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A review on modeling and simulation of building energy systems

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ABSTRACT

Buildings consume about 40% of the overall energy consumption, worldwide and correspondingly are also responsible for carbon emissions. Since, last decade efforts have been made to reduce this share of CO_2 emissions by energy conservation and efficient measures. Scientist across the world is working on energy modeling and control in order to develop strategies that would result in an overall reduction of a building's energy consumption. Development of control strategies asks for a computationally efficient energy model of a building under study. This paper presents a review of all the significant modeling methodologies which have been developed and adopted to model the energy systems of buildings. Attention is majorly focused on the works which involved development of the control strategies by modeling the building energy systems. Models reviewed are presented categorically as per the modeling approach adopted by the researchers. Simulation programs and softwares available for building energy modeling are also presented.

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1. Introduction

A number of methods have been developed to construct load models or energy consumption models that simulate a building/plant system for load prediction or cost saving estimates. Such models vary in magnitude from modeling of a single slab (or a wall) [1] to modeling of a complete building through modeling of rooms subjected to temperature variations. Clarke [2] gave a three stage process for model formulation. In the first step, the building system is converted from continuous state to a discrete state. This involves selection of nodes at the points under study, representing the homogeneous or non-homogeneous control volumes like that of internal air mass, boundary surfaces, building fabric elements, Renewable Energy Systems, equipment of the room, etc. Equations satisfying mass, momentum and energy conservation principles are developed in the second step for each node which is in thermodynamic contact with its surrounding nodes. Last step involves solving the equations derived in the second step for successive time steps to obtain state variables of the node for future time periods as a function of present time state variables with the boundary conditions prevailing at both times.

1.1. Energy consumption in buildings

Driven by the rising population, expanding economy and a quest for improved quality of life, energy consumption has increased and the growth rates are expected to continue, fuelling the energy demand further. Increased energy consumption will lead to more greenhouse gas (GHG) emissions with serious impacts on the global environment. The expected increase in energy demand, along with the predominance of coal in the energy mix, highlights the significance of promoting energy efficiency. Higher rate of urbanization with increased floor space for both residential and commercial purposes has imposed enormous pressure on the existing sources of energy. Limited availability of energy the existing energy resources and highly transient nature of renewable energy sources have enhanced the significance of energy efficiency and conservation in various sectors.

Consumption of electricity has increased in the commercial sector in the past ten years. In commercial buildings, the annual energy consumption per square meter of the floor area is in excess of 200 kW h with air-conditioning and lighting serving as the two most energy consuming end-use applications within a building. Growth in buildings sector energy consumption is fueled primarily by the growth in population, households, and commercial floor space, which are expected to increase by 28% within 2035.

In order to account for the thermo-visual comfort of the occupants and according to functionality (manufacturing, etc), the HVAC systems, lighting systems, electric motors are the major consumers of energy within the buildings sector. Categorical classification of energy consumption by any end use such as heating, cooling, cooking, etc. for both residential and commercial buildings (in U.S.) is shown in Fig. 1 [3].

The top four end uses space heating, space cooling, water heating, and lighting—accounted for close to 70% of site energy consumption. Other end uses, such as consumer electronics, kitchen appliances, and ventilation, made up the remainder.

Energy efficiency and conservation measures are predominantly being considered for salvation of the energy requirements in developing nations such as India. Almost 50% of the energy fuel requirements of India are met through foreign imports. This situation of deficit has led to frequent power cuts (load shedding) in major parts of the country, especially during the peak time of the day. [4]. Conservation can, therefore, go a long way in alleviating the resources crunch in the energy supply sector ensuring a more productive use of existing resources.

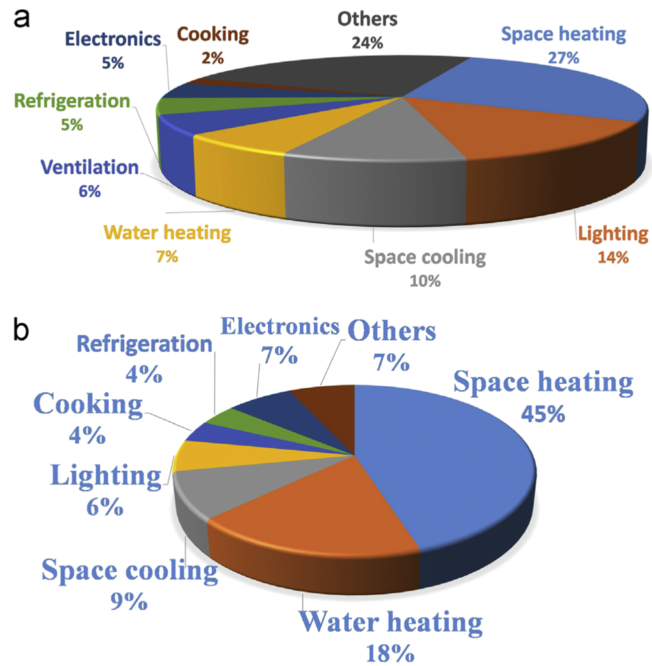

Fig. 1. End use wise energy consumption in (a) residential and (b) commercial, buildings [3].

Energy conservation, which leads to more efficient use of energy without reducing comfort levels, does not mean rationing or curtailment or load shedding, but it is a means of identifying areas of wasteful use of energy and taking action to reduce energy waste. There are vast opportunities to reduce electricity consumption and increase energy efficiency within buildings. It is estimated that new buildings can reduce energy consumption on an average between 20% and 50% by incorporating appropriate design interventions in the building envelope, heating, ventilation and air-conditioning (HVAC, 20–60%), lighting (20–50%), water heating (20–70%), refrigeration (20–70%) and electronics and other (e.g., office equipment and intelligent controls, 10–20%).

1.2. Sustainability

Sustainability is today a goal that just about every organization, institution, business, or individual claims to be striving for, and sometimes claims to have achieved. Given the profound impact of buildings on the environment, the work of HVAC&R design engineers is inextricably linked to sustainability. The engineering sector has seminal influence on building performance, and HVAC&R designers' work is inherently related to overall sustainability in buildings. Sustainability is defined in the ASHRAE GreenGuide [5], in general terms, as "providing for the needs of the present without detracting from the ability to fulfill the needs of the future," a definition very similar to that developed in 1987 by the United Nations' Brundtland Commission (UN 1987). Others have defined sustainability as "the concept of maximizing the effectiveness of resource use while minimizing the impact of that use on the environment" [6] and an environment in which "… an equilibrium … exists between human society and stable ecosystems" [7]. Sustaining (i.e., keeping up or prolonging) those elements on which humankind's existence and that of the planet depend, such as energy, the environment, and health, are worthy goals [5].

This review article is primarily targeted for researchers and scientists engaged in development of control strategies to reduce the energy consumption of a building under study. Most significant part in design of control strategies for building energy