RESEARCH REPORT

INVESTIGATION OF A GROUND-SOURCE HEAT PUMP RETROFIT TO AN ELECTRICALLY HEATED MULTI-FAMILY BUILDING

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INVESTIGATION OF A GROUND-SOURCE HEAT PUMP RETROFIT TO AN ELECTRICALLY HEATED MULTI-FAMILY BUILDING

(CR File No: 6585-C108)

Final Report

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ABSTRACT

This is a report of research to investigate the technical potential and economic benefits of retrofitting electrically heated apartment buildings with ground-source heat pumps. The report presents results of a literature and web search and review of available components and equipment suitable for the application, analyses the most promising combination using an example building complex in the Greater Toronto area. Both the cases of no benefit and full benefit for central air conditioning are considered. Comparisons are drawn with retrofitting natural gas heating systems under the same circumstances. Conclusions and recommendations for new component development are identified and the economic results are as attractive under some circumstances as natural gas heating system retrofits.

EXECUTIVE SUMMARY

Electric baseboard heated apartment buildings are estimated to be in 20 % of the buildings in this sector in the Greater Toronto area. This is estimated to be over 20 million square feet - split between social housing (16 %) and private apartments (84 %). Typical space heating costs within these apartments are high - often exceeding $500/year. This cost could be significantly reduced if heat pump systems could be installed. It is difficult to retrofit baseboard heated apartments with more conventional duct distribution systems because of the space requirements. Replacing the electric baseboards with similarly sized fan-assisted hydronic baseboards would allow the application of water-to-water heat pumps and allow for much lower operating costs and year-round comfort. This is a report of research of such a system and its application potential in this housing market segment.

The research involved identifying system components and equipment suitable for the application, preparing system design concepts and sketches, analyzing the performance of the heat pump system in a Toronto example building, preparing cost estimates for the retrofit, developing two economic scenarios- no summer cooling value and full summer cooling value.

Most of the components needed for the system are currently available in the market place. Two fan-assisted baseboard manufacturers were identified whose products were suited to the application. Fan-assisted baseboard designs allow for lower operating temperatures required for efficient heat pump operation. There were numerous manufacturers of water-to-water heat pumps. The techniques for retrofitting distribution piping in common areas and suites are well known and have much in common with gas heating retrofit in the same buildings.

It was concluded that the cost of the fan assisted baseboards needs to be in the vicinity of $300 per four foot module to be viable. It was also concluded that smaller capacity water-to-air heat pumps would be better suited to this application. Heat pumps should also have controls that adjust supply water temperature in response to load (i.e. indoor - outdoor temperature difference).

The retrofit cost for the case where summer cooling was of no value was too high to recover through operating savings in a reasonable period - the simple payback period was about 23 years. The case where there was full value for summer cooling the simple payback period was just over 11 years. The latter is more attractive than many documented natural gas heating retrofits undertaken in the Toronto area in the early 1990s.

RÉSUMÉ

On estime que 20 % des bâtiments de ce secteur de la Région du Grand Toronto sont dotés de plinthes de chauffage électriques, ce qui représente au-delà de 20 millions de pieds carrés, composés d'ensembles de logements sociaux (16 %) et de collectifs d'habitation privés (84 %). Les coûts annuels du chauffage représentatifs de ce genre d'appartements sont élevés – fréquemment plus de 500 $/an. Ces coûts pourraient être considérablement réduits si on pouvait installer des pompes à chaleur. À cause des contraintes d'espace, il est difficile d'ajouter des conduits de chauffage classiques dans un appartement doté de plinthes électriques. Le remplacement de ces dernières par des ventilo-convecteurs à l'eau chaude autoriserait l'installation de pompes à chaleur eau-eau, ce qui aurait pour résultat de réduire les coûts d'exploitation et d'augmenter le confort pour les occupants. Le rapport dont il est question ici avait pour objet d'examiner un tel système et d'en découvrir les possibilités dans ce secteur du marché du logement.

La recherche consistait à repérer les composants et les équipements convenant au système, à concevoir le système et à préparer les dessins, à analyser la performance d'une installation de pompe à chaleur dans un bâtiment d'essai à Toronto, à calculer le coût des améliorations en rattrapage et à élaborer deux scénarios économiques : le premier où aucune valeur est attribuée à la climatisation d'été et le deuxième où la pleine valeur y est attribuée.

La plupart des composants dont on avait besoin pour l'installation sont offerts dans le commerce. On a trouvé deux manufacturiers de ventilo-convecteurs à plinthe dont les produits convenaient à l'installation. Les ventilo-convecteurs permettent de tirer parti de températures plus basses assurant un fonctionnement efficace des pompes à chaleur. Quant aux pompes à chaleur eau-eau, de nombreux manufacturiers en fabriquent. Les techniques de pose en rattrapage de réseaux de distribution de tuyauterie dans les espaces publics et les appartements sont bien connues et sont similaires à celles employées pour l'installation d'une nouvelle tuyauterie de gaz naturel dans des bâtiments comparables.

On a conclu que le coût des ventilo-convecteurs ne devrait pas dépasser 300 $ pour un module de quatre pieds pour assurer la viabilité financière des travaux. On en a aussi déduit que les pompes à chaleur air-eau de moindre capacité conviendraient mieux pour cette installation. Les pompes à chaleurs devraient également être dotées d'une commande qui permet de régler la température de l'eau en réponse à une augmentation de la demande (c.-à-d. le différentiel de température intérieur - extérieur).

Le coût des améliorations, dans les cas où la climatisation d'été n'a aucune valeur, était trop important pour espérer le récupérer sur une période raisonnable au moyen des économies d'exploitation, la période de récupération simple étant d'environ 23 ans. Quant à l'autre cas, où l'on obtenait la pleine valeur pour la climatisation d'été, la période de récupération simple est légèrement supérieure à 11 ans. Cette dernière est plus avantageuse que de nombreux cas documentés de travaux en rattrapage vers le gaz naturel entrepris au début des années 1990 dans la région de Toronto.

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CONTENT

1. INTRODUCTION

1.1 Background and Objectives

Electric baseboard heating is expensive and widespread in Central Canada in multi-family housing. For example, in Toronto, Marbek [1] estimated that there was a 20% penetration of electric baseboard heating in the apartment sector in post-1970 buldings.

This 20% represents over 21 million square feet of floor space in Toronto - split between social housing (16%) and private apartments (84%). Typical heating cost per unit is conservatively estimated at approximately $500/year with electric heat. This electricity use also results in substantial amounts of pollution produced by power generation plants, resulting in greenhouse gas emissions and poor air quality. This cost can be significantly reduced with a heat pump system (water-to-water) by anywhere up to $330/year.

The problem has always been the difficulty in retrofitting or replacing the existing baseboard electric heaters. Heat pump systems currently used in the multi-family sector require air distribution in the individual suites. This necessitates ductwork which uses valuable space in the apartments and can be quite costly to install. As a result, electric baseboard buildings are rarely retrofitted. Developing a cost effective method to retrofit electrically heated buildings with water-to-water heat pumps would likely result in a substantial reduction in energy use, operating costs and the environmental impacts from electricity production. This system can provide year round comfort (particularly important with seniors buildings) and provide a chance to integrate ventilation.

We propose to investigate the feasibility of replacing the existing baseboard heaters with a fan-assisted hydronic baseboard of approximately the same size and shape or alternatively, radiant panels. These solutions would be less intrusive and would permit the use of a water-to-water heat pump, which itself is smaller in dimensions and lower cost than the more common water-to-air heat pump.

The water-to-water heat pumps would require a piping distribution system to be retrofitted to the building from a central mechanical room, but this can be fitted quite readily in common areas of the building such as in the stairwells and in corridor ceiling spaces.

Once installed the system offers the advantage of year-round comfort for the tenants (heating and cooling) as well as significantly lower operating costs. The new mechancial system also increases the value and marketability of the building from the owners perspective.

1.2 Project Scope

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

1. Identifying the technical characteristics of the existing baseboard electric heating market, specifically, typical baseboard sizing , operating costs and maintenance costs. This would be based on existing published reports and recent Caneta Research work for Hydro One in the

multi-family building sector. This task would be for reference or benchmarking purposes to provide the base case for comparison with the concept designs developed in this research.

2. Conceptual development: Identifying heat pump based retrofit options/alternatives to electric baseboard heating. Specifically, Caneta Research investigated what water-to-water heat pump options/alternatives could replace the existing electric baseboard systems at reasonable cost, with the least impact on available space, and significantly reduce operating costs in these buildings. We examined both fan-assisted hydronic baseboards and radiant panel concepts, looking at recent innovations in allied fields, the technical literature of ASHRAE , the IEA Heat Pump Centre and other HVAC industry publications.

   For example, tangential or linear fans, a Japanese development, are used in some packaged air-conditioning equipment. Longer lengths of these fans would be required to package in a slim housing to allow for output to the space with the lower supply water temperatures associated with water-to-water heat pumps. Inquiries were directed to manufacturers of these fans to get some idea of the availability and utility of these fans in much longer lengths than presently used. Similar approaches were made to manufacturers of radiant panel heating surfaces and other key system components.

3. Caneta Research conducted an equipment and component search to identify available components and equipment for each retrofit option/alternative including: suppliers, physical configurations, heating and cooling capacities, efficiencies and costs. Product information was identified by visiting web sites and contacting suppliers. This information was developed into system concepts for engineers. Diagrams and system sketches, together with design specifications were prepared .

   Design and product parameters for this multi-unit residential retrofit application are:
   - low noise output;
   - achieve the same thermal output with lower water supply temperatures;
   - low space requirements;
   - lower operating costs;
   - enable air-conditioning (may require space dehumidification separately to avoid surface condensation);
   - low installation/capital cost.

   Where existing equipment and components fall short of the application requirements, Caneta identified the weaknesses and suggested changes to make them perform better. Caneta Research identified what new developments were required where components were not available.

4. The more promising options and alternatives were analyzed using a bin calculation energy analysis procedure to predict energy cost savings in comparison to electric baseboard heating. Costing of the alternatives (labour, equipment, materials and maintenance (where possible)) allowed for a comparison of cost/benefit with continuing to heat with electric baseboards in this sector.

5. The final report contains the findings from the existing electric baseboard retrofit market assessment; the concept development of the heat pump based retrofit options/alternatives; the

component/equipment availability review results, system concepts and the cost/benefit analysis results of the promising heat pump options. Recommendations with regard to equipment and component changes or developments were made.

2. CHARACTERISTIC OF EXISTING BASEBOARD ELECTRIC HEATING MARKET

Electric baseboard heating is expensive and widespread in Central Canada in multi-family housing. A Survey conducted by CMHC [2], indicates that on average across Canada, between 53-81% of apartment suites use electric baseboard heating. However the heating type is strongly influenced by regional geographics.

In Toronto, Marbek [1] estimated that there was a 20% penetration of electric baseboard heating in the apartment sector in post-1970 buldings. This floor space is split between social housing (16%) and private apartments (84%). There are estimated to be almost 1000 apartment buildings (> 50,000 ft^2) in Ontario with electric resistance heating but with no air conditioning (see Caneta Research report in Appendix A). This could be considered the potential market for this retrofit system.

Electric heating is often implemented because of its low initial cost, low maintenance cost, and small space requirements. Typically electric baseboards are installed beneath windowsills to prevent discomfort caused by cold window downdraft. Typical electric baseboard designs provide 250W/ft heating capacity. As the cost of electricity increases, electric baseboard heating operational costs increase and further offset the initial capital cost disadvantages associated with more expensive heating system retrofits.

3. COMPONENTS AND EQUIPMENT FOR RETROFIT

3.1 Website and Literature Review

The purpose of the Internet search was to identify manufacturers of water-to-water heat pumps, tangential fan coils, radiant heating / cooling panels, small heat recovery ventilators, and tangential fans. Product information and performance specifications were collected from all applicable manufacturers. An internet search / literature review was also conducted to identify any technical reports and papers detailing retrofitting of electric heated buildings to hydronic heat, particularly with water-to-water heat pumps.

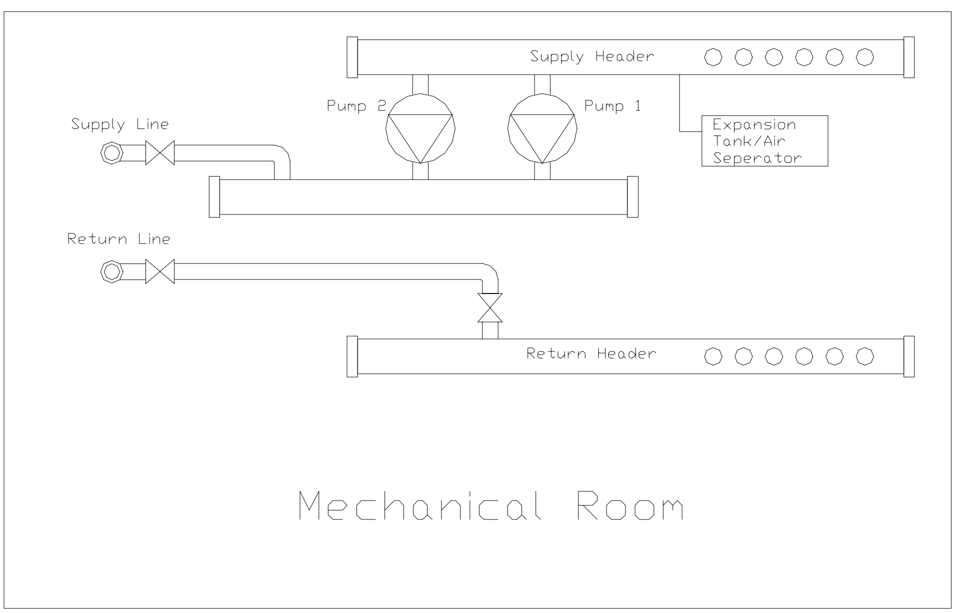
Appendix A, entitled Electric Baseboard Retrofit - Literature Search, a separately bound appendix, contains the Internet search results. Appendix A is comprised of 8 sections. Section 1 contains in depth product information, performance data, dimensional specifications, and installation diagrams for 7 manufacturers of water-to-water heat pumps. The manufacturers included are WaterFurnace, Florida Heat Pump, Carrier, Trane, Comfort System Solutions Inc., Maritime Geothermal, and Hydron Module. Section 2 contains the performance ratings and dimensional specifications for 4 manufacturers of tangential fan coils. Currently this technology has a very small market, and few companies manufacture this product. The manufacturers are Rosemex, MINIB, Carrier, and Myson. Rosemex was the only company that manufactures a product that is slender enough to be used in place of electric baseboards and easy to install in retrofit applications. Section 3 contains heating / cooling performance data, dimensional specifications, and installation guidelines for radiant heating and cooling panels. The manufacturers listed are Hydronic Alternatives, Rosemex, Sterling, and Siebe Comfort Systems. Section 4 lists performance specifications and product information for 6 manufacturers of small heat recovery ventilators suited to apartment applications. The manufacturers are Fantech, Lifebreath, Summeraire, Carrier, Airiva, and Eco Air. Section 5 contains the dimensional specifications for 7 manufacturers of tangential fans. Eucania, Kyung Jin Blower CO. Ltd., Air Vac, MA-VIB, ebn-ZIEHL and Shevah Blower are the major manufacturers of this product. Section 6 is a compilation of 6 case studies of apartment buildings that were retrofitted from electric baseboard heating to natural gas heating. Each case study has a description of the retrofit activities, an actual construction cost, predicted net savings per year, and a simple payback calculation. Section 7 contains all other references that were obtained during the Internet search. Section 8 is a report entitled, Heat Pump Retrofit Guidelines for the MURB Sector. This report provides a good background of the electric heating market in Canada.

3.2 SYSTEM CONCEPTS

3.2.1 System Description

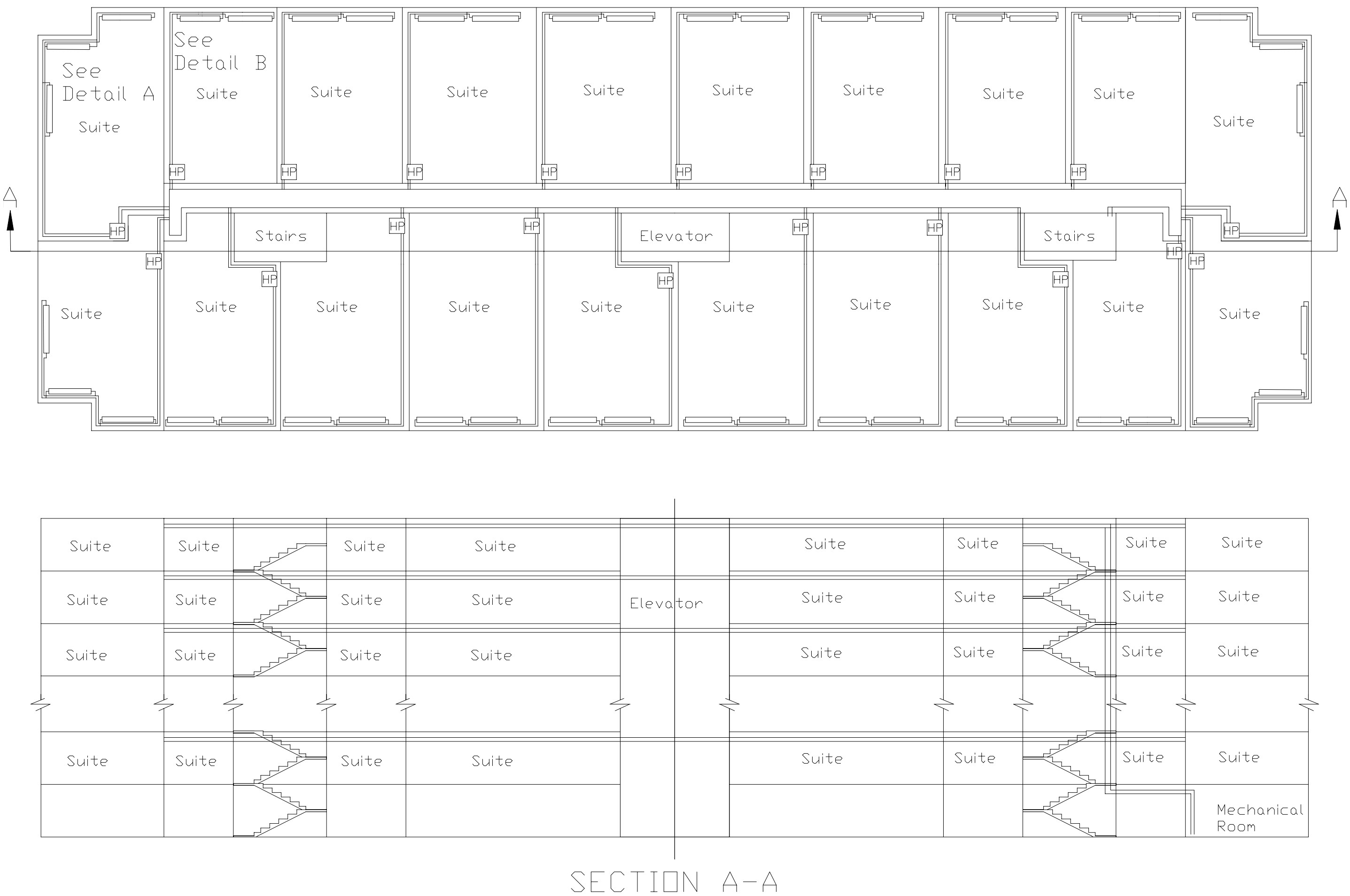
In ground source heat pump retrofits the mechanical room must be located at ground level in order to connect to the vertical underground heat exchangers. If the electrically heated apartment buildings do not have designated mechanical rooms, a ground floor storage room must be converted to serve as the building central mechanical room. A typical mechanical room layout can be seen in Figure 1. The space requirements for a ground source heat pump mechanical room are much less than that for a central boiler and chiller plant.

Figure 1: Typical Mechanical Room Layout



The mechanical room consists of a supply header, return header, expansion tank / air separator, and circulation pumps. These components are used to distribute water from the ground heat exchangers to each of the suite heat pumps through risers and distribution piping installed in the building. A typical distribution piping layout can be seen in Figure 2.

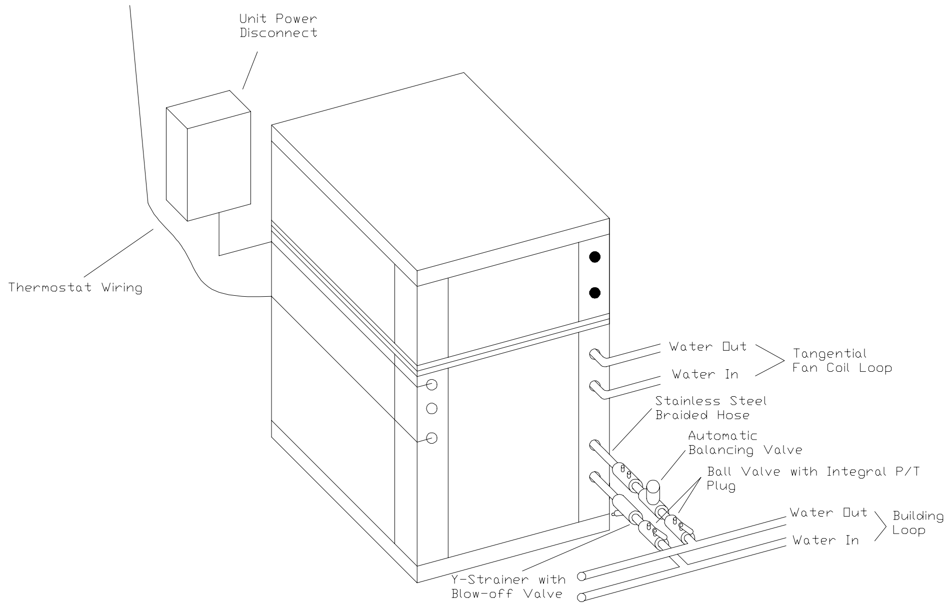
Figure 2: Distribution Piping Layout



Supply and return piping is run vertically (risers) from the mechanical room to the top of the building. If the risers can be routed through the stairwells this would ease the installation process. Piping installed in stairwells must be totally enclosed by a chase consisting of material having the same fire resistance rating as required for the stairwell. Check with local authorities. At each floor level horizontal piping (run outs) is routed from the supply and return risers. The run out piping runs through the corridor on each floor as shown in Figure 2. The piping can be located above a false ceiling when possible or alternatively, enclosed with soffiting in a space at the junction of the wall and ceiling.

One heat pump is installed per suite. The space requirements for the heat pumps range from typically 23"x23"x24" for a 2 ton unit to 30"x30"x23" for a 3 ton unit. The heat pump should be located in a storage room or central closet in the suite. Generally bedroom closets are not large enough to house the heat pump units. Heat pumps should be designed with easy serviceability and maintenance in mind. Trane manufactures a unit that can be fully serviced by simply removing the top panel and opening one service door. This design is ideal for service and maintenance in confined spaces. Most heat pump units used in this type of application have thermal and acoustically insulated cabinets and compressors that are internally isolated and have sound shrouds. These features are sufficient to ensure operating noise does not disturb tenants. The heat pumps are connected to the run out distribution piping as detailed in Figure 3.

Figure 3: Heat Pump Diagram



In-suite piping is installed to connect the heat pump to the tangential fan coils. Typical 1 and 2 bedroom suite piping layouts can be seen in figure 4 and 5, respectively.

Figure 4: Typical One Bedroom Piping Layout

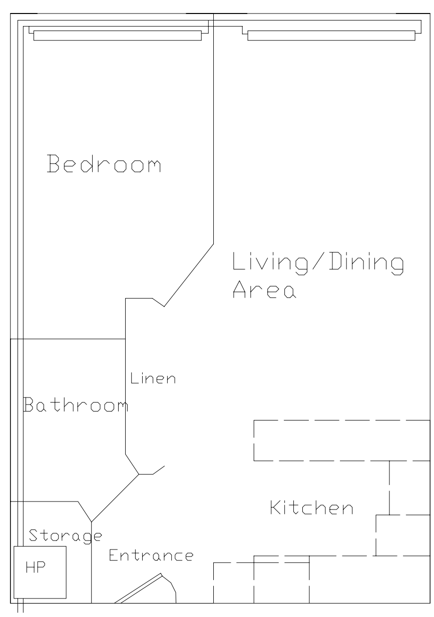
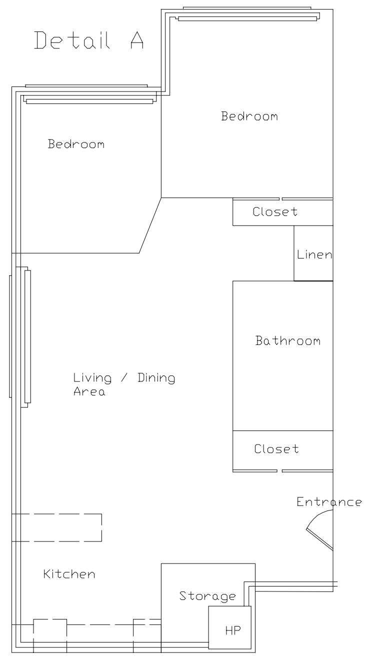


Figure 5: Typical Two Bedroom Piping Layout



The fan coils are piped to the heat pump in parallel to ensure each fan coil operates with the same entering water conditions. The fan coils are installed in place of the electric baseboards usually under a window along an exterior wall. The tangential fan coil was selected with the dimensions of a typical baseboard to ensure the tenants are not inconvenienced by an obtrusive piece of equipment, see Figure 6. Floor level piping can be enclosed in any number of soffiting options; for example wood molding enclosing the pipes in a triangular space at the junction of the wall and floor.

A sample retrofit specification is provided in Figure 7.

Figure 6: Fan Coil Cross Section

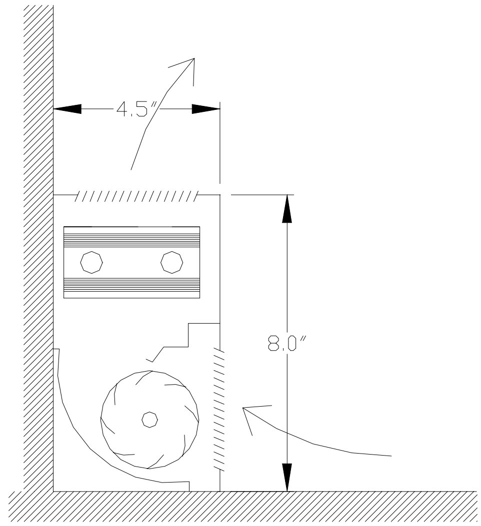


Figure 7: Retrofit Specification

Fan Coil

1. The dimensions of the fan coil must be similar to a typical electric resistance baseboard. A slender design ensures minimal impact on tenant space.
2. The fan coil must operate quietly so that tenants are not disturbed. Noise reducing technologies such as tangential fans that decrease fan operating noise are ideal.
3. The fan coil must operate at incoming temperatures typical of a water to water heat pump in a GSHP system. Typical temperature range is between 110°F to120°F.
4. At the incoming temperature listed above, the fan coil must be capable of providing a minimum heating capacity of 250W/ft, which is typical for an electric baseboard.
5. The fan coil unit must be capable of wall mounting for easy installation.
6. Existing products which meet the above requirements:
   - LOW-FLOW baseboard, by Rosemex.
   - On-Wall Fan unit (Comfort Coil), by Koolfire.

Water-to-Water Heat Pump

1. The available water-to-water heat pump capacities must be between 0.5 tons and 3 tons.
2. The heat pump must employ noise reduction technologies:
   - Thermal/acoustic insulated cabinets.
   - Internally isolated compressor.
   - Compressor shell sound wrap.
3. The heat pump must be designed for easy service access and maintenance. All components must be accessible by removing a maximum of two adjacent panels.
4. The heat pump must operate with minimum entering source temperatures between 25°F to 35°F.
5. The heat pump should be capable of modulating its leaving load temperature in response to change in building load.
6. Existing products which meet the above requirements:
   - Water Furnace
   - Trane
   - Florida Heat Pump

In-suite Piping

1. The in-suite piping must be concealed unless it's located in a storage room or closet.
2. The fan coils must be piped in parallel with the heat pump.
3. The in-suite piping should be installed in drop down ceilings whenever possible.
4. Use soffiting to conceal piping when drop-down ceiling locations are not available.

Mechanical Room

1. Use an existing mechanical room to house the retrofit components whenever possible.
2. If there is not an existing mechanical room, convert a storage room to serve as the mechanical room.
3. Size components according to standard engineering practices.

Ground Source Heat Exchanger

1. Design in accordance with CSA Standard C448.

Figure 7: Retrofit Specification (cont'd)

Distribution Piping

1. The design and installation of the piping system shall conform to the requirements of the Provincial Building and Fire codes.
2. Piping routed through stairwells must be totally enclosed by a chase consisting of material having the same fire resistance rating as required for the stairwell.
3. Support for piping inside a building shall be provided by pipe clamps, which are designed for this purpose.

3.2.2 Design Operating Conditions

A design condition of 250W/ft of tangential fan coil was assumed. This value was selected because it represents the typical output of an electrically heated baseboard, as per the Ontario Hydro report [3]. Matching the output of the fan coil to the electric baseboard on a per foot basis ensures that the length of fan coil installed equals the length of original baseboard removed. This was considered to be important to reduce the intrusive impact of the retrofit.

Based on the assumed design condition (250W/ft), the entering water temperature to the fan coil was calculated using the equation provided by Rosemex, the manufacturer of the fan coil. See Appendix A. The model used in the calculation is the Rosemex LF-250. Its performance characteristics are listed in Appendix A. The LF-250 is 4.21 feet long and requires 0.98 GPM of water.

Rosemex Equation (Manufacturer Supplied):

$$New\,FanCoil\,Capacity = \frac{NewWater(F) - NewAir(F)}{135} \cdot (Capacity\,Given\,in\,Table)$$

The above equation can be written on a per foot basis.

$$\frac{New\,fanCoil\,Capacity}{ft} = \frac{NewWater(F) - NewAir(F)}{135} \cdot \frac{(Capacity\,Given\,in\,Table)}{ft}$$

$$0.25\frac{kW}{ft} \cdot 3.412\frac{MBTUH}{kW} = \frac{NewWater(F) - 65F}{135} \cdot \left(\frac{9.8MBTUH}{4.21ft}\right)$$

New Water (F) = 114.5 F

Based on the above calculation the entering water temperature to the fan coil needed to maintain the 250W/ft design condition is 114.5 F.

The water temperature leaving the baseboard was calculated using, $q=mc_p$ÊT.

$$0.25\frac{kW}{ft} \cdot 4.21ft = 1000\frac{kg}{m^3} \cdot 0.98GPM \cdot 6.309x10^{-5}\,\frac{m^3/s}{GPM} \cdot 4.2\frac{kJ}{kgK} \cdot \Delta T$$

ÊT = 7.29 F

Based on the above calculation the temperature drop across the baseboard at design conditions is 7.3 F. The temperature leaving the baseboard is calculated by subtracting the baseboard temperature drop from the entering water temperature. Temperature leaving the baseboard equals, 114.5 F- 7.3 F = 107.2 F.

The temperatures calculated above are used in conjunction with the heat pump performance maps (see Appendix A) to determine the heat pump operating conditions. Three models were selected, Carrier 50RWS036, Priemier P034W, and Trane WXWA026. The leaving load temperature (LLT) from each heat pump must correspond to 114.5 F, and the entering load temperature (ELT) to each heat pump must equal 107.2 F. The two lowest entering source temperatures (EST) available for each heat pump were selected (typically 30 F and 40 F) to complete the set of conditions needed to determine the heat pump characteristics. Interpolation of the performance maps was required, see Appendix B.

Two assumptions were made while interpolating. The highest possible flow rate was assumed on the load side of the heat pumps. This ensures a maximum number of baseboards can be connected to the heat pump. A source flow rate of 7 GPM was also assumed

In addition to the design operating condition, three additional off-design conditions were examined. These conditions correspond to leaving load temperatures from the heat pump of 110 F, 105 F, and 100 F. The corresponding leaving temperatures from the baseboards were calculated for each of the entering temperatures, using the procedure illustrated above. Using the same heat pumps selected for the design operating conditions, the performance characteristics at the three off design conditions were interpolated from the heat pump performance maps, see Appendix B.

4. ENERGY AND COST/BENEFIT ANALYSIS

4.1 Modelling - Energy Calculations

The bin calculation (see example in Appendix C) assumes a balance point (zero load) at 12.8 °C (55 °F) and the design heating load occurs at -18.9 °C (-2.0 °F). For each apartment size and direction, a heating load was determined from previous work using DOE 2.1E. The bin methodology assumes the heating load varies linearly from zero at the balance point to the design load at the design temperature.

The source heat pump EWT (**HP EWT**) is dependent to the bin temperature based on a procedure outlined by Caneta Research [4] in the development of GSHP algorithms for Hot 2000.

The number of baseboard fan coil units is determined to meet the design load for each apartment assuming 250 Watts per linear foot based on the Rosemex LF-250. The design temperature leaving the heat pump (LLT) is 114.5 °F as determined earlier to obtain the required 250 W/ft frequently used in electric baseboard sizing.

It is assumed for this analysis that the heat pump leaving temperature (LLT) can be controlled by an indoor/outdoor reset device. Temperature reset reduces cycling effects at part-load conditions and improves the heat pump efficiency which is inversely proportional to the LLT. This is modelled by calculating the minimum LLT required for the baseboards to meet the apartment heating load relative to the apartment design load (not the installed baseboard capacity). A minimum cut-off temperature of 100 °F for the LLT is chosen to prevent occupant discomfort from cool air from the baseboard. In the bin calculation spreadsheets, the initial LLT calculation is referred to as **LLT Init** and the value with the minimum cut-off is **LLT Limit**. When the apartment heating load is below that produced by the baseboards with 100 °F water temperature, the system (fans and pumps) are assumed to cycle on-off. The fraction on time of the baseboard system is **Baseboard PLR**.

The baseboard fan energy and in-suite pump energy are both included in the calculation of the per suite energy consumption. The baseboard fan energy is determined based on 60 Watts fan power per baseboard unit and the number of baseboards. The pumping energy required to supply warm water from the heat pump unit to the baseboards is based on a pressure drop of 2.42 kPa per baseboard unit, 5.0 kPa for the GSHP heat exchanger and 0.548 kPa per metre of pipe to and from the baseboard. It was assumed that the heat pump was located near the corridor and the water flowed to the exterior wall then back along the exterior wall to the heat pump a distance roughly equal to the perimeter of the apartment. Four 90°elbows were also included. The flow rate is based on the heat pump manufacturer's specifications.

Due to a limited number of water-to-water heat pump with capacities in the range required for individual apartments, a single heat pump unit (WaterFurnace P034W) is assumed for all the apartments being analyzed in this study. This is the smallest unit available from this manufacturer and has sufficient capacity to meet the design load of the largest corner apartment examined in this study. The performance is penalized more in the smaller apartments due to larger cycling losses but the results are conservative.

The available HP capacity (**Avail. HP Capacity**) is determined based on correlations from the units performance map for heat pump capacity as a function of source entering water temperature (**HP EWT**) and load EWT (**HP ELT**).

Similarly, the heat pump COP is based on correlations from the units performance map for heat pump capacity as a function of source entering water temperature (**HP EWT**) and load EWT (**HP ELT**). In addition, the HP COP is also multiplied by a part load correlation presented in Henderson, Huang and Parker [5], where the heat pump part load is the apartment heat loss divided by the available heat pump capacity.

Hourly compressor, fan and pump input power (**Hourly Compress Input** and **Hourly Fan/Pump Input**) represents the power consumed by the heat pump, baseboard fans and apartment pump at each bin period adjusted to reflect any part load operation of the fans and pumps.

The **Bin Period Total** represents the energy consumption for all the hours associated with a particular bin temperature. **Heating provided** is the heating done by the heat pump (and the electric resistance reference). Input energy is energy consumed by the heat pump, baseboard fans and apartment pump for all the hours associated with a particular bin temperature.

In addition to the small circulation pumps in each apartment moving fluid between the heat pump and baseboards, a ground-source heat pump system requires central pumps to circulate the source fluid (water and anti-freeze solution) through the ground and throughout the building to each individual heat pump. This pump typically runs continuously throughout the year. Kavanaugh and Rafferty [6] recommend 50 to 75 Watts of input pump power for each ton of block cooling load as "good" design.

Since the calculation methodology for this study is done on an individual suite basis, it is impossible to determine the block load for the building. The sum of the individual suite cooling loads results in 616 tons of cooling. It was assumed that the block load is 80% of the individual peak capacity or 493 tons. Assuming the midpoint of the pump power for "good" design of 62.5 W/ton, the input power is 30.8 kW. The bin calculation indicates 6,013 hours associated with heating, so operating continuously, the pump consumes 185,300 kWh of electricity during the heating season. This should be subtracted from the energy savings of the GSHP system over the existing electric resistance heating.

The results from the bin calculation analysis for the model 642 unit two building complex are shown in Tables 1 through 4.

Table 1: Individual Apartment Energy Analysis Results

Apartment Description	Size (ft²)	North Electric (kWh)	North GSHP (kWh)	North Savings (kWh)	East Electric (kWh)	East GSHP (kWh)	East Savings (kWh)	South Electric (kWh)	South GSHP (kWh)	South Savings (kWh)	West Electric (kWh)	West GSHP (kWh)	West Savings (kWh)
Single Wall Units													
Bachelor	500	3,831	1,823	2,009	3,542	1,731	1,810	3,349	1,671	1,679	3,698	1,781	1,917
1 Bedroom	650	4,912	2,353	2,558	4,585	2,251	2,333	4,329	1,987	2,342	4,782	2,313	2,469
2 Bedrooms	1,000	7,231	3,267	3,965	6,939	3,178	3,761	6,536	2,871	3,666	7,225	3,265	3,960
3 Bedrooms	1,500	10,233	4,368	5,865	10,395	4,415	5,980	9,780	4,235	5,545	10,830	4,541	6,289
Corner Units		North West			North East			South East			Sowth West		
2 Bedrooms	1,000	11,882	5,005	6,877	11,511	4,898	6,612	11,007	4,568	6,439	11,231	4,818	6,414
3 Bedrooms	1,500	14,407	5,929	8,478	13,980	5,809	8,170	13,336	5,443	7,893	13,620	5,708	7,912

Table 2: Apartment Peak Loads For Toronto Location - High Wall U-Value (0.112 W/m² °C)

Apartment Description	Size (ft²)	North Cooling (Btu/hr)	North Heating (Btu/hr)	East Cooling (Btu/hr)	East Heating (Btu/hr)	South Cooling (Btu/hr)	South Heating (Btu/hr)	West Cooling (Btu/hr)	West Heating (Btu/hr)	Average Cooling (Btu/hr)	Average Heating (Btu/hr)
Single Wall Units											
Bachelor	500	6,830	6,136	8,096	5,672	7,325	5,364	8,855	5,922	7,777	5,774
1 Bedroom	650	7,649	7,866	9,387	7,342	8,341	6,933	10,264	7,659	8,910	7,450
2 Bedrooms	1,000	9,631	11,581	12,537	11,113	10,810	10,468	13,653	11,570	11,658	11,183
3 Bedrooms	1,500	12,348	16,388	17,049	16,647	14,249	15,663	18,426	17,344	15,518	16,511
Corner Units		North West		North East		South East		South West		Average	
2 Bedrooms	1,000	15,260	19,028	14,630	18,434	15,505	17,628	16,344	17,987	15,435	18,269
3 Bedrooms	1,500	17,813	23,072	17,133	22,388	18,248	21,358	19,150	21,812	18,086	22,158

Table 3: Energy Savings Calculation For Two Building Apartment Complex

	Bachelor No.	Bachelor Savings Per Unit (kWh)	Bachelor Energy Savings (kWh)	1 Bedroom No.	1 Bedroom Savings Per Unit (kWh)	1 Bedroom Energy Savings (kWh)	2 Bedroom No.	2 Bedroom Savings Per Unit (kWh)	2 Bedroom Energy Savings (kWh)	3 Bedroom No.	3 Bedroom Savings Per Unit (kWh)	3 Bedroom Energy Savings (kWh)	Total Energy Savings (kWh)
North	21	2,009	42,179	71	2,558	181,640	12	3,965	47,577	0	5,865	0	271,396
East	20	1,810	36,205	71	2,333	165,647	12	3,761	45,132	0	5,980	0	246,984
South	20	1,679	33,577	71	2,342	166,309	12	3,666	43,987	0	5,545	0	243,873
West	20	1,917	38,341	71	2,469	175,319	12	3,960	47,520	0	6,289	0	261,179
NW	0	n/a	0	0	n/a	0	44	6,877	302,578	14	8,478	118,691	421,269
NE	0	n/a	0	0	n/a	0	43	6,612	284,334	14	8,170	114,385	398,718
SE	0	n/a	0	0	n/a	0	44	6,439	283,327	13	7,893	102,609	385,936
SW	0	n/a	0	0	n/a	0	44	6,414	282,205	13	7,912	102,852	385,058
	81	7,415	150,301	284	9,703	688,915	223	41,693	1,336,659	54	56,132	438,537	**2,614,413**

Table 4: Total Building Cooling Capacity Calculation For Two Building Apartment Complex For Central Pump Energy

	Bachelor			1 Bedroom			2 Bedroom			3 Bedroom			Total
	No.	Suite Clg Load (Tons)	Tot. Suite Clg Load (Tons)	No.	Suite Clg Load (Tons)	Tot. Suite Clg Load (Tons)	No.	Suite Clg Load (Tons)	Tot. Suite Clg Load (Tons)	No.	Suite Clg Load (Tons)	Tot. Suite Clg Load (Tons)	Building Load (Tons)
North	21	0.57	12.0	71	0.64	45.3	12	0.80	9.6	0	1.03	0.0	67
East	20	0.67	13.5	71	0.78	55.5	12	1.04	12.5	0	1.42	0.0	82
South	20	0.61	12.2	71	0.70	49.4	12	0.90	10.8	0	1.19	0.0	72
West	20	0.74	14.8	71	0.86	60.7	12	1.14	13.7	0	1.54	0.0	89
NW	0	n/a	0.0	0	n/a	0.0	44	1.27	56.0	14	1.48	20.8	77
NE	0	n/a	0.0	0	n/a	0.0	43	1.22	52.4	14	1.43	20.0	72
SE	0	n/a	0.0	0	n/a	0.0	44	1.29	56.9	13	1.52	19.8	77
SW	0	n/a	0.0	0	n/a	0.0	44	1.36	59.9	13	1.60	20.7	81
	81	3	52.4	284	3	210.9	223	9	271.8	54	11	81.3	**616**

4.2 Cost Analysis

4.2.1 Option A - Retrofit - Heating Only Benefit

The cost analysis is based on the same sample building, a 642 suite, 2 building apartment complex. Each suite has one water to water heat pump installed. The two building complex requires 2494 fan coils in total. Table 5 summarizes the cost including labour for retrofitting this building.

Table 5: Capital/Labour Costs

	Basic	$/unit	$/ton	Total Cost
Engineering Fee				
Design and supervision	$30,000			$30,000
Central Components				
Main circulation pumps	$4,600		$40	$29,240
Mechanical room piping	$4,500		$12	$11,892
System controls	$8,500			$8,500
Chemical treatment	$4,000		$5	$7,080
Cleaning and flushing	$800	$15		$10,430
Water balancing	$1,200	$25		$17,250
GSHP adjustment factors			$350	$215,600
Ground heat exchanger			$1,000	$616,000
Distribution Components				
Mechanical room to suite piping (risers and runouts)			$550	$338,800
Zone components				
Heat pump unit		$952	$377	$843,163
Baseboard unit		$300		$748,200
Heat pump and baseboard installation		$150	$15	$105,540
In-suite piping and concealment		$635	$30	$426,034
Condensate drain		$135		$86,670
			Total	$3,494,399

The cost data for the main circulation pumps, mechanical room piping, system controls, chemical treatment, cleaning and flushing, water balancing, heat pump and baseboard installation, in-suite piping and concealment, condensate drain, and mechanical room-to-suite piping was provided by an industry contact [7]. The cost to connect the heat pump to the distribution piping and to the baseboard, and conceal the piping in the suite is all included in in-suite piping and concealment. The cost of the mechanical room-to-suite piping was provided for new construction and was increased by 25 percent to a value of $550/ton to account for the additional labour and materials associated with retrofitting. Because the cost data provided is based on a water source heat pump system additional cost adjustments were added to accurately represent the cost for a ground source heat pump system. The ground source heat pump adjustment factors were taken from the Ground Source Heat Pump Engineering Manual [8]. The additional costs are for larger heat pumps, larger pipe sizes, larger circulation pumps, and the addition of pipe insulation due to lower loop temperatures than with a conventional water-loop system. A ground source heat pump system also requires a ground heat exchanger. The ground heat exchanger consists of 230 vertical bores each 350 feet long. This represents an average heat exchanger bore length of 125 feet per apartment in the example building. These values are based on an assumed vertical bore length of 130 ft/ton [9]. An average value of $1000/ton for the vertical heat exchanger was used for the cost estimate [9].

The cost of the heat pump unit (including thermostat) was taken from RSMeans [10]. RSMeans does not publish cost data for water-to-water heat pumps so a water source heat pump was selected. This approximation is acceptable because the additional cost for the water-to-water heat pump is included in the ground source heat pump adjustment factors.

The fan coil cost per unit (including thermostat) provided by a local representative of the manufacturer based on 2,500 units purchased is $650. This price is not, in the authors' opinion, an accurate representation of the cost in a mature market, because the market is currently very small for such fan coil equipment. As the market for this product increases the price would significantly decrease. A cost of $300 per unit was assumed based on a review of similar baseboards listed in RSMeans [10].

From the energy calculations undertaken in the modelling phase, it was determined that the annual energy savings for this building were 2,429,104 kWh. This value corresponds to the annual total energy savings (2,614,413 kWh) minus the annual central pump energy use (185,309 kWh). To determine the annual dollar savings an electricity charge was taken from an EE4 simulation of a similar building. This charge represents the total building electricity cost including electrical demand divided by the building energy consumption in kWh. The electricity charge was calculated as $0.0847/kWh. When this rate is applied to the retrofitted building it results in a total annual savings of $205,745. The annual maintenance cost for the building is $57,831. This was calculated using a maintenance cost of $0.01093/ft^2, a value taken from a survey report for GSHP systems in a multi-unit residential building [11]. It is assumed that the annual maintenance cost for the electrically heated building is negligible. Table 6 summarizes the economics to retrofit the sample building.

Table 6: Cost/Benefit Summary

Retrofit Cost	Annual Savings	Maintenance Cost	Cost/Suite	Simple Payback
$3,494,399	$205,745	$57,831	$5,443	23.6

Several retrofit projects were undertaken by the Onario Ministry of Environment and Energy and Consumers Gas to determine the cost effectiveness of converting a baseboard electrically heated apartment to natural gas heating[12]. Table 7 summarizes 5 case studies that were conducted.

Table 7: Electric Heating to Natural Gas Heating Retrofits

Case	Building	Retrofit Cost	Annual Savings	Suites	Cost/Suite	Simple Payback
1	11 Storey Apartment	$480,926	$13,964	108	$4,453	34.4
2	14 Storey Apartment	$771,538	$55,654	156	$4,946	13.9
3	6 Storey Apartment	$303,460	$2,158	60	$5,058	140.6
4	11 Storey Apartment	$394,976	$30,427	101	$3,911	13.0
5	6 Storey Apartment	$433,174	$46,397	114	$3,800	9.3

4.2.2 Option B - Retrofit - Heating and Cooling Benefit

A second analysis was undertaken to determine the cost to retrofit the same electrically heated sample building with mini-split cooling units in each suite. In this retrofit option the mini-split system would provide the desired cooling and the existing electric baseboards would provide the required heating. A cost break down for the mini-split retrofit is shown in Table 8. The mini-split unit cost and installation cost was taken from RSMeans.

Table 8: Mini-split Retrofit Cost

	Cost ($)
Mini-split unit	892,298
Installation	242,924
Engineering Fee	10,000
Total Cost	1,145,223

A cost comparison between the mini-split retrofit and the GSHP retrofit can be seen in Table 9. It is assumed that the cooling energy consumption and maintenance cost for both systems is equal, therefore the total savings result strictly from heating energy savings. The calculated simple payback for the GSHP retrofit is 11.4 years. If the building owner decides to install cooling in the building as part of a renovation and building improvement project the GSHP retrofit is then a more attractive option.

Table 9: Retrofit Options - Cost Comparison

GSHP Retrofit Cost	Mini-split Retrofit Cost	Incremental Capital Cost	GSHP Energy Savings	Simple Payback Years
$3,494,399	$1,145,223	$2,349,176	$205,745	11.4

5. CONCLUSIONS AND RECOMMENDATIONS

Tangential fan coil is a suitable technology for retrofitting electric baseboard apartments. This technology has been used in packaged air conditioners from the far east for over ten years. However, it is currently very expensive in the configuration needed here. The fan blades are made of aluminum rather than sheet metal. The price of the tangential fan coil provided by the local representative was not considered reflective of a mature market. As the demand for the product increases and the components within the fan coil become standardized the cost should decrease significantly. Efforts could also be made to reduce cost by substituting less expensive materials and by improving the heat transfer characteristics of the tangential fan coil surface. An additional product survey discovered a company located in Vancouver named Koolfire that manufactures an on-the-wall fan coil unit that cost between $189 to $395. The heating capacity ranges between 3,000 to 10,000 Btu/h. This product meets the physical constraints of a baseboard and has been used in electric baseboard to ground source heat pump system retrofits in the Vancouver area. Based on this product our assumption of $300 for the fan-coil is reasonable.

Further investigation should be undertaken to optimize the control of the leaving water temperature from the heat pump. A heat pump that can operate with a lower leaving (and hence entering) water temperature in response to a change in load (i.e. outdoor reset), will operate at a higher efficiency. Preliminary investigation indicates that given the current technology it should be possible to control the heat pump in this manner. For example the water flow rate through the heat pump could be controlled. It was assumed in the energy analysis that the heat pump was capable of varying the leaving temperature down to 100 F, in response to lower heating load conditions.

Smaller heat pumps in the bachelor and 1 bedroom suites would increase the energy savings and decrease the physical space occupied by the heat pump. Currently few companies manufacture products less than 3 tons. These smaller water-to-water heat pump units would quickly become available if these retrofit applications could be developed.

The simple payback period of 23.6 years calculated here for this retrofit is generally not competitive with that reported for natural gas retrofits to baseboard heated apartments in the Toronto area in the early 1990s. However, the other advantage offered by this retrofit is the ability to provide very efficient air conditioning comfort in summer where it did not exist before. This should add considerable value to buildings implementing this heat pump retrofit. The proposed retrofit is a viable option for a building owner who wishes to add cooling to an electrically heated building without air conditioning. The proposed retrofit when compared to a mini-split cooling system retrofit has a much more attractive payback period of 11.4 years.

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Appendix A: Electric Baseboard Retrofit - Literature Search

(Separately Bound)

Appendix B: Determination of Heat pump Operating Conditions

Heat Pump Performance - Design Condition

*Design Conditions**

Calculated entering water temp to baseboard to maintain 250 W/ft**

114.5 F

Calculated leaving water temperature from baseboard

107.2 F

*Based on LF-250 (Fan assisted Baseboard) by Rosemex
**250W/ft taken from Report by EnerMark

CASE 1: Carrier 50RWS036 (See Electric Baseboard Retrofit Binder)

Requirements
EST= 20 F, 40 F
LLT= 114.5 F
ELT= 107.21 F

Assumptions:
Load GPM =9
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate						Pressure Drop (PSI)	
ELT	EST	LLT	HC	KW*	COP	Source	Load
100	30	105.8	26.2	2.2	3.49	5.8	3.6
120	30	125.7	25.6	2.83	2.65	5.8	3.3
100	40	106.4	29	2.02	4.21	5.0	3.6
120	40	126.3	28.2	2.59	3.18	5.0	3.3

INTERPOLATION						HP Pressure Drop (PSI)		Baseboard Pressure Drop (PSI/module)**
ELT	EST	LLT	HC	KW*	COP	Source	Load	
107.21	30	112.97	25.98	2.43	3.19	5.80	3.49	0.152
107.21	40	113.57	28.71	2.23	3.84	5.00	3.49	0.152

**module = LF-250
*Compressor only

CASE 2: Premier Series P034W (See Electric Baseboard Retrofit Binder)

Requirements
EST= 30 F or 40 F
LLT= 114.5 F
ELT= 107.21 F

Assumptions:
Load GPM =9
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate						Pressure Drop (PSI)	
ELT	EST	LLT	HC	KW*	COP	Source	Load
100	30	105.3	23.3	2.39	2.9	3.5	4.7
120	30	125.2	23.2	2.97	2.3	3.5	4.5
100	40	106.2	27.1	2.4	3.3	3.5	4.7
120	40	126.1	26.8	2.98	2.6	3.5	4.5

INTERPOLATION

ELT	EST	LLT	HC	KW*	COP	HP Pressure Drop (PSI) Source	HP Pressure Drop (PSI) Load	Baseboard Pressure Drop (PSI/module)**
107.21	30	112.47	23.26	2.60	2.68	3.50	4.63	0.152
107.21	40	113.37	26.99	2.61	3.05	3.50	4.63	0.152

**module = LF-250
*Compressor only

<u>CASE 3</u>: Trane WXWA 026 (See Electric Baseboard Retrofit Binder)

Requirements
EST= 30 F or 40 F
LLT= 114.5 F
ELT= 107.21 F

Assumptions:
Load GPM =4
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate

ELT	EST	LLT	HC	KW*	COP	Pressure Drop (PSI) Source	Pressure Drop (PSI) Load
100	25	106.52	13.10	1.79	2.14	5.09	7.02
120	25	126.32	12.70	2.02	1.84	5.09	7.02
100	45	109.65	19.40	2.07	2.75	5.06	7.02
120	45	129.36	18.80	2.33	2.36	5.06	7.02

INTERPOLATION

ELT	EST	LLT	HC	KW*	COP	HP Pressure Drop (PSI) Source	HP Pressure Drop (PSI) Load	Baseboard Pressure Drop (PSI/module)**
107.21	25	113.66	12.96	1.87	2.03	5.09	7.02	0.152
107.21	45	116.75	19.18	2.16	2.61	5.06	7.02	0.152

**module = LF-250
*Compressor only

Notes:

EST = Entering Source Temperature
ELT = Entering Load Temperature
LLT = Leaving Load Temperature
HC = Total Heating Capacity

Baseboard LF-250		
Fan Power/Module =	60	Watts
GPM/Module =	0.98	GPM

Heat Pump Performance - Off-Design Conditions

Based on LF-250 (Fan assisted Baseboard)

CASE 1: Carrier 50RWS036 (See Electric Baseboard Retrofit Binder)

Requirements
EST= 20 F, 40 F
LLT= 110 F
ELT= 103.4 F

Assumptions:
Load GPM =9
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate

						Pressure Drop (PSI)	
ELT	EST	LLT	HC	KW*	COP	Source	Load
100	30	105.8	26.2	2.2	3.49	5.8	3.6
120	30	125.7	25.6	2.83	2.65	5.8	3.3
100	40	106.4	29	2.02	4.21	5.0	3.6
120	40	126.3	28.2	2.59	3.18	5.0	3.3

INTERPOLATION

						HP Pressure Drop (PSI)		Baseboard Pressure Drop (PSI/module)**
ELT	EST	LLT	HC	KW*	COP	Source	Load	
103.4	30	109.18	26.10	2.31	3.35	5.80	3.55	0.152
103.4	40	109.78	28.86	2.12	4.03	5.00	3.55	0.152

**module = LF-250
*Compressor only

Requirements
EST= 20 F, 40 F
LLT= 105 F
ELT= 99.1 F

Assumptions:
Load GPM =9
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate

						Pressure Drop (PSI)	
ELT	EST	LLT	HC	KW*	COP	Source	Load
100	30	105.8	26.2	2.2	3.49	5.8	3.6
120	30	125.7	25.6	2.83	2.65	5.8	3.3
100	40	106.4	29	2.02	4.21	5.0	3.6
120	40	126.3	28.2	2.59	3.18	5.0	3.3

INTERPOLATION

						HP Pressure Drop (PSI)		Baseboard Pressure Drop (PSI/module)**
ELT	EST	LLT	HC	KW*	COP	Source	Load	
99.1	30	104.90	26.23	2.17	3.53	5.80	3.61	0.152
99.1	40	105.50	29.04	1.99	4.26	5.00	3.61	0.152

**module = LF-250
*Compressor only

Requirements
EST= 20 F, 40 F
LLT= 100 F
ELT= 94.8 F

Assumptions:
Load GPM =9
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate						Pressure Drop (PSI)	
ELT	EST	LLT	HC	KW*	COP	Source	Load
100	30	105.8	26.2	2.2	3.49	5.8	3.6
120	30	125.7	25.6	2.83	2.65	5.8	3.3
100	40	106.4	29	2.02	4.21	5.0	3.6
120	40	126.3	28.2	2.59	3.18	5.0	3.3

INTERPOLATION						HP Pressure Drop (PSI)		Baseboard Pressure Drop (PSI/module)**
ELT	EST	LLT	HC	KW*	COP	Source	Load	
94.8	30	100.63	26.36	2.04	3.71	5.80	3.68	0.152
94.8	40	101.23	29.21	1.87	4.48	5.00	3.68	0.152

**module = LF-250
*Compressor only

CASE 2: Premier Series P034W (See Electric Baseboard Retrofit Binder)

Requirements
EST= 30 F or 40 F
LLT= 110 F
ELT= 103.4 F

Assumptions:
Load GPM =9
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate						Pressure Drop (PSI)	
ELT	EST	LLT	HC	KW*	COP	Source	Load
100	30	105.3	23.3	2.39	2.9	3.5	4.7
120	30	125.2	23.2	2.97	2.3	3.5	4.5
100	40	106.2	27.1	2.4	3.3	3.5	4.7
120	40	126.1	26.8	2.98	2.6	3.5	4.5

INTERPOLATION						HP Pressure Drop (PSI)		Baseboard Pressure Drop (PSI/module)**
ELT	EST	LLT	HC	KW*	COP	Source	Load	
103.4	30	108.68	23.28	2.49	2.80	3.50	4.67	0.152
103.4	40	109.58	27.05	2.50	3.18	3.50	4.67	0.152

**module = LF-250
*Compressor only

Requirements
EST= 30 F or 40 F
LLT= 105 F
ELT= 99.1 F

Assumptions:
Load GPM =9
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate						Pressure Drop (PSI)	
ELT	EST	LLT	HC	KW*	COP	Source	Load
100	30	105.3	23.3	2.39	2.9	3.5	4.7
120	30	125.2	23.2	2.97	2.3	3.5	4.5
100	40	106.2	27.1	2.4	3.3	3.5	4.7
120	40	126.1	26.8	2.98	2.6	3.5	4.5

INTERPOLATION

ELT	EST	LLT	HC	KW*	COP	HP Pressure Drop (PSI) Source	Load	Baseboard Pressure Drop (PSI/module)**
99.1	30	104.40	23.30	2.36	2.93	3.50	4.71	0.152
99.1	40	105.30	27.11	2.37	3.33	3.50	4.71	0.152

**module = LF-250
*Compressor only

Requirements
EST= 30 F or 40 F
LLT= 100 F
ELT= 94.8 F

Assumptions:
Load GPM =9
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate

ELT	EST	LLT	HC	KW*	COP	Pressure Drop (PSI) Source	Load
100	30	105.3	23.3	2.39	2.9	3.5	4.7
120	30	125.2	23.2	2.97	2.3	3.5	4.5
100	40	106.2	27.1	2.4	3.3	3.5	4.7
120	40	126.1	26.8	2.98	2.6	3.5	4.5

INTERPOLATION

ELT	EST	LLT	HC	KW*	COP	HP Pressure Drop (PSI) Source	Load	Baseboard Pressure Drop (PSI/module)**
94.8	30	100.13	23.33	2.24	3.06	3.50	4.75	0.152
94.8	40	101.03	27.18	2.25	3.48	3.50	4.75	0.152

**module = LF-250
*Compressor only

<u>CASE 3</u>: Trane WXWA 026 (See Electric Baseboard Retrofit Binder)

Requirements
EST= 30 F or 40 F
LLT= 110 F
ELT= 103.4 F

Assumptions:
Load GPM =4
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate

ELT	EST	LLT	HC	KW*	COP	Pressure Drop (PSI) Source	Load
100	25	106.52	13.10	1.79	2.14	5.09	7.02
120	25	126.32	12.70	2.02	1.84	5.09	7.02
100	45	109.65	19.40	2.07	2.75	5.06	7.02
120	45	129.36	18.80	2.33	2.36	5.06	7.02

INTERPOLATION

ELT	EST	LLT	HC	KW*	COP	HP Pressure Drop (PSI) Source	Load	Baseboard Pressure Drop (PSI/module)**
103.4	25	109.89	13.03	1.83	2.09	5.09	7.02	0.152
103.4	45	113.00	19.30	2.11	2.68	5.06	7.02	0.152

**module = LF-250
*Compressor only

Requirements
EST= 30 F or 40 F
LLT= 105 F
ELT= 99.1 F

Assumptions:
Load GPM =4
Source GPM=7

PERFORMANCE MAP DATA - Used to interpolate						Pressure Drop (PSI)	
ELT	**EST**	**LLT**	**HC**	**KW***	**COP**	**Source**	**Load**
100	25	106.52	13.10	1.79	2.14	5.09	7.02
120	25	126.32	12.70	2.02	1.84	5.09	7.02
100	45	109.65	19.40	2.07	2.75	5.06	7.02
120	45	129.36	18.80	2.33	2.36	5.06	7.02

INTERPOLATION						HP Pressure Drop (PSI)		Baseboard Pressure Drop (PSI/module)**
ELT	**EST**	**LLT**	**HC**	**KW***	**COP**	**Source**	**Load**	
99.1	25	105.63	13.12	1.78	2.15	5.09	7.02	0.152
99.1	45	108.76	19.43	2.06	2.77	5.06	7.02	0.152

**module = LF-250
*Compressor only

Notes:
EST = Entering Source Temperature
ELT = Entering Load Temperature
LLT = Leaving Load Temperature
HC = Total Heating Capacity

Appendix C: Sample Bin Analysis

Table C1: Water-to-Water Heat Pump/Radial Fan Baseboard Analysis - 3 Bedrooms Apartment (South West) in Toronto

Outdoor Bin Temp. Min (°C)	Max (°C)	Avg. (°C)	HP EWT (°F)	Bin Hours (hours)	Apartment Heat Loss (kW)	(Btu/hr)	Apartment Heat Gain (kW)	(Btu/hr)	Apartment Operating Parameters: LLT Initial (°F)	LLT Limit (°F)	Basebrd PLR	Basebrd ΔT (°C)	HP ELT (°F)	Avail. HP Capacity (MBH)	Adjust. HP COP	Hourly Compress. Input (kWh)	Hourly Fan/pump Input (kWh)	Bin Period Total: Heating Provided (10^3 Btu)	Input Energy (kWh)
35	38	36.5	80.67	0			2.6	9,018											
32	35	33.5	77.00	4			2.3	7,876											
29	32	30.5	73.33	60			2.0	6,735											
26	29	27.5	69.66	212			1.6	5,593											
23	26	24.5	66.00	364			1.3	4,452											
20	23	21.5	62.33	569			1.0	3,310											
17	20	18.5	58.66	796			0.6	2,169											
14	17	15.5	54.99	742			0.3	1,027											
11	14	12.5	51.32	839	0.0	54			65.5	100.0	0.01	2.87	94.8	31.7	0.58	0.03	0.00	45	25
8	11	9.5	47.66	596	0.2	590			70.1	100.0	0.15	2.87	94.8	30.2	2.37	0.07	0.02	352	57
5	8	6.5	44.27	604	0.3	1,127			74.8	100.0	0.28	2.87	94.8	28.9	2.71	0.12	0.04	681	100
2	5	3.5	42.29	911	0.5	1,664			79.5	100.0	0.41	2.87	94.8	28.1	2.83	0.17	0.06	1,516	215
-1	2	0.5	40.30	994	0.6	2,201			84.2	100.0	0.55	2.87	94.8	27.4	2.86	0.23	0.08	2,188	308
-4	-1	-2.5	38.32	715	0.8	2,738			88.9	100.0	0.68	2.87	94.8	26.6	2.85	0.28	0.10	1,957	276
-7	-4	-5.5	36.67	453	1.0	3,274			93.6	100.0	0.82	2.87	94.8	25.9	2.83	0.34	0.13	1,483	210
-10	-7	-8.5	36.67	368	1.1	3,811			98.2	100.0	0.95	2.87	94.8	25.9	2.87	0.39	0.15	1,403	197
-13	-10	-11.5	36.67	324	1.3	4,348			102.9	102.9	1.00	3.11	97.3	25.9	2.81	0.45	0.15	1,409	196
-16	-13	-14.5	36.67	154	1.4	4,885			107.6	107.6	1.00	3.49	101.3	25.8	2.70	0.53	0.15	752	105
-19	-16	-17.5	36.67	55	1.6	5,422			112.3	112.3	1.00	3.87	105.3	25.8	2.59	0.61	0.15	298	42
-22	-19	-20.5	36.67	0	1.7	5,958			114.5	114.5	1.00	4.05	107.2	25.8	2.55	0.68	0.15	0	0
-25	-22	-23.5	36.67	0	1.9	6,495			114.5	114.5	1.00	4.05	107.2	25.8	2.57	0.74	0.15	0	0
-28	-25	-26.5	36.67	0	2.1	7,032			114.5	114.5	1.00	4.05	107.2	25.8	2.59	0.80	0.15	0	0
	Total			6,013														12,084	1,731
																		HSPF	**6.98**

Apartment Load Data

	IP	SI
Apartment size (ft²)	500	
Peak Heating	5,672	1.66
Design htg temp	-2.0	-18.9
Balance Point	55.0	12.8
Peak Cooling	7,610	2.23
Design clg temp	91.0	32.8

Baseboard Calculations

Required fan coil (ft)	6.6
Length per unit (ft)	4.21
# baseboards in apartment	2
Tot. install. baseboard (MBH)	7.18
Fan energy/radial fan (W/unit)	60
Total fan (Watts)	120

HP Performance data

Flow rate (l/s) 0.568

Correlations	Cap.	COP	PLR
A	8.3149	3.3253	0.0102
B	0.5145	0.1942	1.1813
C	0.0342	-0.0007	-0.2467
D	-0.0013	-0.0505	0.0556
E		0.0002	
F		-0.0009	

Pump Power

Pipe ΔP (kPa)	16.8
Baseboard ΔP (kPa)	4.8
Heat pump ΔP (kPa)	5.0
Total pressure drop (kPa)	26.6
Pump efficiency (%)	60
Motor efficiency (%)	75
Pump input power (Watts)	33.6