Energy-saving Buildings Assessment through Stochastic Hybrid Model-based Evaluation

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Abstract. Optimizing the energy consumption of buildings is an increasingly important topic in ICT. Smart Buildings monitor and control their energy consumptions and safety-related aspect through networks of sensors and actuators connected to the Internet. Policies of energy consumption can be adopted to optimize the interactions among the involved nodes, while satisfying required safety and reliability levels. Stochastic hybrid formalisms have been proved a viable solution for evaluating the effectiveness of energy saving solutions for Smart Buildings, to support tuning of the most suitable one.

The analysis and prediction of the energy consumption of ICT systems is nowadays an important research topic, both from environmental and economical point of view. Concerning dependability-critical application domains, as for example critical energy-aware buildings, energy saving must be addressed in conjunction with other properties requested to the system, including reliability, safety and availability.

Recently, Smart Buildings have been introduced to describe different solutions concerning energy optimization and facilities management of intelligent buildings [6, 8]. Examples of these solutions are the monitoring and control of energy consumptions and safety-related aspects through sensors connected to the Internet, and the deployment of renewable energy sources. Quoting [8]:

> *"Buildings account for 40% of energy end-use in the EU and making them more efficient is therefore key in order for the EU to achieve its goals of reducing CO2 emissions by 20%, improving the energy efficiency by 20% and achieving 20% renewable generation by 2020."*

New challenges are represented by the development of sustainable energy-saving and safe solutions for buildings, whose technologies are mainly legacy systems. The optimization of the energy consumption of an air conditioning system is a representative example. Indeed, by adjusting the amount of external air based on the level of occupancy, a healthy level of air can be maintained while optimizing the amount of needed heated and chilled water. Moreover, air toxicity detectors (e.g. carbon monoxide and carbon dioxide sensors) can be used for activating fire suppression actuators (e.g. sprinklers). In the case of chemical laboratory buildings, actuators can also be used for controlling shower decontamination agents and sealing door mechanisms, to isolate the contaminated area.

Smart Buildings can be considered as an instantiation of Cyber-physical systems [5], where sensors and actuators communicate with each others through the Internet and interface with the environment. Hence, communication-centric applications are mainly involved, and energy-saving policies can be adopted for optimizing the energy consumption of the deployed nodes (i.e. sensors and actuators) [9]. For instance, asynchronous messages passing can be adopted to increase the lifespan of sensors and decrease their probability of failure. Indeed, sensors can remain in a stand-by state and interact periodically, instead of being always available. Moreover, a protocol can decrease its energy consumption by reducing the number of messages, and by pre-emptively turning off those nodes that are not involved in the communications. Finally, it is more convenient to turn on those sensors that are closer to the base-station, to reduce the energy consumption.

Stochastic model-based analysis is a valuable approach to analyse and predict energy consumption in combination with other non functional properties, such as reliability, safety and availability. A case study of an energy-saving Cyber-physical system belonging to the railway domain has been previously analysed by the authors [2, 1]. The continuous and probabilistic nature of the involved phenomena has been addressed through stochastic hybrid models. In particular, Stochastic Activity Networks [7] and Stochastic Hybrid Automaton [4], together with Möbius [3] and Uppaal SMC [4] tools, have been adopted to analyse and predict the energy consumption and reliability of the case study.

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