SIMULTANEOUS OPTIMAL DESIGN AND CONTROL OF FUTURE BUILDING ENERGY SYSTEMS UNDER VARIOUS PRICING SYSTEMS AND GOVERNMENTAL DIRECTIVES

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ABSTRACT

As mandated by several directives issued by the European Union, starting from 2020, new buildings have to fulfil demanding low-energy standards. This new restrictions require the installation of renewable energy technologies, storage systems, and improved insulations. Due to the stringent requirements for such future building systems, the complexity of the design process will increase inevitably. Therefore, this paper presents a design framework for the optimal selection and sizing of such building systems. Various building components are implemented in the framework using mixed-integer linear programming techniques. In order to enable a reasonable comparison of various configurations, the problem solver computes an optimal operating strategy simultaneously. Finally, the impact of regulatory policies and variable pricing systems on the design of the building components are examined.

INTRODUCTION

Increasing energy prices and the more stringent legal regulations for the use of fossil fuels and CO2 emissions of buildings will result in the introduction of more building-integrated production. In addition, with the introduction of a “smart grid” on the supply side, the impact of the interactions between the building and the supply grid increases. Introducing renewable energy sources such as wind and solar power plants will result in a fluctuating electricity production, raising a significant need for balancing power. The so-called “smart buildings” could provide a significant part of this ancillary service.

The design of such smart building systems and its services is a computationally complex task. The variety of building applications, local weather conditions, governmental restrictions and energy tariffs makes it even more difficult to generalize the process of optimal component design. Based on these conditions, the building designer must assure an optimal selection and sizing of the building components, while pursuing the goal of an optimal operation of them.

MODEL FRAMEWORK

The process of simultaneous design and selection of building services is based on a framework previously described by the authors in [Ashouri et al., 2013]. The tool is called the smart building designer (SBD). Figure 1a shows the implemented devices in the SBD framework and the interconnections among them. Certain devices are installed in the building in order to convert the available resources into the appropriate deliverable types of energy. The outputs of the converters are transferred to the building envelope in the form of heating or cooling power, or electricity. However, the energy management system or the optimizer (in the design phase) decides how the power flows are distributed among the converter devices and other parts of the system. The optimizer controls the total input and output energy flows, as well as the internal flows between any two converters.

The storage devices provide an energy buffer between the converters and the consuming devices. In addition, the external block provides gas and electricity to the building system.

The principal optimization problem of the SBD framework is to find the optimal selection and sizing of building components in order to minimize a multi-criterion cost function. Since the optimal design and the corresponding operating problem are correlated, the SBD uses an optimal control approach. Hence, the design process is separated from the control problem. This separation means that if the suggested design is used, no other control strategy yields better results (i.e. a lower cost function). Vice versa, if the building is operated using the suggested optimal control strategy, no other component design is advantageous. Such an approach is referred to as a simultaneous optimization of control and design [Bansal et al., 2002]. The simultaneous optimization of the design and operation is performed for a full year, while the objective is extended to 20 years, which represents a typical life-time of the building services. The total objective function to be minimized consists of three monetary cost terms associated with investment ($O_{inv}$), operating ($O_{opr}$), and discomfort ($O_{dcm}$), as well as a term
representing the subsidies (S) for all devices:
\[ O_{\text{tot}} = O_{\text{inv}} + O_{\text{opr}} + O_{\text{dcm}} - S \] (1)

RESULTS AND DISCUSSION

As concepts such as zero-energy buildings are being introduced by governments, a constraint on the annual energy consumption \( L_{E} \) is introduced. This constraint ensures that all calculated optimal control strategies lead to a maximum annual energy consumption smaller than or equal to the energy limit, within the building envelope. The effect of applying such limitations on the design of the building is shown in Figure 1b. For values of \( L_{E} \) greater than 50 \( \text{kWh/m}^2\text{a} \), the constraint is not affecting the optimization results considerably. Standard devices such as gas boilers (BGA) and heat pumps (AHP) and vapour compression systems (VCS) are selected. As the external consumption limit becomes tighter, local energy production is needed. For a value of \( L_{E} \) smaller than 40 \( \text{kWh/m}^2\text{a} \), a photovoltaic system (PVS) and solar thermal collectors (STC) are integrated. However, the installation of storage devices such as battery systems (BAT) or thermal energy storages (TES) does not seem to be necessary until a very bounding constraint of \( L_{E} \) smaller than 20 \( \text{kWh/m}^2\text{a} \) is applied. In addition, when the dimension of the STC becomes large enough, an absorption chiller system (ACS) replaces the vapour compression system (VCS).

CONCLUSION

The potential for the optimization of building services is increased due to the development of renewable energy sources and storage technologies. In this paper, a modular framework called the Smart Building Designer is described, which enables the derivation of an optimal component design and operation strategy of the building system. The investigations show that the SBD is able to solve the optimization problem for one year in less than 10 min on a typical computer. This ability is mainly due to the accurate but control-oriented formulation of MILP models. The SBD precalculates the required boundary conditions using the raw data such as those gained from meteorological measurements (temperature and solar irradiation), occupancy schedule, and spot-market electricity rates. Due to the modular and flexible framework, the user of SBD are able to optimize arbitrary building systems. The sensitivity analyses also demonstrate how increasing energy-carrier prices or governmental legislation results in different optimal designs.

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REFERENCES
