Model-based estimation of rooms’ energy consumption in building with renewable energy sources

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The use of renewable energy systems (geothermal, sun collectors) is advantageous over conventional (gas, oil, electricity) in reducing CO₂ emission as well as heating and cooling costs of buildings. This allows buildings to operate in an energy efficient manner and environmentally friendly basis.

Modern environmentally-friendly buildings reduce environmental pollution by using a mixture of conventional and renewable energy-sources to heat and cool the building and provide domestic water (Chwieduk, D., 2003). Such hybrid systems allow, for example, the use of CO₂-neutral solar power on sunny days and back them up with conventional systems, when there is insufficient sunlight on a cloudy winter day. Due to this changing availability of their energy sources, the renewable systems usually need to be back up by conventional units such as gas boilers, resulting in hybrid systems.

However, the conventional back-up systems also reduce the building’s energy efficiency as they burn fossil fuels. Determining the amount of energy provided by each renewable or conventional unit is therefore an integral part of building performance analysis of environmental-friendly buildings. Furthermore, it is important to analyse a building’s energy consumption down to consumers on room level to identify energy leaks and optimise the building’s performance. But, hybrid systems also have an increased complexity that renders it harder to analyse the building’s performance. Analysing a building’s energy consumption down to room level also requires a high amount of measurement equipment, such as sensors and meters in each single room. Therefore, detailed building performance analysis is often hampered by high monitoring cost, and practitioners often request alternative cost-efficient methods (Jagemar, L. and Olsson, D., 2007).

This paper develops an estimation algorithm to analyse building’s energy consumption down to room level. The algorithm is adjustable in its information requirements to different sensing and metering equipment available in a building, providing a flexible usage from rough estimations with few sensors to detailed computations with a high density sensing deployment. It subdivides the building heating energy consumption down from system level to room level based on simple temperature sensors and a central heat meter with the flow rate $Q_{FH}$. Therefore, a relative heating coefficient $C_r$ is defined that provides a measurement of the room’s heating capacity in relation to other rooms. Furthermore, the individual room’s control algorithms are remodelled to estimate the valve opening $v_r$ of each room from the temperature sensors. Resulting in an estimation for the room’s heat flow $\dot{Q}_r$ as

$$\dot{Q}_r \approx \frac{v_r \cdot C_r}{\sum C_r} Q_{FH}.$$  \hspace{1cm} (1)

The algorithm is further combined with a previously introduced data mining approach to estimate the thermal comfort level of room’s users from the temperature sensors (Ahmed, A. et al., 2009). Both
approaches can be used for offline data analysis and for online monitoring as so-called virtual sensors (model-based sensors) to estimate the heat flows and thermal comfort in rooms. This provides a broad set of performance metrics from energy consumption to user comfort to support building performance analysis, monitoring, and optimisation (Augenbroe, G. and Park, C.-S., 2005).

The approach is validated using the Environmental Research Institute (ERI) building as an existing low-energy building with a hybrid HVAC system using geothermal heat pumps as well as solar thermal units as renewable energy resources. The ERI building is located in the main campus of University College Cork, Ireland and is used as “Living Laboratory” by the Informatics Research Unit in Sustainable Engineering (IRUSE) and the Irish strategic research cluster ITOBO (ITOBO, 2007) to serve as a full-scale test bed for Intelligent Buildings demonstrating building performance concept (Keane, M., 2005).

The building’s mechanical HVAC system is introduced and its basic control principles are explained. Then the buildings energy consumption is analysed investigating the geothermal heat pumps and the buildings underfloor heating system. The energy consumption is decomposed to room level using the proposed algorithms. The rooms’ are further classified based on their occupants’ thermal comfort. Based on this information, rooms with abnormal energy consumption are identified and optimisation alternatives are discussed.

The approach can basically be applied to any buildings heating system that rooms are individually controlled, as long as a representative static or dynamic relative heating coefficient $C_t$ can be defined. Using this coefficient and remodelling the control behaviour minimises the needed sensor equipment. The combination with an approach to estimate the thermal comfort in the rooms (Ahmed, A. et al., 2009) further complements the basis for decision making to improve a buildings energy consumption. Both approaches mainly utilise simple temperature sensors. As wireless temperature sensors provide nowadays a cheap and easy integration in old and new building (Menzel, K. et al., 2008), the approaches provide simple ways to evaluate buildings system efficiency and rooms’ consumption while reducing the building monitoring cost.

References


