market but also on the electricity market is more realistic if there are more electricity providers e.g. from renewable energy resources. This is technically possible with the PowerMatcher and where future research is further aimed at.

There is some limitation in the design of the aquifer balance study with respect to building climate control. This becomes most visible when the “Air Conditioning Unit Agent” is

discussed. The building demand for cold is the highest during the summer in the afternoon. Then supply of cold by the “Air Conditioning Unit Agent” is not possible, as the outdoor temperature is generally high. When the PowerMatcher system is used without any forecasting or scheduling mechanism it represents a real-time market. The control is based on the current state of the process. One solution to solve this may be the introduction of an extra Option based market, where heat or cold can be bought in advance, likewise the way it is handled in the real world electricity market system. Options, then, provide the long term modelling view and the bids the real-time adjustment view. Another possibility is the use of an external computational program estimating the heat or cold demand for the next 24 hours and use combinatorial optimization [7] to get the optimal installation components production profile. This will be the input for agent based architecture for coordination of heating and cooling in buildings.

The purpose of the project is to prove the validity of the design must be proved through simulations. The intelligence of the agents will be useful in further developments of the heat matcher, based on the PowerMatcher.

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