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A Modelica library for the agent-based control of building energy systems

Felix Bünning, Roozbeh Sangi *, Dirk Müller

Institute for Energy Efficient Buildings and Indoor Climate, E.ON Energy Research Center, RWTH Aachen University, Mathieustraße 10, 52074 Aachen, Germany

HIGHLIGHTS

- A Modelica library for the agent-based control of building energy systems is developed.
- The library offers a variety of cost functions in order to realize different optimization goals.
- The functionality of the concept is proven with a simulation example of a building energy system.

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ABSTRACT

Building energy systems account for one third of the primary energy demand in the OECD member countries. Due to global warming and growing energy scarcity, a higher energy efficiency of these systems is required. As a result, building energy systems become more complex and often contain multiple heat and cold suppliers. The selection of the ideal supplier based on the current system state requires new control strategies. Multi agent systems depict a promising technology for the problem. There are agent-based frameworks available for many programming languages, but not for the modelling language Modelica, which is commonly used for building simulation. In the course of this work, a Modelica library for the agent-based control of building energy systems based on market mechanisms is introduced. The structure of the library, different types of agents, the concepts of agent communication and the trading of capacity adjustments are discussed. The library offers a variety of cost functions in order to realize different optimization goals. The functionality of the concept is proven with a simulation example of a building energy system controlled with agents from the introduced library. The system depicts a plug&play solution to optimize the performance of complex building energy systems with interchangeable optimization goals. Due to communication via Ethernet, the control system can be coupled to real energy systems.

1. Introduction

In the course of advancing global warming, which is associated with certain substances in the atmosphere, more and more laws regarding the conversion of energy have been passed with the aim of lowering the emission of said substances. Simultaneously, these policies aim at lowering the dependency on fossil fuels whose finiteness might otherwise lead to shortages in energy supply.

A large share of the primary energy demand in the OECD member countries is held by air conditioning and heating as well as hot water applications. On a global level, low temperature heat accounts for 44% of the world's total final energy demand [26]. Consequently, this area also underlies policies with increasing severity. Taking into account that renewable energy sources for the building sector such as photovoltaics, heat pumps and combined-heat-and-power units are becoming profitable, such components are installed in private and commercial buildings with increasing quantity. Often more than one of such components are operated in parallel to increase cost effectiveness and the security of supply.

Consequently, the complexity of building energy systems has severely increased in the recent past. Therewith the need for controlling concepts that can handle such complexity has arisen. Besides concepts like Model-Predictive control and Artificial Neural Networks, the concept of agent-based control realized through Multi-Agent Systems (MAS) promises good results in the area of HVAC control.

Multi-Agent Systems were successfully applied in the areas of logistics and telecommunication in the past [39]. Inherently this concept is suited to solve complex control problems and is there-

* Corresponding author.
E-mail address: roozbehsangi@gmail.com (R. Sangi).

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fore predestined for the control of complex energy systems. For the development of such systems, tools for multiple programming languages and programming environments are available [2], but not for the object-oriented language Modelica.

Modelica is a modelling language commonly used for the dynamic simulation of thermo-hydraulic systems. It is receiving growing attention in the use of modelling and simulation of building energy systems, as recent studies indicate: In Wetter et al. [43] a Modelica library for the simulation of building energy systems is introduced. Ali et al. [1], Perera et al. [28], Sangi et al. [34] and Fuchs et al. [14] use Modelica in order to model, simulate and investigate in building energy systems as well as district heating systems. MAS will play an important role in the control of future building energy systems (see Section 2.2). Consequently, a Modelica library for MAS is needed.

In the course of this work a library for the agent-based control of building energy systems in the modelling language Modelica is developed, implemented and finally validated in a case study. The library allows "plug-and-play" implementation of MAS into any model of a building energy system in the Modelica environment, thus allowing the investigation in agent-based building energy system control through dynamic simulation.

Different from all other MAS (to the best of the authors' knowledge), the presented MAS depicts a solution that through UDP/IP-communication can be run on distributed machines, enabling the user to integrate both software and hardware into the optimization problem. Furthermore, the cost functions can be changed without interfering with the agent system leading to a flexible solution in which the individual user can optimize their energy system for an individual optimization goal with only minor engineering effort.

2. Overview on Multi-Agent Systems

2.1. The concept of agents and Multi-Agent Systems

Agents. The concept of agent-based control is a concept which allows to control complex systems by splitting the main objective of the system into smaller objectives which so-called agents try to obtain by interacting with each other. Although the concept is widely spread in the scientific area, especially in the field of computer science and information technologies, there is no unified definition of the term agent.

After the term first appeared in the context of a dissertation in 1985, in which the term agent is connected with the attributes of autonomy and problem-solving behaviour [32], further attributes such as proactivity and the ability to work towards higher goals [42], the ability to perceive the changes of their surroundings and to react on them [10], the ability of rational calculation and organization of actions to achieve higher aims as well as permanent activeness [21], socialness and truthfulness [4] were defined by various authors.

In VDI 2653 agents are defined as encapsulated entities, hardware or software, with specified objectives. An agent attempts to achieve these objectives through its autonomous behaviour, in interacting with other agents and their surrounding. In addition, several characteristics such as autonomy, scope of action, interaction, encapsulation, persistence, goal-orientation and reactivity are defined.

Multi-Agent Systems. VDI 2653 describes Multi-Agent Systems (MAS) as a set of agents interacting to fulfil one or more tasks. Bellifemine describes MAS as entities that can model complex systems and introduces the possibility of agents having common or conflicting goals. These agents are able to interact with each other both indirectly, by acting on the environment, or directly via communication and negotiation. Depending on their task they may cooperate to reach a common goal or compete to achieve their own aims [4].

An MAS can be used to control complex systems. One advantage over a holistic control concept is the possibility of splitting the often very complex control problem into sub-problems and -tasks and dividing them between the agents. This approach is beneficial for the developer as the analysis of those sub-problems is more accessible than the analysis of the holistic problem and thus also the implementation of the systems solving these problems. Furthermore, an agent-based approach has the advantage of being more easily adjustable during the runtime of the system as new agents can be implemented and added to the system.

2.2. Use of Multi-Agent Systems in energy-system control

MAS have received growing recognition in various fields over the past few years. Beginning in the fields of computer science, such as Human Computer Interaction, where agents help the user depending on their already existing experience with the software, or Information Retrieval, where agents search the Internet for specific information for their user, now agent-based systems have also reached the field of logistics and telecommunication [39]. As a consequence of growing complexity in the various fields of science, MAS also receive growing attention in the fields of chemistry, biology, physics, sociology and economics [21]. In recent years the field of energy generation and distribution has become much more complex due to the increase of renewable energies and the concept of smart- and micro-grids. MAS depict a promising technology to control the described energy systems.

Regarding the use of MAS to control classical smart- and micro-grids, i.e. systems which generate and distribute electricity, a lot of research has been conducted (for example [18,22,23,46,19,20,30,31,44,3]). However, also the use of MAS for complex energy systems for the generation and distribution of heat or cold, such as building energy systems, HVAC systems and district heating grids, has recently gained growing attention.

In Huberman and Clearwater [16] a market-based MAS is used to distribute warm and cold air in an office building. The system uses a double-blind auction procedure in which agents bid to buy and sell warm and cold air. The auction is managed by a central auctioneer. Experiments with a real office building show an even temperature distribution in the building without leading to excessive actuator movement. Qiao et al. [29] introduces an MAS which combines the control of a building energy system with user interaction. The system is built of personal agents, local agents and central agents. Personal agents act as teachable assistants which carry personal user information, such as preferred room temperature, humidity and the current location of the user. Local agents act as mediators, policy enforcers and information providers. The tasks of the central agent are decision aggregation and interfacing services. A similar system based on personal agents, local agents and central agents is used in Yang and Wang [45]. Personal agents are developed to predict user preferences by learning their behaviours. Local agents act as mediators, information providers, decision makers and control executors while the central agent facilitates collaboration between the local agents while regarding the overall system goal. The functionality of the system regarding effective control of the building energy system while satisfying occupants' demands is proven with simulations and case studies.

In Wang et al. [41] a system using only central and local agents is used. The central agent contains the main intelligence of the system. It calculates set point of temperature, illumination and humidity based on user preferences and outdoor information using particle swarm optimization. The local agents use fuzzy controllers to control the actuators in order to reach said set points. In Wang et al. [40] an indoor energy and comfort management system