Evaluating the district energy performance
Using a multi agent system

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Abstract: Despite the availability of many energy performance calculation methods, local governments, property developers and housing associations find it hard to define solutions for the built environment. A decision support tool is developed to help decision makers choosing suitable energy saving solutions for a district. A multi agent system (MAS) is considered for the development of the energy evaluation model. In a case study of a district with individual and district HVAC systems, the usability of the MAS is tested. The prototype built in Netlogo shows energy evaluation with agents is possible, but more work is needed to fully apply the advantages of a MAS.

1.   INTRODUCTION

1.1   Decision support tool

New plans are being made for Kyoto's runner up, while most countries are still struggling to achieve the targets for 2012. The built environment, accountable for 40% of the total CO_2 emission, plays an important role in meeting the emission targets. The building industry realizes this and tries to develop energy efficient buildings. Unfortunately, the large amount of possible (complex) energy efficient measures and individual building projects make it hard for decision makers to define energy efficient

solutions. A decision support tool could help them choosing suitable energy saving measures for a building project.

The objective of the research project discussed in this paper, is to develop an energy evaluation and optimization model for the built environment.

1.2   Requirements

The increased attention for energy efficient buildings has not made it easier for players in the building industry. There a lot of different definitions for zero energy buildings (W/E adviseurs, 2009) and at least the same amount of energy calculation methods (IEA Annex 31, 2004). These methods all have different qualities (Vreenegoor, Hensen, et al., 2008a). Some tools are useful to compute the energy performance of one building and others of a group of buildings. Some are focussed on residential buildings and others on commercial buildings, existing or new buildings. The type of rating can differ from dynamic simulation, to simple calculation or even a checklist. A lot of countries have developed an energy performance calculation specialized for their situation. To enlarge the usability of the evaluation model, it should be independent of the energy calculation method.

More and more energy saving issues occur at the district, city or municipality level instead of the building level. Cities are almost bidding against each other with ambitious energy saving and CO_2 emission reducing targets. At these levels, district systems become more attractive to apply both financially as well as energy efficiently. Together with a lack of energy performance calculation methods at the district level, it is more difficult for decision makers to find the optimal design solution for their building project. Therefore the decision support system should be at least at the district level.

To fulfil the requirements, a multi agent system (MAS) is proposed for the development of the energy evaluation model.

2.   ENERGY EVALUATION MODEL

2.1   Meta-diagram

A meta-diagram (*figure 1*) is designed for the energy evaluation model. This meta-diagram considers a unit, household, technique and connection type. These classes are clarified in the following text.

The unit describes a living space, this could be a terraced house but also an apartment. This unit can be part of a group of units, like an apartment is

part of an apartment building and a terraced house is part of a district. In the unit lives a household. The household is a separate entity in the energy evaluation model because their behaviour has a large influence on the eventual energy consumption (Vreenegoor, Vries et al., 2008b).

The unit is connected to one or more techniques. This link is described by the class 'Connection type' with the attributes type, direction and properties. The attribute 'type' describes the type of energy, like electricity, heat or sun, and 'direction' shows the direction of the energy flow. A technique can be described as an instance that has an energy demand and/or offer, for instance a building system, power station or the sun.

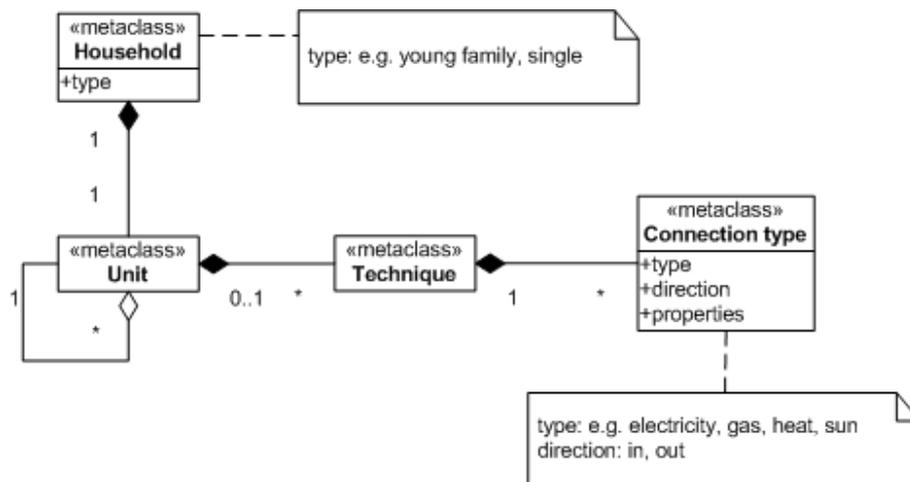To test the meta-diagram, it is applied in a case study which is described in the next paragraph.

Figure 1. Meta-diagram energy evaluation model

2.2   Case study

A small district is designed for implementation of the meta-diagram. This district consists of in total 21 dwellings, divided over three blocks of terraced houses and three blocks of semi-detached houses (*Figure 2*). The first block of terraced houses is build before 1946 and has a (Dutch) energy label 'E'. The second block is from the building period 1976 - 1979 and has a D-label. The third block of terraced houses, with a C-label is build between 1989 and 2000, The semi-detached houses are build before 1966 and score a F-label.

In the case study reference values (SenterNovem, 2007) are used for the building construction, systems and energy performance.
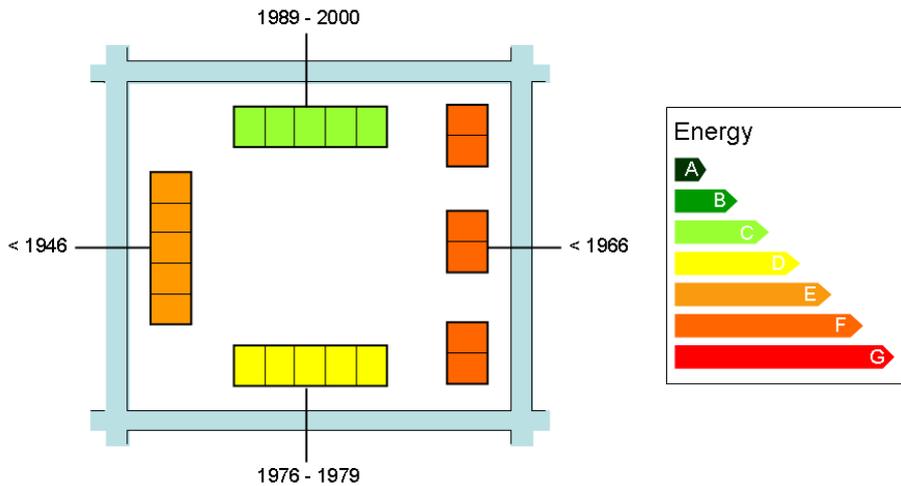

Figure 2. Case study: district of 21 dwellings

To see if the meta-diagram of the energy evaluation model can be applied at the district level, two variants of the case study are developed. In the first variant, the houses receive individual building systems: a boiler for heating and solar panels to generate electricity. In the second variant a combined heat and power generation system (CHP) is used for heating and power generation at district level. The ventilation system in the houses is kept the same as the reference value.

Table 1. Class instances case study

Class	Instance
Unit	- District
	- House group
	- House
Household	- Profile1
	- Profile2
Technique & connection type	- Electricity network
	- Gas network
	- DHW network
	- Heat network
	- Boiler
	- CHP
	- Solar panel
	- Solar energy

2.3 Instances of meta-diagram classes

Table 1 shows the class instances needed for the case study. In the next paragraphs the class instances are explained.

2.3.1 District, house group and house

As mentioned before the class 'Unit' describes a living space like a house or apartment. A house has a demand for hot water (heating and domestic hot water), electricity (appliances), gas (cooking) and cold water (cooling). The later is left aside in this stage of the research. In the house a certain household is living which influences the energy demand. A house can be part of a group of houses.

The house group could consist of one or more houses like an apartment building or block of terraced houses. The district could consist of one or more house groups like a neighbourhood, city or municipality.

2.3.2 Household profiles

The household profiles describe a household living in a unit. The household influences the energy demand of the unit. In the energy evaluation model multiple profiles will be implemented. These profiles determine for instance how high the inside temperature is in the winter, how many residents live in a unit, what their activity schedule is in the house, etcetera.

2.3.3 Energy networks

To gather the energy offers and demands, fictive energy networks are introduced at building, district and national level. The later could be the actual national power and gas station. The energy networks are considered to be from the class 'Technique'. Four different energy networks are distinguished: electricity, heating, gas and domestic hot water (DHW). The network receives energy from one or more energy generating techniques and delivers energy to demanding techniques and units. When the energy demand at unit level is larger than the offer, the district (or national) network will support the loss-making network.

2.3.4 Boiler

The boiler describes a high efficient combination boiler. The system receives gas from the gas network and produces hot water for heating and domestic hot water. The hot water is supplied to the heat and DHW network

of the unit. The boiler is an individual building system and therefore connected to one unit.

2.3.5   CHP

The CHP is a combined heat and power system which operates at the district level. The system receives gas from the gas network at district level. This is used to produce hot water, for heating and domestic hot water, and generate electricity for a district. The CHP is connected to district energy networks.

2.3.6   Solar panels

The instance solar panel is a photovoltaic panel. These panels use solar energy to generate electricity. In this case study the solar panels are individual systems and therefore belong to one unit. The generated electricity is offered to the electricity network of that unit.

2.3.7   Solar energy

To implement the sun, an instance 'solar energy' of the class 'Technique' is created. This technique offers solar energy to the complete district. In this case study only the solar panels make use of this energy, in a future case multiple techniques could also make use of the solar energy like a solar boiler.

2.4   Application in practice

Figure 3 shows the diagram of class instances in case of an exciting district. The diagram consists of a district called Woensel. This district consists of six house groups in total: three groups of 'terraced houses' and three groups of 'semi-detached houses', with respectively five and two houses (total of 21 houses). In order to show a more orderly diagram, the amount of houses is limited in *figure 3*.

One of the houses is specified in *figure 3a*. In each house lives a household of a certain profile. The houses are connected to four energy networks of the type electricity, gas, heating and domestic hot water. These networks deliver energy to the house. At unit level the boiler provides heating and domestic hot water to the matching networks and demands electricity and gas. Solar energy is delivered to the total district. The solar panel uses this energy to generate electricity and delivers it to the electricity network.

At district level again four energy networks are situated. These networks deliver energy to the networks of the units in case the unit is connected to a district system. In the case study a CHP system produces hot water and generates electricity for the matching energy networks. The CHP system asks gas.

In case the demand side of the electricity and gas network at unit level is larger than the offer, the shortage of energy is demanded from the energy networks at the district level. In case the district networks cannot deliver enough energy, the demand is met by the national gas and electricity network.
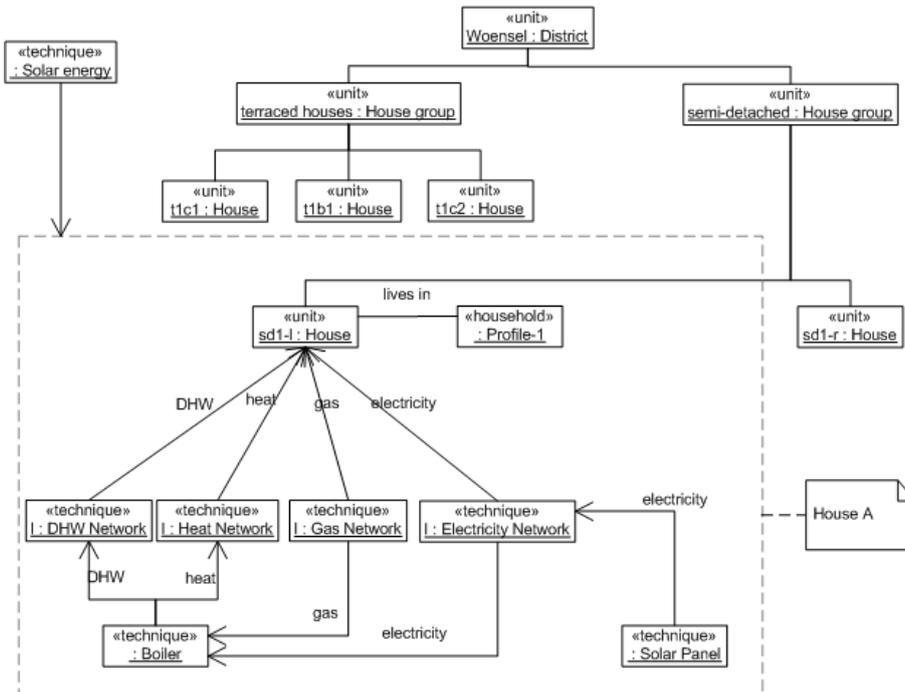

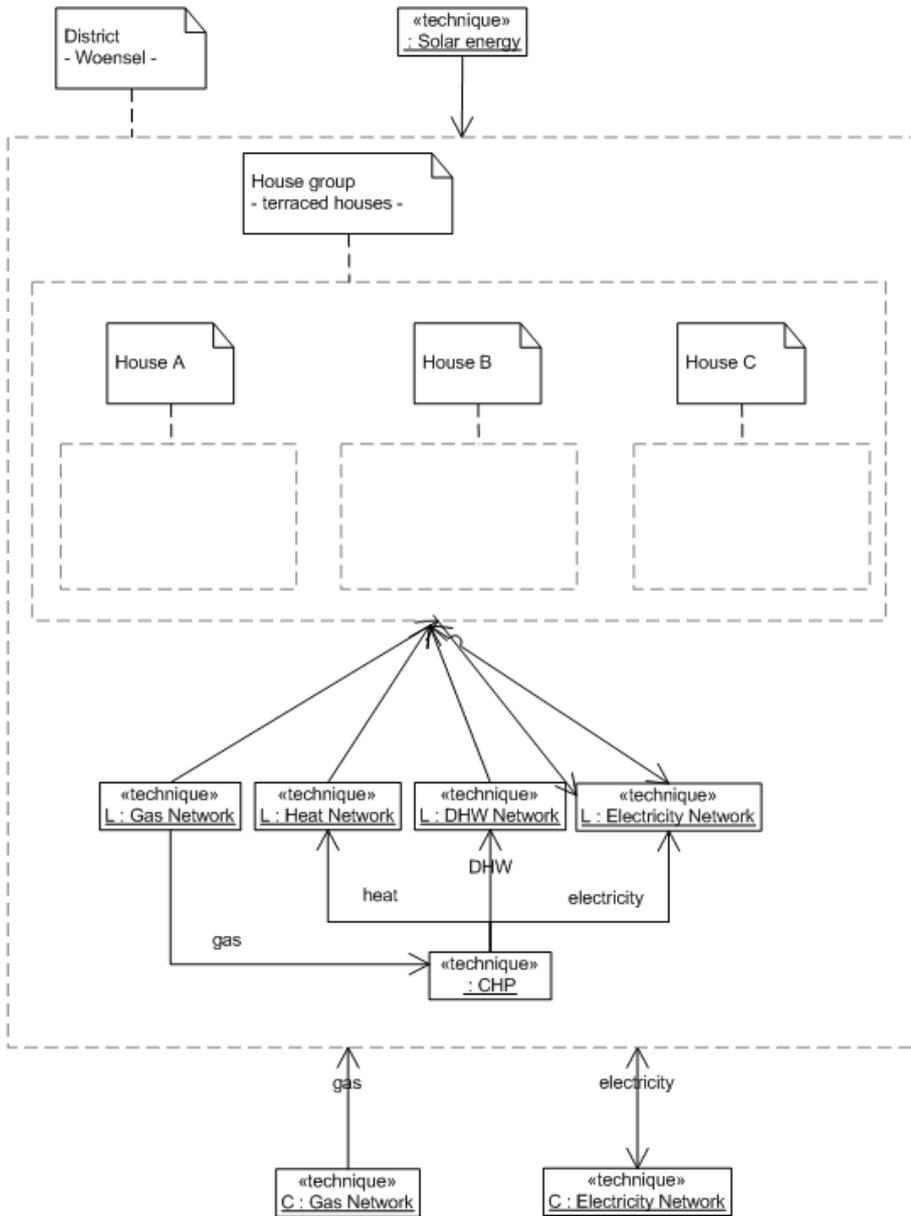*Figure 3a.* District energy evaluation model of case study – unit level

Figure 4b. District energy evaluation model of case study – district level

3.   MULTI AGENT SYSTEM

A multi agent system (MAS) is a system of multiple interacting software agents. An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives (Weiss, 1999). MAS can be used to solve all kinds of problems, like online trading, disaster response and modelling of social structures.

In the field of energy and the built environment the use of agents is still limited. In paragraph 3.1, three interesting agent models are discussed.

3.1   Other work

3.1.1   Energy flow and comfort optimisation

This MAS (Pennings, 2009) is developed to control building systems. The building systems exchange energy (e.g. electricity, heat, hot water) to perform actions. To exchange the energy, the market mechanism is implemented in the MAS. Some building systems are dependent on the allocation of multiple energy resources. Therefore an optimization technique is used to find the optimal configuration of building systems with multiple energy markets.

The MAS is programmed in C#. The main functionality of the MAS is to coordinate the energy flows in the building and find optimal settings of systems operating in an environment. The dynamic processes of the building and its systems are simulated in Matlab. A simulation agent is used for the interface between Matlab and the multi-agent environment. Each building system is represented by an agent. The agents produce and/or consume energy. Exchange of energy is dependent on the price of the specific energy on its exchange market.

The research showed a case study with a building consisting of a central air conditioning system and local heating and cooling units. Compared to a conventional control system, the case study pointed out that the energy consumption can be reduced using the developed MAS, while comfort is maintained within the range of user preferences.

3.1.2   Power management

Our electricity consumption is growing and is expected to rise even more. For several reasons, decentralized electricity generation is coming up. As a result, the current electricity infrastructure is expected to evolve into a

network of networks, in which all systems parts communicate with each other and influence each other (Kok, Warmer, et al., 2005).

Several multi agent systems are developed to control the matching of supply and demand in electricity networks (Oyarzabal, Jimeno, et al., 2005), (Trichakis, 2009), (Roossien, 2009). The operation of most of these MAS is the same. Therefore further explanation of MAS for power management is in this paper limited to one. ECN (Energy research Centre of the Netherlands) has developed a market-based MAS, called PowerMatcher. In the PowerMatcher each generator, electricity consuming installation and electricity storage is represented by a control agent. The agents negotiate and buy or sell the consumed, respectively produced, electricity on the exchange market.

In a field test the electricity demand and supply of nine dwellings with CHP systems were controlled. The use of the PowerMatcher led to a reduction of 30% of the peak load of the electricity network in a summer period (Roossien, 2009).

3.2   Modelling environments

Multi agent systems can be programmed from scratch or you could make use of a software framework. There are several free agent modelling environments available like JADE, Repast Symphony, MASON, Swarm and Netlogo. All of these modelling environments offer several generic services to simplify the implementation of multi agent systems. JADE, Repast and MASON are developed in Java. Swarm is developed in Objective-C and a Java version allows Swarm Objective-C libraries to be called from Java. Netlogo provides its own simple yet powerful programming language.

JADE (Java Agent DEvelopment Framework) is specialized for development of applications that require negotiation and coordination among a set of agents, where the resources and the control logics are distributed in the environment.

Repast (Recursive Porous Agent Simulation Toolkit) started as a Java implementation of Swarm and is certainly the most complete Java platform (Railsback, Lytinen, et al., 2006). Many classes for geographical and network functions are included.

MASON (Multi-Agent Simulator Of Neighbourhoods) offers relatively few tools which makes it more appropriate for experienced programmers. MASON is suitable for computationally intensive models.

Swarm provides a fairly complete set of tools. The swarm concept, a hierarchy of separate swarms each with its own collection of objects and schedules of their actions, helps to organize models and is therefore suitable for complex MAS.

Netlogo started as an educational tool, is easy to use and well documented. The Netlogo programming language makes it suitable for less experienced programmers. Starting to build a model in Netlogo can be a quick and thorough way to explore design decisions (Railsback, Lytinen, et al., 2006).

3.3   MAS for energy evaluation

The examples described in 3.1 are market-based. This seems a very logical approach for the evaluation of the energy consumption in the built environment. After all, the building industry is interested in both energy efficient as well as economical solutions. The MAS described in paragraph 3.1 are for controlling building and/or district systems. One of the challenges in this research project is to find out if agents can be used to evaluate the energy performance and optimize the district design. To test this, a first prototype is implemented in Netlogo because of the advantages mentioned in paragraph 3.2.

In this first version of the energy evaluation model the following agents are implemented: unit, boiler, solar panels and four different energy networks. There are seven types of units based on the dwelling type (end house, terraced house and semi-detached house) and the building period as described in paragraph 2.2. The agents are linked as shown in *figure 3*. For the energy performance simulation a time step of 3 hours is chosen to enable the design of the household behaviour and sun rise and setting.

The energy evaluation model is independent of the energy performance calculation method. Therefore an external file (.csv) is used for the energy performance values. This file holds the values for the energy generated by the solar panel, electricity demand for appliances, gas demand for cooking, heating and domestic hot water and the electricity needed to run the boiler. The values are obtained from reference dwellings (SenterNovem, 2007, VROM, 2009) and converted into the unit 'MJ/3 hours'.

For each boiler, solar panel and unit an energy consumption schedule is made to implement the household behaviour and sun rise and setting. *Table 2* shows examples of the schedules for the heating demand, solar rise and setting and electricity demand for appliances. The schedules take the heating season and longer daylight period in the summer into account. The schedules can differ per household type.

In the Netlogo interface, the user can change the beginning and end time of the calculation period to examine for instance the energy consumption in the winter or summer period. The links are used to pass the energy demands and offers to the energy networks per unit. The evaluation model returns the electricity and gas consumption per unit and for the whole district.

Table 2. Schedule for solar energy, heating and electricity demand

Time step		Solar panel	Heating	Electricity
1	(00.00 – 03.00)	0	0	0
2	(03.00 – 06.00)	0	0	0
3	(06.00 – 09.00)	Qpv	heating season: Qh else: 0	Qe
4	(09.00 – 12.00)	Qpv	0	0
5	(12.00 – 15.00)	Qpv	0	0
6	(15.00 – 18.00)	Qpv	0	0
7	(18.00 – 21.00)	summer: Qpv else: 0	heating season: Qh else: 0	Qe
8	(21.00 – 00.00)	0	0	Qe

4.   CONCLUSIONS

4.1   MAS for energy evaluation

The meta-diagram described in paragraph 2.1 is implemented in Netlogo. The first prototype showed it is very well possible to use a multi agent system to calculate the energy consumption for a district. Netlogo provided an easy to use agent framework and supported quick prototyping, but the full advantage of a multi agent system is not yet fully applied.

4.2   Future work

The energy evaluation model in Netlogo will be further developed. The district systems and networks will be implemented, which will make comparison of individual and district systems possible. Besides that, a market mechanism will be implemented. This mechanism will start negotiation between the demanding and offering agents to find the best price for energy.

To support decision makers in the built environment choosing the optimal renovation solution for a district in need, an optimization technique will be added to the energy evaluation model. In a later stadium of the research project, the type of optimization technique and optimization criteria will be chosen.

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