RESEARCH HIGHLIGHT

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Investigation of a Ground-Source Heat Pump Retrofit to an Electrically Heated Multi-Family Building

INTRODUCTION

From the mid 1960s to the mid-1980s, electric baseboards were a popular space heating option in multi-unit residential buildings (MURBs) due to their low capital cost, ease of installation, non-intrusive nature, ease of metering and, at the time, the low cost of electricity. As a result, it is estimated that electric baseboards are used in 53 percent to 81 percent of the stock of MURBs, depending on geographic location.

However, since the mid-1980s, a number of factors have arisen that have rendered electric baseboard heating undesirable. Increased electricity costs, the demand for air-conditioning (necessitating the installation of forced air systems), perceptions of low quality and poor comfort and in some areas, government regulations, have all but eliminated electric baseboard from consideration in new buildings. However, for the stock of buildings that still use electric baseboards there has been little in the way of cost-effective retrofit options that could be installed to reduce the cost of space heating, improve occupant comfort and renew building systems. Consequently, most of the buildings originally fitted with electric baseboard heating continue to make do with these same systems today.

In 2002, Canada Mortgage and Housing Corporation (CMHC), initiated a study of heat pump based retrofit options for electrically heated apartment buildings through CMHC's External Research Program. The feasibility of ground source based retrofit systems has improved with the development of low-profile fan coil systems that could be installed in the same location as existing electric baseboards. The project evaluated the technical characteristics of MURBs equipped with electric baseboard space heating, developed concepts for retrofit options, evaluated the availability of products and services required to provide heat pump based retrofit options and assessed the most promising alternative.

RESEARCH PROGRAM

The research plan and method of analysis for the baseboard retrofit investigation involved the following tasks:

1. Identifying the technical characteristics of the existing baseboard electric heating market to provide baseline information to which heat pump retrofit options could be compared.
2. Developing the concept of a heat pump based retrofit option for buildings equipped with electric baseboards. A set of performance parameters was developed to guide the conceptual development.
3. Conducting an equipment and component search to identify available sources for each retrofit option and to identify gaps in the available technologies and knowledge.
4. Analyzing the water-to-water heat pump option to estimate space heating energy consumption and the energy/cost savings in comparison to the electric baseboard base case.
5. Reporting the findings of the project in terms of the retrofit option developed, its costs and associated space heating energy savings. Recommendations with respect to the need for additional research and development for specific products and research areas were also developed.

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FINDINGS

Characterization of Electric Baseboard Space Heating:

Electric baseboard heating is widespread due to its relative popularity during the time when much of the stock of multi-unit residential buildings was constructed in Canada. It has been estimated by CMHC that electric baseboard heating is used in anywhere between 53 percent to 81 percent of multi-unit residential buildings—depending on regional location. Electric baseboard heating was popular due to low initial cost, low maintenance costs and small space requirements. Electric baseboards typically supply heat at the rate of 250 W per linear foot of baseboard. To be equally non-intrusive, the baseboard fan-coils would have to have a cross-sectional profile of no more than 100 mm by 200 mm.

Literature Search for Product and Equipment Documentation and Related Research:

Manufacturers of water-to-water heat pumps, tangential fans and fan-coil sets, radiant heating and cooling panels, and heat recovery ventilators were sourced, particularly with respect to equipment appropriate for apartment size loads and space. An appendix to the research report (separately bound due to size) was compiled consisting of eight sections covering information such as:

- information on the physical, operational and performance specifications for water-to-water heat pumps, tangential fans and fan coils, radiant panels, apartment size heat recovery ventilators that are appropriately sized for apartments
- case studies of the retrofit of natural gas-fired space heating systems to buildings previously fitted with electric baseboards
- a list of other references and research consulted over the course of the study

Selected Retrofit System Concept:

The retrofit system ultimately selected for detailed analysis was a water-to-water ground-source heat pump based system. A conceptual system was developed for an hypothetical building. The system would be supplied with water from vertical bore holes containing closed loop heat exchange piping. The water would be delivered to the building via a supply header located in a mechanical room that would have to be provided for within theexisting ground floor plan of the building. Circulation pumps in the mechanical room would deliver the water to a vertical riser for distribution to each floor. At each floor level, lateral piping, located in a dropped ceiling or valance, would deliver the water to each apartment.

Within each apartment, the water would be supplied to a heat pump unit. Each heat pump unit would have dimensions ranging between 600 mm x 600 mm x 600 mm to 750 mm x 750 mm x 750 mm—depending on the space heating capacity. The heat pumps would be designed to work with a minimum entering source water temperature in the range of -3.8°C (25°F) to 1.7°C (35°F.) The heat pump capacities were specified as being between two and three tons to reflect commercially available products. The heat pumps would be installed in an existing closet or storage room within each apartment. Bedroom closets would not likely be a good location due to the noise associated with heat pump operation. Consideration would also have to be given to access to the unit, and the unit's interior components, for maintenance. Units should also be selected that have proper pipe isolation, compressor sound insulation shrouds and isolation mounts, and acoustically insulated cabinets.

The heat pump would deliver heated water to tangential fan coil units located along the exterior perimeter of the apartment. Tangential fan coils have a sufficiently small profile (112 mm deep by 200 mm high) that they make relatively unobtrusive replacements for electric baseboards. The piping could be concealed in dropped ceilings, valances or behind specially constructed baseboards. The fan coil units would be designed to have the same length as the electric baseboards they replace. The fan coils would be designed to provide the same 250W/foot as supplied by the original electric baseboards. The motor in each fan coil would consume approximately 60 watts. The heat pump would supply water in the range of 45.5°C (114°F) to meet the heating capacity requirements of the tangential fan coils. The return water temperature to the heat pump would be in the range of 41.7°C (107°F.) Water is returned to the main distribution system, and ultimately to the ground loop heat exchanger, in parallel with the ground source supply water.

Energy Consumption Simulations:

The physical characteristics of the hypothetical 642 unit building project were developed to create a model that could be assessed in terms of energy consumption and system costs. The heating load for the building project was calculated using the DOE 2.1 energy simulation software. This was used, in conjunction with an estimate of balance point temperature, to determine the cumulative space-heating load over time via a bin calculation spreadsheet. Assumptions were made concerning the outdoor temperature reset controls for the heat pumps, heat pump water circulation pumping electricity consumption, main building and ground-source heat pump loop pumping electricity consumption and heat pump coefficient of performance.

Space heating energy consumption and associated annual costs, for both electric baseboard and the ground-source heat pump system scenarios, were calculated for each apartment and the overall building. The ground-source system energy use was adjusted to include the electricity consumption associated with the fan-coils, individual heat pumps and main distribution system pumps. Net space heating energy savings associated with the replacement of electric baseboards with the retrofit heat pump system were estimated to be 2,429,104 kWh per year providing an annual cost savings of $205,745. The cost of the conceptual retrofit system was estimated to be $3,494,399 ($5,443/apartment). The capital cost, combined with the estimated increased maintenance costs associated with heat pump systems ($57,831/year) provided a simple payback period of over 20 years. If the analysis included an air-conditioning option for the summer months, the payback period would be just over 10 years.

Recommendations for Future Research and Development

Over the course of the project, many issues relating to the design and development of ground-source heat pump systems for use in apartments came to light. For instance, the cost of the tangential fan coil units is now prohibitively high due to low production and the use of expensive materials and components. Further study should be given to finding ways to optimize the temperature of the water leaving the heat pump for the fan-coil circuit, based on an outdoor air temperature reset strategy. This would serve to improve the efficiency of the heat pump system. Research is also needed for the development of heat pumps that have both heating and cooling capacities that are appropriate for apartments-size loads.

While the payback period was too long for ground-source heat pumps to be an attractive retrofit option for electric baseboard equipped buildings from a strictly economic perspective, there are other factors that may make this approach worthy of consideration. For instance, ground-source heat pumps can provide air-conditioning where none was available before. This may be advantageous in the conversion of buildings from rental to condominium units.

IMPLICATIONS FOR THE HOUSING INDUSTRY

This research project served to evaluate the current state-of-the-art of ground-source heat pump systems as they could be applied as a space heating system retrofit in multi-unit residential buildings. The study showed that the retrofitting of buildings currently fitted with electric baseboard space heating with some form of ground source based heat pump system is possible but is not economically viable based on space heating energy savings alone. The study also showed that heat pump manufacturers could optimize the design of heat pumps and heat pump systems, to reduce system costs, improve efficiency and better meet the needs of multi-unit residential buildings.

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