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IFAC-PapersOnLine 49-27 (2016) 313–317

A Multidisciplanary Approach to Improve Energetic Performance in Smart Buildings

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Abstract: The building turns out to be an important source of energy savings that can not be ignored in the goal of reducing energy consumption. But it is impossible to save energy and to reduce the confort of the users. This paper outlines a new research program in which a STIC laboratory and a heat transfer laboratory work together to optimize the performance of existing buildings. It presents an original approach that combines research on new devices that can store heat, on management of various energy sources and thermal and electrochemical storage facilities, and an implication of user in the decision making process in order to take into account his/her feelings by a comprehensive knowledge of the subjective comfort notion.

Keywords: Smart house, supervision, thermal confort models, heat storage / recovery, power management

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1. INTRODUCTION

Fulfil world growing energy needs is a societal challenge that mobilizes worldwide governments, scientific research teams and major players in the economy and industry.

Given the production of electric power, the current position of France is characterized by mass nuclear production units and a power grid suitable for transporting very high power over long distances to consumption points (RTE (2015)). However the report published by ADEME (French Environment & Energy Management Agency), in October 2015, caused quite a stir by considering a realistic energy mix from 80% to 100% from renewable sources by 2050, in France (ADEME (2015)). In addition to a mutation of the grid structure, this transformation of production facilities requires a massive decentralization. Smaller production units must be located as close to consumption areas, including with regard to domestic uses. In this regard, the so-called energy transition law, passed in France in July 2015, requires a paradigm shift in terms of electrical energy. The objectives set for 2020 require reconsider in-depth the current methods of management and control of energy flows that are now highly variable. To cope with the high variability of renewable energy, suitable storage means appear to be essential for designing sustainable management systems.

In the field of smart grids, about the uses and necessities of storage, we can quote the VENTEEA project conducted in France by ERDF. The storage solution integrates a battery Lithium with a total capacity of 1.3 MWh and a capacity of 2 MW. This storage is required in order to allow a nearby wind farm to participate in the high-voltage network settings. Similarly, this storage issue concerns the management of the energy consumed in buildings, especially in the smart building framework. Indeed, in France, the building sector is the largest consumer of energy among all economic sectors with 43% of total final energy (ADEME (2008)). This sector represents 21% of CO2 emissions. Thus, the building turns out to be an important source of energy savings that can not be ignored in the goal of reducing energy consumption. To achieve this, besides the optimization of existing equipment, it is also necessary to improve methods of energy management in order to better integration of renewable energy, and also to successfully change behaviours of occupants in connection with heating.

For this purpose, two laboratories of the University of Reims Champagne-Ardenne decided to join forces and pool their skills to comprehensively address energy savings in homes with a system approach. This fact is a strong line of the project that we present in this paper. The Research Group in engineering sciences (GRESPI) has a well known expertise in the field of thermal processes. It helps in understanding the mechanisms involved in comfort conditions in a residential environment. GRESPI laboratory is also involved for its expertise in applied science in thermal materials, including the optimization of thermal energy storage in the building environment.

The Research Centre in Science and Technology of Information and Communication (CReSTIC) provides scientific expertise in the fields of digital technologies and energy conversion. These technologies will include large-scale analysis of the extensive data collected within the building or provided by users, to optimize energy consumption.

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.710

Mixing human-machine interface technologies, thermal and electrochemical storage capabilities, renewable energy integration and a comprehensive knowledge of the subjective comfort notion in order to improve performances of the energy management system of the building to save energy and simultaneously educate users to change their behaviours is the challenge addressed by this project.

2. SUBJECT AND SYSTEM DESCRIPTION

2.1 Production and conversion

Several energy sources must cooperate to meet the building's heating needs. The main power supply is of electrical origin. It is obtained by a conventional grid connection. Several ancillary sources contribute to improving the energy balance by exploiting renewable energy. The first one is the wind energy. A wind generator will deliver a ten kilowatts peak power. This is a vertical axis wind turbine. The Darrieus type rotor has a height of 9 meters. The Darrieus turbine is well suited to operating in environment where urban turbulence, due to the proximity of the buildings, are quite significant. The low level noise of the turbine, compared to a three-blade rotor, is another advantage of this technology. The wind turbine will be set on top of a 18 meters high mast. Solar energy will be exploited in two ways. The first one consists in a direct conversion of radiation into heat through the use of solar thermal plants. The second one consists in the use of photovoltaic panels to compensate for the wind generator and smooth the effects of intermittent wind.

At any time, the management system must determine the use of sources of electricity. They may be used to reduce power consumption to the power grid. They canalso be stored in heat form via the Joule effect or stored in Lithium electrochemical storage. The managment system will balance between immediat use, thermal storage or electrochemical storage / recovery taking into account various criterion as peak power needs, electricity instant cost, life cycle cost of batteries, the green energy objective ratio. Of course, all these energy exchanges require to ensure the necessary conversions between different sources, storage devices, and the power grid. It must also ensure the automatic switching circuitry to allocate or share each power / storage resources.

2.2 Heat storage / recovery

The storage will be ensured by a module which consists mainly of phase change material (PCM). The design and the size of the module will depend on the targeted use of the stored energy, i.e. for a room, an apartment or a building.

Charging phase: the module will be designed to enable the choice between two power-feeds, namely hot fluid and electric current. Heat carried by thermal fluid onto the storage module is expected to come mainly from solar thermal plants. Electric current is either recovered from electric batteries, electric grid during inexpensive off-peak periods, and/or from intermittent energy generators such as wind power plants and photovoltaic panels. The device should incorporate a hydraulic pipe for heat feeding. A metallic grid will be embedded within the PCM volume and will be connected to both heat pipe and electric feed, for the purposes of heat transfer enhancement onto the PCM volume and electricity to heat conversion.

Discharging phase: During discharging phase, the heat recovery will be ensured by a cold fluid (e.g. water) flowing through same hydraulic pipe as during the charging phase. For the purpose of the room heating, the module will be directly positioned inside the targeted room. In this case, the module will be covered by a heat spreader (infrared radiator or fin system). For the purpose of apartment or building heating, the module will be positioned in a common area. The heat spreading components will be connected to the module by a pipe network. Therefore, the design of the heat storage system will depend on the targeting purpose.

Design and validation via numerical modeling and experimental tests: Despite of various studies focused on heat storage via PCM embedding heat transfer enhancer such as metallic foams (e.g. [Sharma et al. (2009), Fan and Khodadadi (2011)]), questions that designer has systematically to ask, what kind of PCM, metallic grid, hydraulic pipe, and heat spreaders enable to maximize the device performance? Material characterization, design and simulation are essential to better understand the phenomena, in particular the structure properties relationships at different scales, and to answer to the above questions. In this project, two numerical models will be respectively implemented in a Computational fluid dynamics (CFD) code to design the storage system and component at different scales. Considering PCM infiltrated metallic foams as example of the storage component, a numerical model at the characteristics scale of few pores [Randrianalisoa et al. (2015)] will be used to design the composite structure satisfying the heat transfer constraints and then to establish thermal properties structure relationships. At the scale of the storage module, a CFD model such as in [Tay et al. (2012)] will be build to simulate and predict the response of the system for a given couple of device components (storage, pipe and heat spreader) and operating conditions. To assess the model suitability, two experimental tests will be designed. The first set up is devoted to characterize thermal properties of PCM based composite materials. Especially, it will be used to validate the pore scale model. The second one is a prototype of the storage module and will be used to ensure the suitability of the CFD model at the device scale.

3. THERMAL COMFORT PERCEPTION

Various parameters influence thermal comfort. Some of these parameters are related to the user (its activity, clothing) and others are related to the indoor environment (air temperature, surrounding surfaces temperature, air relative velocity, degree of turbulence, water vapor pressure and relative humidity). At present, taking into account of thermal comfort is made with methods developed from static approaches, simplifying the complexity of interactive phenomena. Thus, constructive requirements and recommendations for designers encourage the oversizing of equipments and systems like Heating Ventilation and Air Conditioning (HVAC), cooling, etc. However, these