Combined High-Efficiency Systems for Buildings

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http://www.ae.unl.edu/faculty/li.shtml

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Abstract

Buildings represent about 40% of primary energy, 70% of electricity consumption and 38% of carbon emissions in the U.S. (DOE, 2003). In aggregate, hot water heating and space heating/cooling contribute more than half of the total building energy consumption and carbon emissions. The existing building systems are designed to use three separate systems to serve the three functions. That is, a boiler for hot water heating, a furnace for space heating, and an air conditioner (AC) for space cooling. Their performances are evaluated by their individual efficiencies. To conserve energy, we have been mainly focusing on how to optimize the design and operation of each individual system but neglecting the interactions among different systems and the opportunities in improving the overall efficiency. Consequently, the 2nd law efficiencies of each individual system have approached their practical limits (0.95 for electrical boiler, 0.90 for furnace and 0.9 for AC), while the overall 2nd-law efficiency is still lower than 0.50. Besides, water usage in buildings is very wasteful: we use drink water for toilet flushing, garden irrigation and fire protection; and a huge amount of energy residing in wastewater is discharged to the environment without being used. The objective of this project is to develop an integrated heat-pump/water-reclamation system for hot water heating, space cooling/heating and waste/rain water reclamation, which can reduce: a) drink water usage in buildings by 50%; b) total energy usage for hot water heating, space heating and cooling by 50%; c) electricity peak demand by 30%; and d) the total costs for equipment/installation/ maintenance by 50%.

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To reduce energy consumption from buildings, U.S. Department of Energy (DOE) set a goal to achieve Zero-Net Energy Buildings from two perspectives: on the one hand, to reduce the average energy use of housing by 40% to 100% through improving building energy systems efficiency and conservation, and on the other hand to offset the rest of the energy usage through on-site renewable energy generation (DOE, 2009). Although it is a long way to achieve the goal, it is generally realized that the biggest hurdle for renewable energy solutions is how to shorten the payback period and make them cost-effective. A lot of innovative technologies in this regard have resulted and a lot of research is ongoing.

However, the state-of-the-art for energy-efficiency technology innovation has been mainly focused on improving each individual building energy systems. For example, the efficiency of air conditioning equipment has improved substantially over the past 20 years and is approaching the practical limit that can not be surpassed in a cost-effective manner. Unfortunately, the overall efficiency of the building energy usage is low and the overall performance for whole building energy usage has not been optimized. In addition, heat and waste/rain water have not been reclaimed and used for heat rejection of the space cooling and heating. We propose to develop an innovative sustainable domestic water heating, space heating/cooling and wastewater/rain water reclamation system. Our idea is to manage and control the total energy-input of the whole buildings, rather than decentralized use of energy for each individual system. A multiple heat-pump system will be adopted to manage the energy resources and thus reduce peak energy-demand. Moreover, water resources are also important for our environment and can provide heat rejection and supply for energy saving. Allied with the water and thermal reclamation, this concept and the system are important and worth pursuing further for controlling total energy-input into the buildings. The proposed research aims to pioneer an entirely new energy and water resources management system in buildings to correct all above-mentioned deficiencies in the currently available technology. Successful completion of this research will not only provide fundamental understanding of the control of energy and water resources in buildings, but will also have very significant implications for energy conservation. We expect that the proposed system can reduce: a) water usage in buildings by 50%; b) total energy usage for hot water heating, space heating and cooling by 50%; c) electricity peak demand by 30%; and d) the total costs for equipment/installation/ maintenance and save the habitable space.