6. ENERGY EFFICIENT BUILDING DESIGN AND THERMAL ENERGY STORAGE

Edward Morofsky
Energy & Sustainability Innovation and Solutions Directorate, PWGSC, Place du Portage, Phase 3, 8B1, Gatineau, Quebec KIV6E3, Canada

Abstract. This chapter discusses the potential for cost-effectively reducing the energy intensity of office buildings by applying proven technologies, especially the use of ground source systems with thermal energy storage. It is shown that significant energy use reductions are possible without increases in capital costs and that reductions of more than 50% are possible within normal investment criteria. Energy storage techniques need to be adapted to these reduced energy levels. Energy efficient buildings are better suited to energy storage. Low-energy building design can contribute to dramatically reduced energy usage and can be applied to all new building projects. The example of a small office building located in Canada is used to illustrate this potential. The reference energy level is that specified by the minimum (or prescriptive) requirements of the Canadian Model National Energy Code for Buildings (MNECB) 1997. Costs and savings evaluated include energy, capital and maintenance. Typical small and large office buildings were analyzed. The role of energy storage was also considered. The results indicate that energy savings greater than a 50% reduction can be achieved with attractive economic returns through careful selection and application of existing technologies. Energy savings greater than 50% were achieved in four cases for the small office building with discounted payback periods between 2.5 and 6 years. The 50% energy reduction relative to the MNECB is the threshold for high performance buildings. It is possible to achieve 25% reduction compared to the base case building with no incremental cost. With careful selection and application of efficient building technologies at the early stages of design, and adjustment of equipment sizing to account for reduced demands, many designs result in energy savings of 30–40% with no incremental cost. A brief guide to design options for the building side of ground source heat pump systems is then presented. Ground source heat pump systems can significantly lower heating and cooling operating costs and can qualify designs for energy efficiency and renewable energy credits under various building rating schemes. Both distributed or incremental heat pumps and central heat pumps as applied to closed loop ground source systems are considered. Available products are identified for each design option as well as pumping arrangements, system

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schematics showing components for each design option, and outdoor air systems. A table comparing the design options is also provided. In addition to a schematic drawing of each system, elevation sketches showing zone component arrangements for both distributed and under floor designs are given. Some recent Canadian building designs are then summarized. They show a range of retrofit and new building options using innovative approaches and cost-effective results.

Keywords: Building design; Canadian Model National Energy Code for Buildings; cost-effectiveness; DOE 2.1 E; energy storage; energy code; energy efficiency; energy simulation; ground source heat pumps; low-energy; MNECB; TES; thermal energy storage; water loop heat pump.

6.1. Introduction

The potential for cost-effectively reducing the energy intensity of office buildings by applying proven technologies is calculated. The use of ground source systems with thermal energy storage is included. It is shown that significant energy use reductions are possible without increases in capital costs and that reductions of more than 50% are possible within normal investment criteria. Energy storage techniques need to be adapted to these reduced energy levels. Energy efficient buildings are better suited to energy storage. Heating reductions in Canada are greater than cooling and this tends to make heating and cooling loads more comparable. Low-energy building design can contribute to dramatically reduced energy usage and can be applied to all new building projects. The example of a small office building located in Canada is used to illustrate this potential. The reference energy level is that specified by the minimum (or prescriptive) requirements of the Canadian Model National Energy Code for Buildings [1] (MNECB) 1997. Costs and savings evaluated include energy, capital and maintenance. A typical small and large office building were analyzed. The results indicate that energy savings greater than a 50% reduction can be achieved with attractive economic returns through careful selection and application of existing technologies. Energy savings greater than 50% were achieved in four cases for the small office building with discounted payback periods between 2.5 and 6 years. The 50% energy reduction relative to the MNECB is the threshold for high performance buildings. It is always possible to achieve 25% reduction compared to the base case building with no incremental cost. With careful selection and application of efficient building technologies at the early stages of design, and adjustment of equipment sizing to account for reduced demands, many designs result in energy savings of 30–40% with no incremental cost. A brief guide to some design options for the building side of ground source heat pump systems is then presented. Ground source heat pump systems can significantly lower heating and cooling operating costs and can qualify designs for energy efficiency and renewable energy credits under various building rating schemes. Both distributed or incremental heat pumps and central heat pumps as applied to closed loop ground source systems are considered. Available products are identified for each design option as well as pumping arrangements, system schematics showing components for each design option, and outdoor air systems. A table comparing the design options is also provided. A schematic drawing of each system is given. Some recent Canadian building designs are then summarized. They show a range of retrofit and new building options using innovative approaches and cost-effective results.

6.2. Low Energy Building Design Economics and The Role of Energy Storage

6.2.1. INTRODUCTION TO LOW-ENERGY DESIGN

MNECB 1997 contains cost-effective minimum requirements for energy efficiency in new buildings. The MNECB provides maximum thermal transmittance levels for building envelope components per type of energy for different regions of Canada. These levels were determined using regional construction and heating energy costs in a life cycle cost analysis. As well, the MNECB gives regional U-values for windows, references energy efficient equipment standards, and identifies when heat recovery from ventilation exhaust is required for dwelling units. To allow flexibility in achieving a minimum level of energy efficiency, the code offers three compliance approaches: a Prescriptive Path, a Trade-off Path, and a Performance Path. The Prescriptive Path was used as the reference level in this study.

Two generic office building models, the smaller having a floor area of 4,200 m^2, the larger having a floor area of 24,300 m^2 were simulated using the DOE 2.1 E software. The two buildings provided different opportunities to significantly reduce energy use. These buildings were the base cases to which subsequent design modifications to the buildings were compared. Full details on both the small and large buildings in various Canadian locations can be found in the project report [2].

Some basic data on the small building is given below:

- Natural gas-fired central boiler heating.
- Individual zone packaged rooftop DX air cooled (EER = 8.9) with economizer cooling.
- Walls—Brick, batt and rigid insulation.

- Built-up roof, rigid insulation.
- Double-glazed windows, grey tint, aluminum frame with thermal break.
- Solar Heat Gain Coefficient (SHGC) = 0.54.
- Lighting load = 17.8 W/m^2.
- Equipment Appliance Load = 7.5 W/m^2.
- Elevator load = 1 × 30 kW.
- Occupant density = 25 m^2/person.
- Percent fenestration = 40%.
- Fenestration U-value (W/m^2 C) = 3.2.
- Opaque wall U-value (W/m^2 C) = 0.55.
- Roof U-value (W/m^2 C) = 0.47.
- No below grade wall insulation.
- No perimeter floor insulation.
- Infiltration = 0.25 l/s/m^2 exterior wall.
- Outdoor air = 0.4 l/s/m^2 floor area.

The MNECB provides the energy reference level. A reference construction budget was developed by applying and costing conventional equipment to satisfy the energy reference level. The small building has a packaged rooftop, direct expansion cooling unit with an economizer and a natural gas-fired central boiler. The large building has an individual floor variable–air-volume system with central make up air, a cooling tower and economizer with hydronic radiation heating supplied by a natural gas-fired central boiler.

The list of technologies considered is described in rows S1 to S26 in Table 1 and includes envelope, lighting, smart controls, HVAC, renewable energy and equipment aspects. Each of the 26 measures was analyzed individually in terms of energy reduction and life cycle cost in comparison to the base case. The results are shown in Table 4 as percentage energy reduction and payback in years. Individual measures were then grouped into 13 measure sets and shown as columns SA through SM in Table 4. For example, measure set SA contains individual measure S1, S7 and S10. Energy savings and payback of the measure sets are shown in the last two rows of Table 4. Note that measure set energy reduction may be different that the simple sum of the savings associated with individual measures. For example, the savings of S1 (3.7%) + S7 (13.2%) + S10 (13%) equal to 29.9%, while the simulated energy reduction of SA is 28%. The grouping into measure sets attempts to account for such interactions among measures.

Significant energy savings with attractive economic returns were attained. Energy savings over 50% were achieved in five measure sets (SG, SJ, SK, SL, SM) in the small office building and four of these had discounted payback periods between 2.5 and 6 years. The 50% savings relative to the MNECB is considered as the high performance building threshold. Thus, the small

TABLE 4. Individual measures and measure sets with energy and cost comparisons to the base case

Measure*	Energy savings	Payback	SA	SB	SC	SD	SE	SF	SG	SH	SI	SJ	SK
S0	0.0												
S1	3.7	2.5	*	*	*	*	*	*	*	*	*	*	*
S2	2.5	2.8			*		*	*		*	*		*
S3	3.1	5							*			*	
S4	1.1	137											
S5	8.0	7.7						*			*		
S6	9.3	9.3											
S7	13.2	8.5	*	*	*	*							
S8	21.0	10.4							*			*	
S9	3.2	6.1				*		*	*		*	*	
S10	13.0	5.6	*	*									
S11	4.9	6.3		*	*			*	*		*	*	
S12	2.8	28.6											
S13	0.1	8.2											
S14	0.0	Never											
S15	16.4	0			*								
S16	16.7	0								*	*	*	
S17	34.0	14.2				*							*
S18	18.6	0					*	*	*				
S19	0.8	0			*	*	*	*	*	*	*	*	*
S20	2.1	8							*			*	
S21	2.0	24.6											
S22	2.2	244											
S23	–	?											
S24	1.8	0					*	*	*	*	*	*	*
S25	1.6	0					*	*	*	*	*	*	*
S26	1.0	10.9							*			*	
Energy savings (%)			28	32	40	46	31	44	56	30	43	53	52
Simple payback (years)			12	6	0.5	15	0	0	3	0	0	5	6

* S0: Base case, S1: Lighting power density of 11.5 W/m^2, S2: Perimeter daylighting with light dimming, S3: Occupancy sensors for lighting, S4: Active solar shading, S5: Add low-emissivity coating to windows, S6: Add low-emissivity coating and argon fill to windows, S7: Add low-emissivity coating, argon fill, and vinyl framed windows, S8: Triple-glazed low-e coated, argon filled, vinyl framed windows, S9: Increase wall insulation by ΔRSI = 0.9, S10: Condensing boiler (thermal efficiency = 95%), S11: Central air-to-air heat recovery 60% annual effectiveness, S12: Solar air preheating system, S13: Install high efficiency motors on supply fans, S14: Variable speed pump on heating loop, S15: WLHP system with condensing boiler and cooling tower, S16: WLHP system (same as S15) plus thermal storage, S17: WLHP system with ground source, S18: Radiant panel heating and cooling with displacement ventilation, S19: Low flow faucets, S20: Heat pump water heaters, S21: Solar thermal domestic hot water system, S22: Photovoltaic electric array, S23: Microturbine with heat recovery, S24: Low-energy office equipment, S25: Elevator efficiency measures, S26: Increase roof insulation by ΔRSI = 0.9.

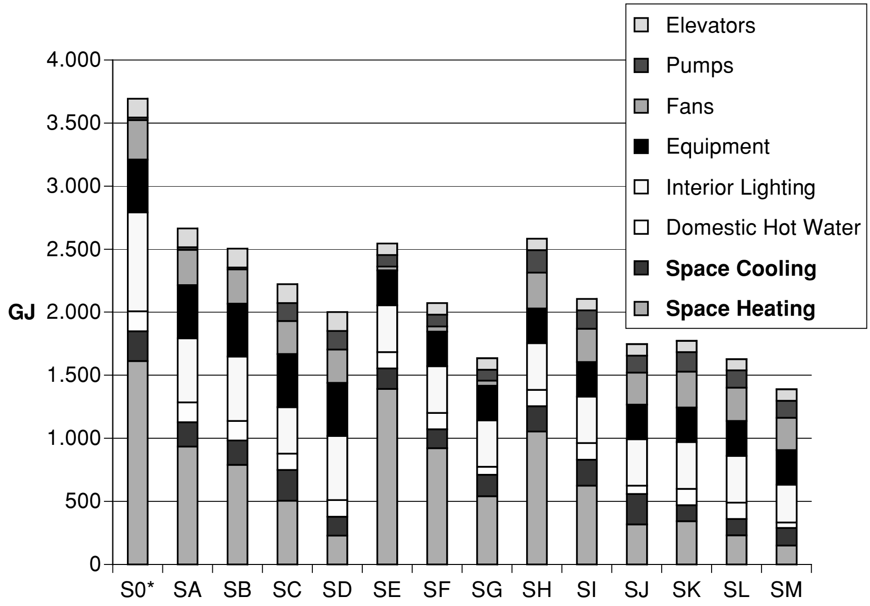

Figure 14. Energy usage versus measure sets for a small office building in Ottawa

office can apply a variety of measure sets to achieve this high performance level.

6.2.2. SIMULATION RESULTS

The DOE 2.1 E model was used to simulate the various measures and measure sets. Figure 14 presents the energy usage for the small office building in Ottawa, Canada. Energy usage is disaggregated into eight end-uses to indicate where measure sets impact energy reduction. These simulation results show that applying proven technologies can reduce energy consumption from the reference MNECB level by 25–65%.

6.2.2.1. *The Role of Energy Storage*

Measure S15 is a water loop heat pump system and reduces energy by 16% with an immediate payback. When included as part of measure set SC it achieves a 40% energy reduction at a payback of 0.5 years. Measure S16 is S15 with an increased storage capacity of about 30%. The cost is roughly $50 per kW cooling capacity. This gives a 16.7% energy savings with an immediate payback. When S16 is included in measure sets SH, SI and SJ it can achieve 3, 43 and 53% energy reductions at 0, 0 and 5 years paybacks, respectively. This storage measure (S16) does not have much of an impact

TABLE 5. Space heating and cooling versus measure sets for Ottawa

	Measure sets													
	S0	SA	SB	SC	SD	SE	SF	SG	SH	SI	SJ	SK	SL	SM
Space heating (MJ)	1,6	935	791	503	227	1,3	922	541	1,0	623	318	344	230	148
Reduction heating (%)	—	42	51	69	86	14	43	66	35	61	80	79	86	91
Space cooling (MJ)	235	192	190	244	152	162	149	168	199	208	240	125	131	140
Reduction cooling (%)	—	18	19	−4	35	31	37	28	15	12	−2	47	44	41

on energy reduction, but when grouped with compatible measures in SI and SJ it is effective. Measure S17 is a ground source heat pump system and individually saves 34% energy at a payback of 14.2 years. When included in measure sets SK, SL and SM is reduces energy usage by 52, 56 and 65% at 6, 6 and 22 years paybacks. In actual projects small storages also serve to reduce the capital costs of ground source heat pump systems and can be used as a backup with standby electric or natural gas-fired boilers.

Table 5 gives the heating and cooling requirements for each measure set and the percentage reduction from the base case. It is seen that reduction in heating requirements is generally greater than cooling requirements, in many measures twice as great. Cooling is generally electrically driven and more expensive per unit of heating or cooling delivered. Cooling storage has always been more popular in Canada and the increase in energy efficient building designs should maintain this preference. For storage systems supplying both heating and cooling, energy efficient designs are better balanced in heating and cooling requirements. A complication is the low temperature needed for latent cooling due to the high summer humidity. Separate latent and sensible cooling need to be considered.

6.2.3. ECONOMIC ANALYSIS

A life cycle cost analysis was done to evaluate the economic attractiveness of the various measure sets. Included in the analysis is the impact on equipment sizing, usually a saving. The sizing changes can result in a significant cost reduction for the measure sets. In order to realize the payback periods shown, equipment must be sized in accordance with load reductions.

The analysis used projected average annual escalation rates of commercial sector electricity and fuel input prices supplied by Natural Resources Canada.

A real discount rate of 10% was used to convert all future expenses and savings into current dollars. This allowed calculation of the net present value of the savings and costs. Also calculated were the discounted payback period and the simple payback period. Each of these quantities was calculated over a life cycle analysis period of 20 years, the assumed life of the mechanical system. Maintenance costs were considered to remain constant in real terms.

There are several measure sets with immediate payback; SE, SF, SH, SI. Measures SE and SF are radiant panel systems with displacement ventilation. These systems have a similar cost to the base case, but they offer energy savings. Furthermore, significant sizing reductions, mainly in the cooling tower and chiller sizes, offset the incremental cost of the envelope and heat recovery measures. Because the elevator efficiency measures offer a net savings in capital cost, the capital cost of the other measures is further offset.

Measures SH and SI are hydronic water loop systems with water-to-air heat pumps. These systems also offer energy savings over the base case, but have an incremental cost over the base case. Other than the system type, these measures are the same as SE and SF, so either payback period is immediate for similar reasons.

A microturbine with heat recovery was one of the measures modeled. It has not been included in any of the measure sets. A more comprehensive analysis was done that took account of the different treatments of electricity and thermal energy and the effects of varying electricity and natural gas prices. This analysis is available in a separate report [6].

6.2.4. LOW-ENERGY BUILDING DESIGN CONCLUSIONS

The performance and economics of the measure sets applied to the small office building have demonstrated that significant energy reductions with attractive economic returns, are possible through careful selection and application of individual measures. Energy savings over 50% were achieved in five measure sets (SG, SJ, SK, SL, SM) in the small office building and four of these had discounted payback periods between 2.5 and 6 years. The 50% savings relative to the MNECB is considered as the high performance threshold. Thus, the small office can apply a variety of measure sets to achieve this high performance level.

It is possible to achieve 25% reductions compared to the base case building with no incremental cost (SE, SF, SH, SI). With careful selection and application of efficient building technologies at the early stages of design, and adjustment of equipment sizing to account for reduced demands, designs can result in energy savings of 30–40% with no incremental cost.

To successfully apply energy efficient designs, it is helpful to use an integrated design process involving energy simulation specialists to facilitate and support the architect and the mechanical and electrical engineers. The energy specialist works as an integral part of the design team to ensure that measures are properly planned and implemented and that their impacts are accounted for in HVAC equipment sizing. This process has now been applied in numerous designs where the energy reductions have confirmed simulation results.

The existing stock of buildings represents a much larger opportunity than new buildings for energy savings. Many of the measures and results presented here would be applicable to existing buildings when major system upgrades, replacements or building retrofits are undertaken. There may even be cases where pre-mature retrofits could be justified on a life cycle cost basis.

6.3. Design Options for Ground Source Heat Pump Systems [5]

6.3.1. INTRODUCTION

This section is a brief guide to design options for the building side of ground source heat pump systems for office buildings. Ground source heat pump systems can significantly lower heating and cooling operating costs and can qualify designs for renewable energy credits under several sustainable building rating programs.

There are a variety of design approaches that can be taken. Both distributed or incremental heat pumps and central heat pumps as applied to closed loop ground source systems are considered. Available products are identified for each design option as well as pumping arrangements, system schematics showing components for each design option, and outdoor air systems. Table 6 compares design options.

In addition, a schematic drawing of each system, elevation sketches showing zone component arrangements for both distributed and under floor designs are given. Drawings of two approaches to vertical ground heat exchanger layout are also shown.

6.3.2. DISTRIBUTED WATER LOOP HEAT PUMP (WLHP) SYSTEMS

This is a conventional water loop heat pump system using a boiler and cooling tower to maintain the water loop temperature (see Measures S15–S17 in Section 6.2). Since outside air handling unit and other terminal devices like unit heaters, wall fin convectors, etc which are often used with this water loop heat pump system need a different operating water temperature than that of the water loop, a plate heat exchanger is used between the primary heating circuit

TABLE 6. Comparison of ground source heat pump system types

Features	Distributed water loop heat pump with ground loop	Central reversing heat pump withground loop	Central multiple heat pumps with ground loop
1 Simultaneous heating & cooling	The system can provide simultaneous heating and cooling to individual spaces inside the building as heat pumps operate under control of zone thermostats.	The system can provide simultaneous heating and cooling with the help of 4 pipe fan coil units. During heating season, central heat pump maintains the temperature of the heating loop. The cooling loop exchanges heat with the low temperature ground loop that passes out of the central heat pump. During summer, the central heat pump reverses its cycle, rejecting heat to the ground loop. The cooling loop bypasses the ground loop and passes through the evaporator of the central heat pump.	The system can provide simultaneous heating and cooling by the use of both cooling & heating side of heat pumps. During the heating season, if there is no demand for cooling a diverting valve connects the low temperature side of the heat pump loop to ground loop. During the summer, heat pumps reject heat to ground loop. When there is simultaneous demand for heating & cooling, the water loops on both low and high temperature side are isolated from the ground loop and the cooling and heating water is supplied by the respective secondary pumps.
2 Heat pump system capacity	The total installed capacity of heat pumps will be more than the central heat pump.	The size of the central heat pump will be smaller when compared to the total installed capacity of heat pumps in the distributed water loop heat pump system. This is because the central heat pump is sized to meet the block load of the entire building.	The size of the central heat pump will be smaller when compared to the total installed capacity of heat pumps in a distributed water loop heat pump system. This is because the central heat pump is sized to meet the block load of the entire building.

3 Space requirements	Space savings are not expected at the zone level. However space required for mechanical room components may be lower when compared to central heat pump system.	Space savings arising from the smaller size of boiler and cooling tower is offset by the addition of central heat pump. Use of fan coil units at the zone level is not expected to result in space savings because of larger requirement of air flow arising from lower temperature difference across the heating coil.	Space savings are expected with no need for a boiler and cooling tower. However this may be offset by the presence of a few larger water-to-water heat pumps.
4 Use with radiant floor heating and cooling	Radiant floor heating and cooling cannot be done with this system.	The system appears to be quite compatible with radiant floor heating and cooling. Since the supply temperature of water will be relatively lower, it looks ideal for use with radiant floor heating and cooling as the control of surface temperature will be easier.	This system can be used with radiant floor heating & cooling. During mid-season when there is demand for simultaneous heating and cooling, the low temperature side of heat pumps may have to depend on ground loop more often for heat source. In the case of only primary pumps, control of floor temperature during cooling may be difficult due to lower cooling supply temperature.
5 Humidification	Humidification can be done at the system level by having humidifier section at the air-handling unit supplying fresh air. The humidifier can be electric or gas type. Another method is to use evaporative pads such as GLASdek from Munters. This eliminates the use of gas or electricity for humidification.	Humidification can be done at the system level by having humidifier section at the air-handling unit supplying fresh air. The humidifier can be electric or gas type. Another method is to use evaporative pads such as GLASdek from Munters. This eliminates the use of gas or electricity for humidification.	Humidification can be done at the system level by having humidifier section at the air-handling unit supplying fresh air. The humidifier can be electric or gas type. Another method is to use evaporative pads such as GLASdek from Munters. This eliminates the use of gas or electricity for humidification.

(cont.)

TABLE 6.6. (*Continued*)

Features	Distributed water loop heat pump with ground loop	Central reversing heat pump withground loop	Central multiple heat pumps with ground loop
6 Noise, maintenance, first cost	Noise at the occupied spaces can be a problem if proper care is not taken during design. Maintenance may become laborious and expensive. The first cost is expected to be less than a central heat pump system using ground loop.	Substantial reduction in noise level can be expected in the conditioned spaces by eliminating heat pumps at the zones. However central heat pump may require special attention to reduce the noise level. The maintenance is expected to be lower when compared to the conventional distributed water loop systems. A fan coil unit requires less maintenance than a heat pump due to fewer moving parts. The first cost of this system is expected to be higher than the distributed water loop heat pump system. Addition of a central heat pump and separate piping for hot and cold water should result in higher first cost.	Substantial reduction in noise level can be expected in the conditioned spaces by eliminating heat pumps at the zones. However central heat pumps may require special attention to reduce noise level in vicinity of mechanical room. This system when used with VAV air handling systems will further reduce the noise levels in occupied spaces. Maintenance may not be lower due to the presence of more rotating machinery and controls. The first cost of this system is expected to be higher than the distributed water loop heat pump system. Addition of secondary pumps and separate piping for hot and cold water will result in higher first cost. The cost involved with the ground loop may result in a higher first cost.
7 Outdoor air	Outdoor air is treated and pre-conditioned by a central water-to-air heat pump. The outdoor air is delivered into the return air plenum of the zone heat pump units. A total enthalpy wheel can reduce the energy consumed for treating outdoor air.	Outdoor air is treated and supplied by a central air-handling unit. The required amount of air is delivered into the return air plenum of the fan coil units. The air-handling unit is provided with a hot water coil and chilled water coil. Both the coils are served by central reversing heat pump. A total enthalpy wheel can reduce the energy consumed for treating outdoor air.	Outdoor air is treated and supplied by a central air-handling unit. The required amount of air is delivered into the return air plenum of the fan coil units. The air-handling unit is provided with a hot water coil and a chilled water coil. Both the coils are served by central reversing heat pump. A total enthalpy wheel can reduce the energy consumed for treating outdoor air.

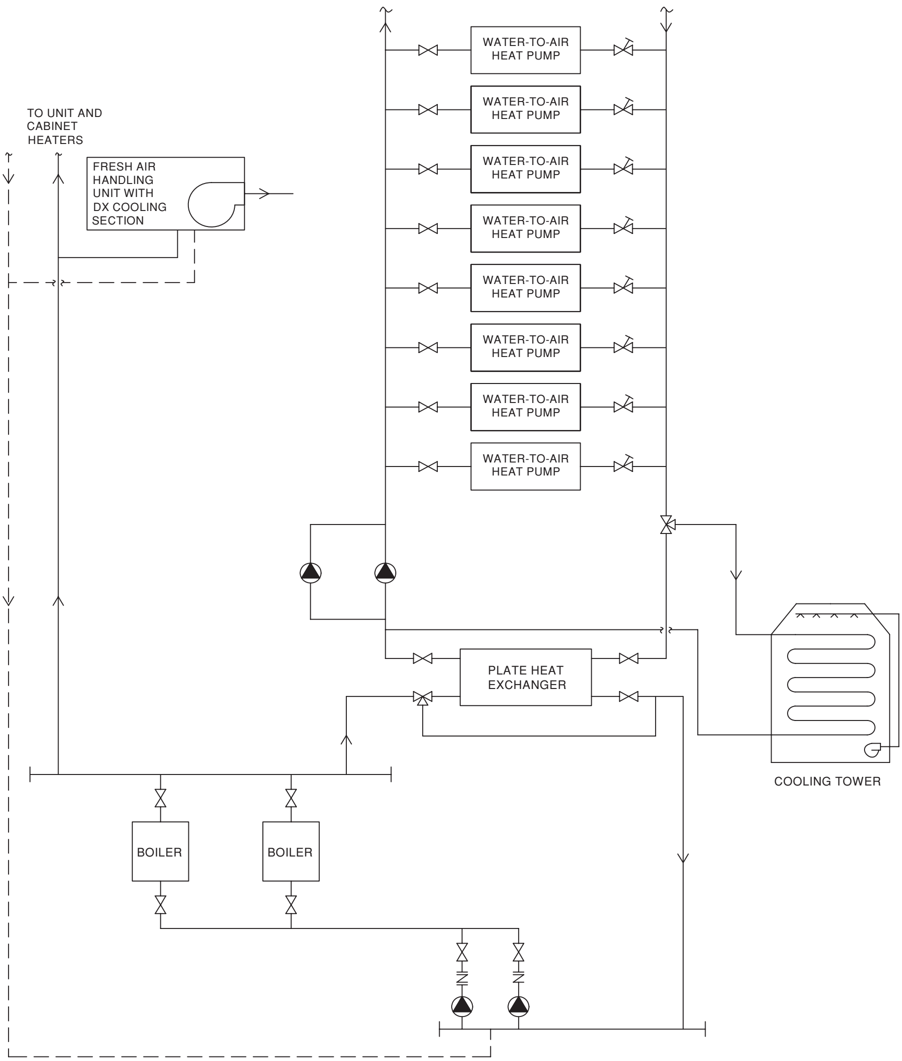

Figure 15. Conventional water loop heat pump system

and the water loop. The outside air-handling unit may have a DX cooling coil and a hot water coil or it may use a water-to-air heat pump for heating and cooling of outside air. See Figures 15 and 16.

The water-to-air heat pumps are available in the market from various manufacturers ranging in capacity from 1/2 tons and upward. Manufacturers include ClimateMaster, McQuay, Trane, Carrier, Waterfurnace and Florida Heat pump.

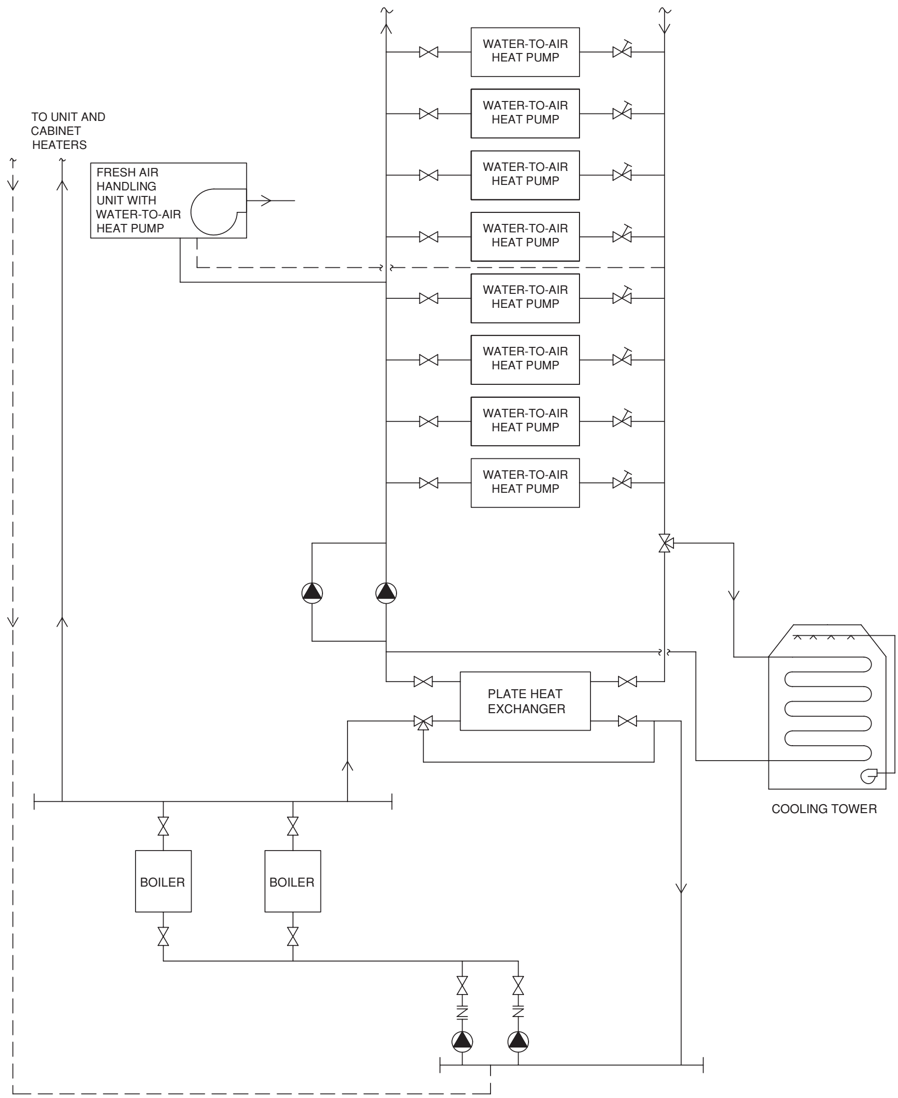

Figure 16. Conventional water loop heat pump system with fresh air heating by water-to-air heat pump

The system is very simple in configuration. The water-to-air heat pumps are installed in the individual spaces to be heated and cooled. The water loop connecting the heat pumps helps to transfer heat within the building. When the loop temperature rises above the design temperature, the water is directed through a cooling tower. The water loop extracts heat from the primary boiler heating circuit when the loop temperature falls below the design minimum temperature.

The simplicity of the system should result in lower first cost and lower maintenance cost when compared to the systems discussed in the following sections.

Advantages:

- Simultaneous heating and cooling available.
- Lower first cost than the central heat pump systems using ground loop.

Disadvantages:

- Noise in occupied spaces.
- Maintenance may become laborious and expensive.
- Not suitable for radiant cooling.
- Operating cost may be higher than the central heat pump systems using ground loop.

6.3.2.1. *WLHP with Air Source Heat Pump Water Heater*

This is a variation of the above system with a heat pump water heater replacing the boiler. The hot water is stored in a storage tank and released to the water loop to meet the peak loads during extreme weather conditions. The storage facility gives a certain degree of freedom for the air-to-water heat pump to choose the time of operation to suit the weather conditions. This system may not be suitable for regions with extreme cold weather. However, this is an environmentally cleaner system. See Figures 17 and 18.

Many of the commercially available air-to-water heat pumps have only published operating data in the entering air temperature range above 40 °F. The performance data below 40 °F is readily available for Toyo and Continental units. Capacity and performance data at ambient temperatures below 40 °F are required to be suitable for use in a water loop heat pump system. Commercially available air-to-water heat pumps in the North American market include Continental, Toyo Carrier, Mac Systems and Environmentally Engineered Equipment Inc.

6.3.2.2. *WLHP with Ground Loop Heat Exchanger*

Figure 19 depicts a water-loop heat pump system where the cooling tower and boiler have been replaced with a ground heat exchanger. This is the most common configuration of ground source heat pump used in commercial buildings.

6.3.3. CENTRAL HEAT PUMP (CHILLER) WITH GROUND LOOP

A central heat pump is used for providing heating water for space heating. The heat source is the ground loop. A stand-by boiler is provided to meet

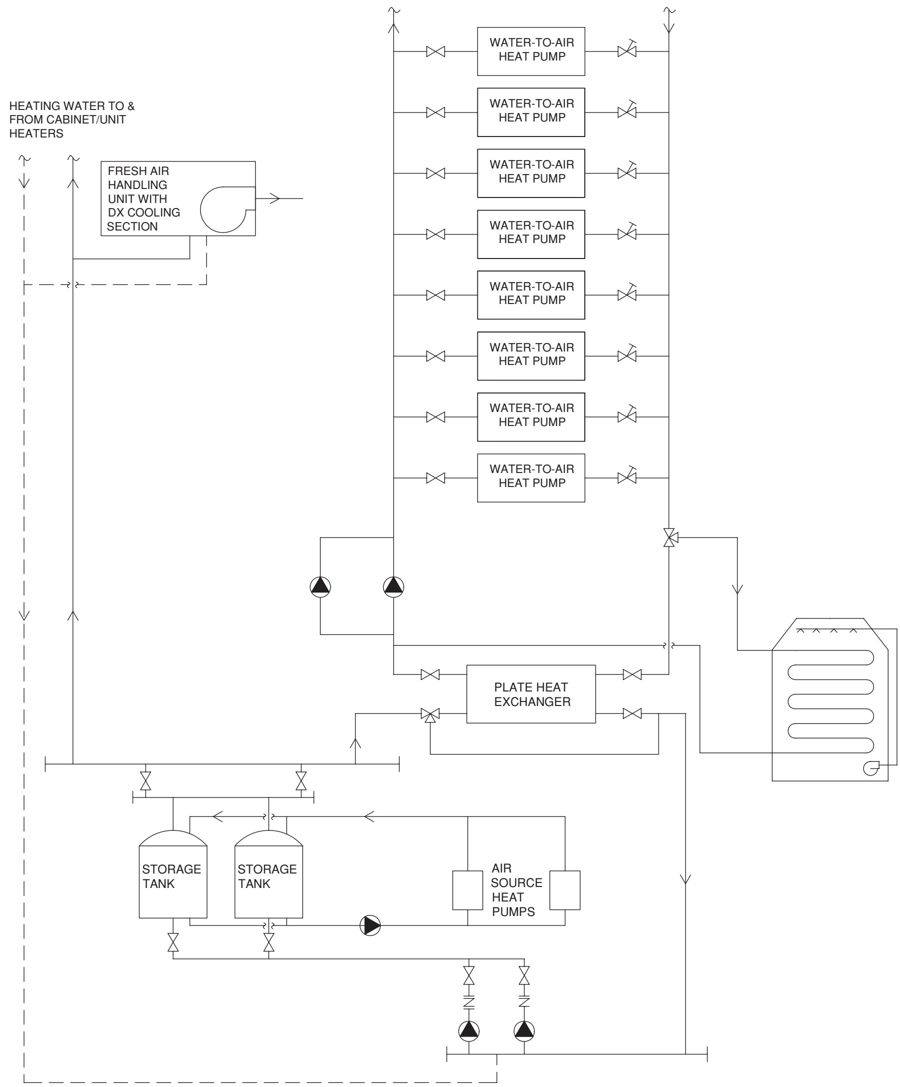

Figure 17. WLHP with air source heat pump water heater

peak loads during extreme weather. A 4-pipe fan coil unit is used at the zone level for cooling and heating. Outside air is supplied into the building by a central air-handling unit fitted with a heat recovery wheel and humidifier section.

The central heat pump is a reversing type. During summer, the central heat pump acts as a chiller supplying chilled water for cooling and rejecting heat to the ground loop. When there is a demand for simultaneous heating

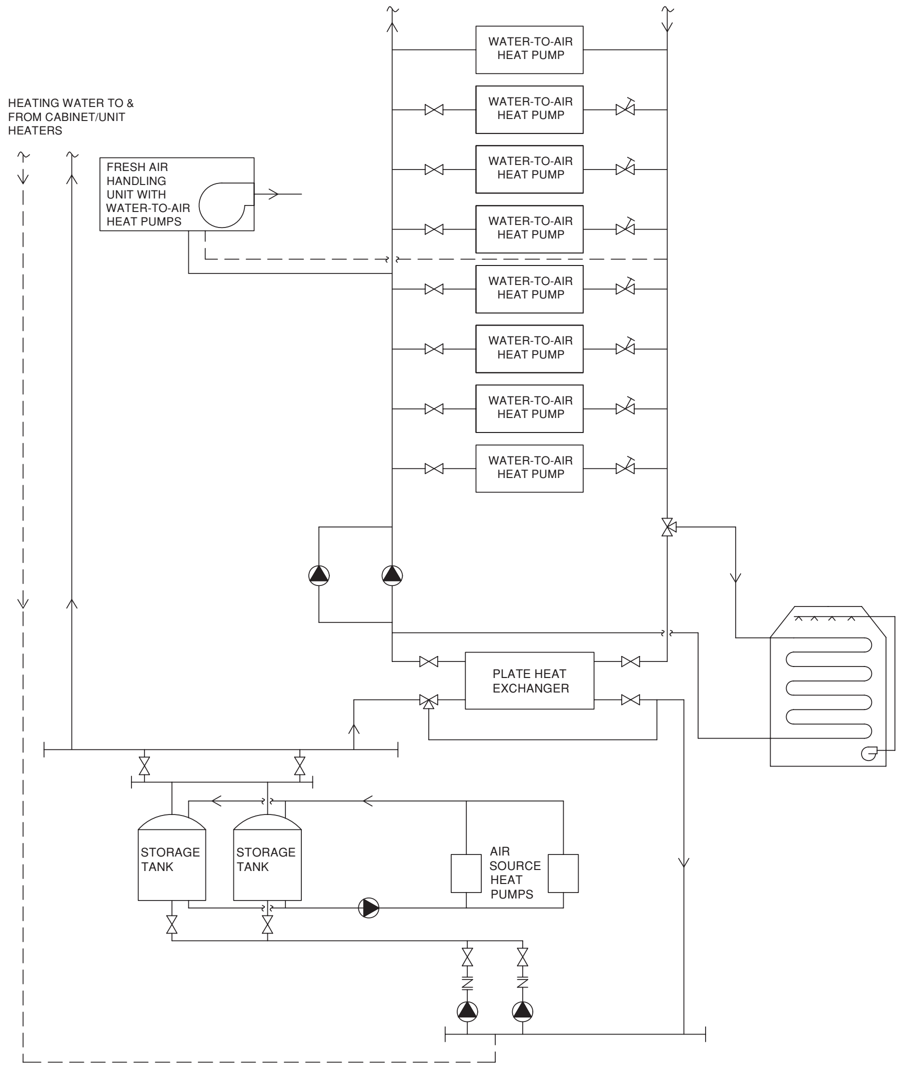

Figure 18. WLHP with air source heat pump water heater and fresh air heating by water-to-air heat pump

and cooling, the central heat pump resumes its heating mode of operation. The cooling circuit then bypasses the chiller and passes through the plate heat exchanger rejecting heat to the colder ground loop. It should be noted that the ground loop will be colder as it reaches the plate heat exchanger after passing through the evaporator of the central heat pump (see Figure 20).

A cooling tower is provided in series with the ground loop to assist during peak loads in extreme weather conditions. The cooling requirement of the

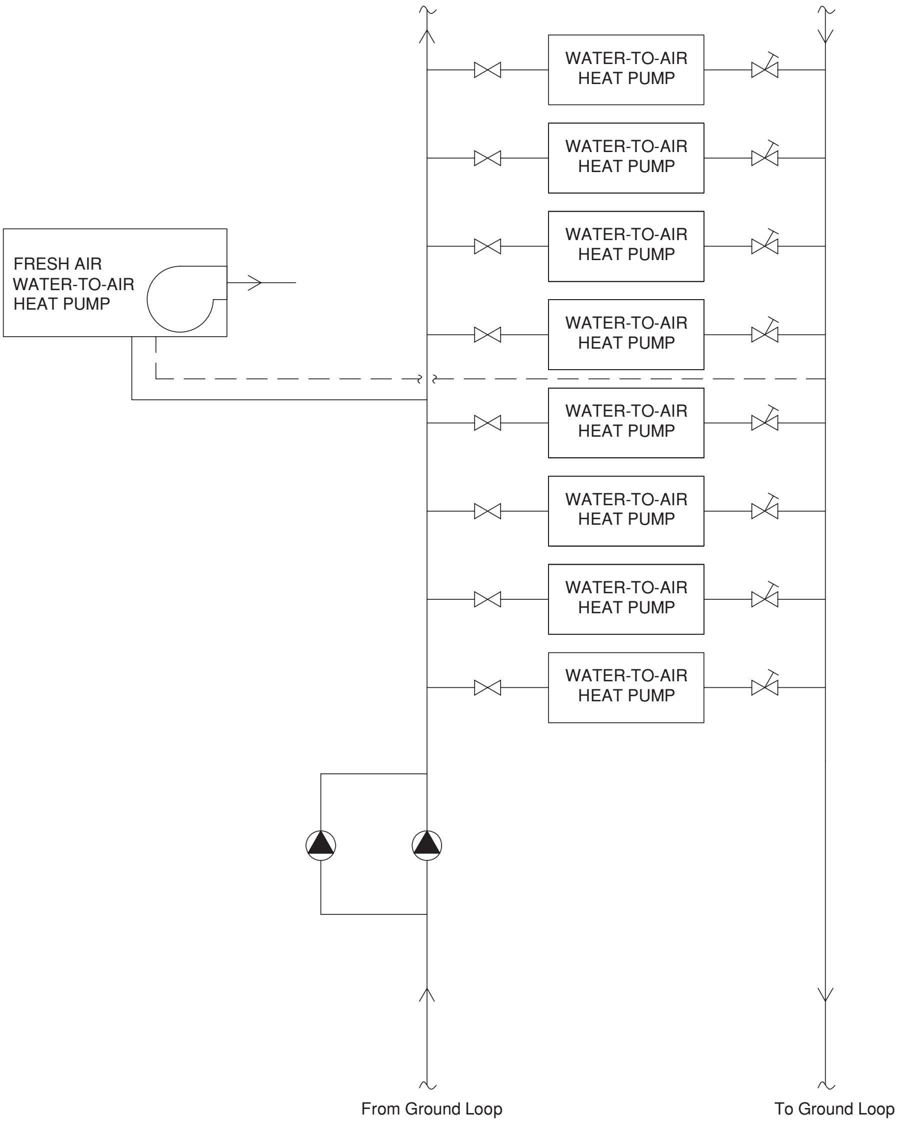

Figure 19. WLHP with ground loop

building is often far in excess of the heating requirement, which would lead to ground loop heat exchanger requirements that are too large and costly. The ground loop heat exchanger is then sized to the maximum amount of heat extracted during the design heat hour. The cooling tower is sized to meet the cooling heat rejection requirements in excess of the ground loop heat exchanger capability. A diverting valve directs the ground loop fluid through

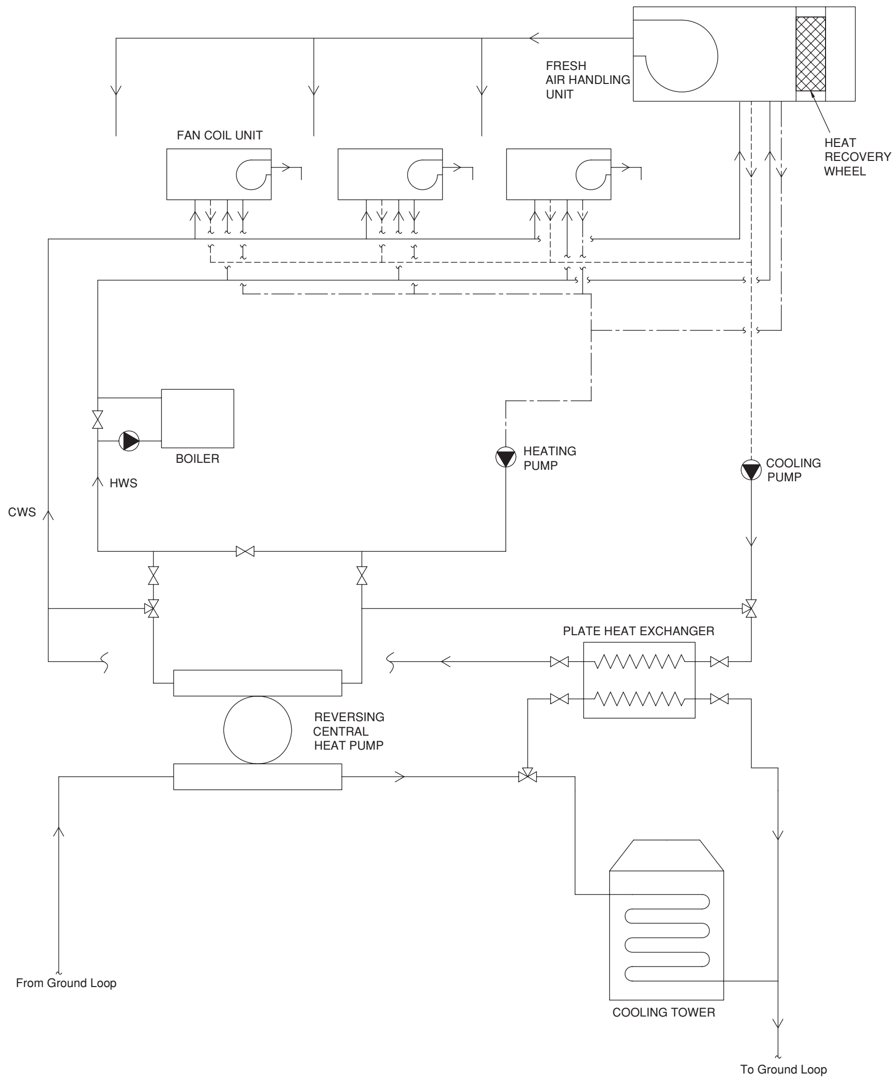

Figure 20. Central heat pump/chiller with ground loop

the cooling tower when the temperature of the fluid leaving the condenser of the chiller exceeds the design leaving temperature.

The parallel water flow circuits through the cooling tower and the plate heat exchanger helps to control the temperature of the cold water flowing through the heat exchanger during simultaneous cooling and heating demand. In such situations, the cooling tower circuit serves only as a return path for the diverted fluid to the ground heat exchanger.

If the temperature of the fluid from the ground loop falls below design during winter, the central heat pump may not be capable of maintaining the heating water supply temperature. In such a situation, the heating water will be directed through the stand-by boiler that will add the required heat to maintain the heating supply temperature. Use of evaporative pads in the air-handling unit for humidification will eliminate the need for natural gas for humidification and the system will be more energy efficient.

Commercially available large heat pumps (chillers) that can be employed include FHP manufacturing Co., Waterfurnace, ClimateMaster, Hydron Module LLC, Addison Products Co., Trane Heat Harvester Energy Efficient products and McQuay. More than one unit may have to be used in a building depending on the heating load and the model of equipment chosen. However this will not result in any significant change in the schematic shown for a single chiller/heat pump. The above manufacturers are located in North America.

Advantages:

- Simultaneous heating & cooling can be provided.
- Low noise levels in the occupied zone.
- Higher energy efficiency through the use of ground source and a central heat pump.
- Suitable for radiant floor heating and cooling.
- Lower maintenance cost.

Disadvantages:

- More plant space may be required.
- Higher first cost.
- Ground loop must be sized to meet the heating and cooling loads during extreme weather conditions.

6.3.4. CENTRAL HEAT PUMP (CHILLER) WITH GROUND LOOP AND HEAT PUMP WATER HEATER

This system is very similar to Central Reversing Heat Pump with Ground Loop but it uses a heat pump water heater instead of a boiler to meet peak loads during extreme weather conditions. The heat pump water heater is a water-to-water heat pump operating on the ground loop. The heated water is stored in a storage tank and is released to the hot water circuit when required. The overall system energy efficiency will improve by the use of the water-to-water heat pump in place of a boiler (see Figure 21).

The same models mentioned in Section 6.3.3 can be used to heat the water. However the heat pump can be a heating only type. The capacity of the unit is sized to meet the peak load in excess of the capacity of the central heat pump at

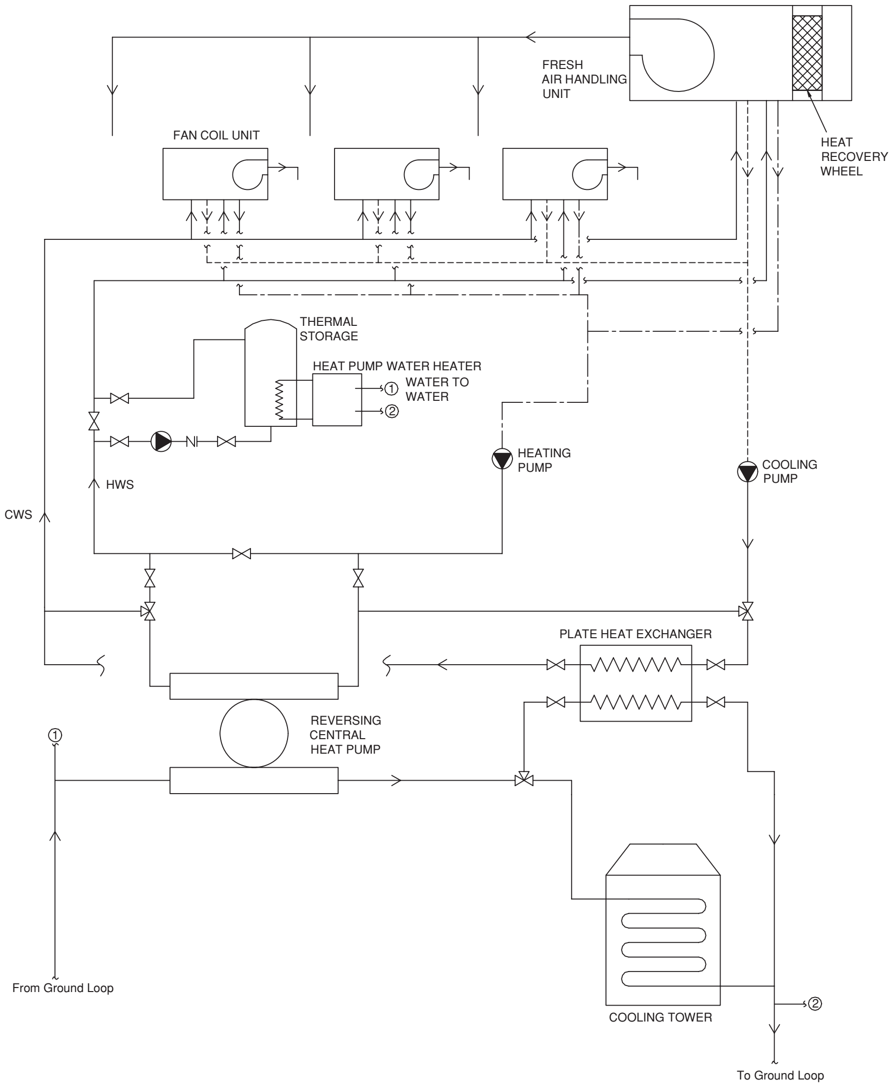

Figure 21. Central heat pump/chiller with ground loop and heat pump water heater

the extreme winter conditions. This means that the water-to-water heat pump can be much smaller in capacity than the central heat pump (chiller).

When the temperature of the heating water falls below the design temperature during the heating season, the water stored in the tank will be released to the heating circuit. The water-to-water heat pump will maintain the temperature of stored water in the tank. The storage tank allows the heat pump water heater to operate at a lower output than the heating demand of the building. Compared to a boiler-assisted system, depending on how electricity is generated, this system can have lower CO_2 emissions.

6.3.5. CENTRAL MULTIPLE HEAT PUMP SYSTEM WITH GROUND LOOP

This system comprises multiple water-to-water heat pumps working at the plant level providing simultaneous heating and cooling to the building using both the high and low temperature sides of each heat pump. It uses the ground loop during the cooling or heating season. A primary–secondary pumping system installed at both the low and high temperature sides circulate the cooling and heating water between the plant and the terminal units.

Small to medium size water-to-water heat pumps are considered in this system. Since the primary pumps are common to all the heat pumps, this system may not be ideal for projects where large size multiple heat pumps are used. It is better if dedicated primary pumps are used in the case of large multiple heat pumps. This is discussed in Section 6.4.1.

Commercially available water-to-water heat pumps under 10 tons capacity range that can be employed in this application include FHP manufacturing Co., Waterfurnace, ClimateMaster, Hydron Module LLC, Addison Products Co., and Trane.

During the summer, the heating side of the heat pump rejects heat to the ground loop. The water flow through the heat pump condensers is diverted from the secondary circuit to the ground loop by diverting valves as shown on the schematic diagram (Figure 22). When there is no cooling demand, the low temperature side of the heat pumps is connected to the ground loop to provide a heat source.

The combination of primary–secondary pumping and ground loop make the control system more complex. The secondary pumps have variable speed drives for better energy efficiency. The 3-way valve at the inlet of the heating secondary pumps is on–off type. This is because there is no mixing of supply and return water in the heating circuit. It should be noted that the heating supply temperature of the heat pumps will be in the range of 40–55 °C. It is economical to supply heating water at the maximum available temperature and this eliminates the need for mixing supply and return water in the heating circuit. The valve only isolates the secondary heating circuit from the primary when there is no heating demand. The primary circuit, on the other hand, will be connected to the ground loop when the condenser entering temperature exceeds the design value and the ground loop circulating pump is started. When heating demand rises, the secondary heating circuit will be connected to the primary again and the ground loop temperature will start dropping. A modulating 3-way valve at the inlet to the primary heating pumps will allow diverting only a portion of the fluid to the ground loop and result in better

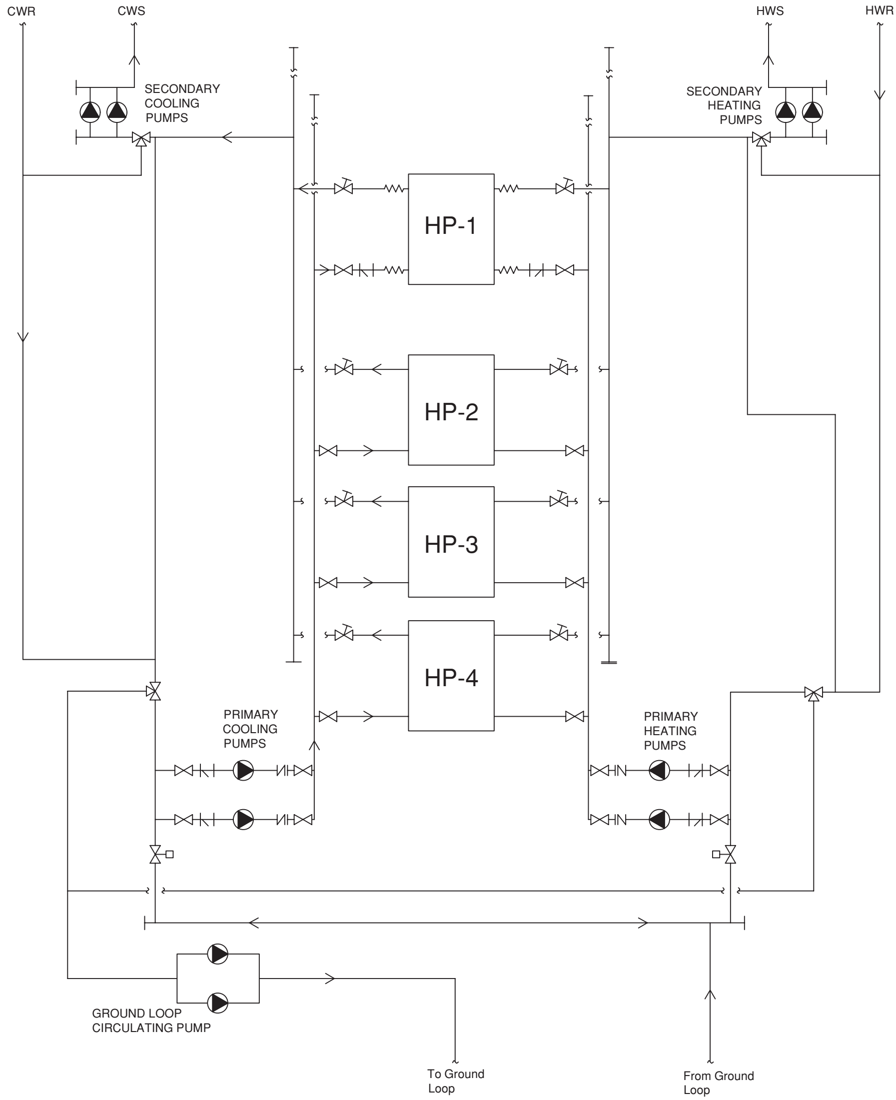

Figure 22. Central multiple heat pump system with ground loop and primary/secondary pumping

control of the temperature of the primary heating circuit. This requires variable flow capacity for the ground loop circulating pumps and will increase the first cost.

When the cooling load is smaller than the heating load, the 3-way valve at the inlet of secondary cooling pumps allows mixing of the supply and return water to maintain the design cooling supply temperature to the load.

The secondary cooling circuit is isolated from the primary when there is no cooling load.

The operation and control of this system will be complex and maintenance cost will be higher. As an alternative, secondary pumps are eliminated and primary only pumping is considered (Section 6.3.6).

6.3.6. CENTRAL MULTIPLE HEAT PUMP SYSTEM WITH PRIMARY PUMPING

In this case, each central water-to-water heat pump has a dedicated pump to circulate water. The water flow through the terminal devices is varied with the help of a bypass between supply and return header pipes. The advantage with this system is that the pumps can be shut off along with heat pumps with decreasing load during summer season. This scheme will be quite suitable for use with large multiple heat pumps as it will be less complicated and easy to operate than primary–secondary pumping discussed in the previous section. It is also suitable for use with small to medium size heat pumps as long as the number of units used is limited (see Figure 23).

The differential pressure controller shown in the schematic diagram helps to maintain the required differential pressure head and bypasses the flow from the supply to the return when the demand drops. This may lead to shutting off the heat pumps or connecting the primary circuit to the ground loop as discussed in the previous section. When the heat pump is shut off, the circulating pumps can be shut off simultaneously. This saves operating cost. The heat pumps in the Central System can be shut off only when both the cooling and heating demand is satisfied. In other words, the heat pump can be shut off when the heating supply temperature increases only if there is no cooling load to be met.

Advantages:

- Simultaneous heating & cooling can be provided.
- Low noise levels at the occupied zones.
- Higher energy efficiency through the use of ground source and central water-to-water heat pumps.
- Suitable for radiant floor heating and cooling.

Disadvantages:

- Higher first cost.
- More maintenance due to the presence of complex controls and rotating machinery.
- Ground loop shall be adequately sized to meet the heating & cooling loads during extreme weather conditions.

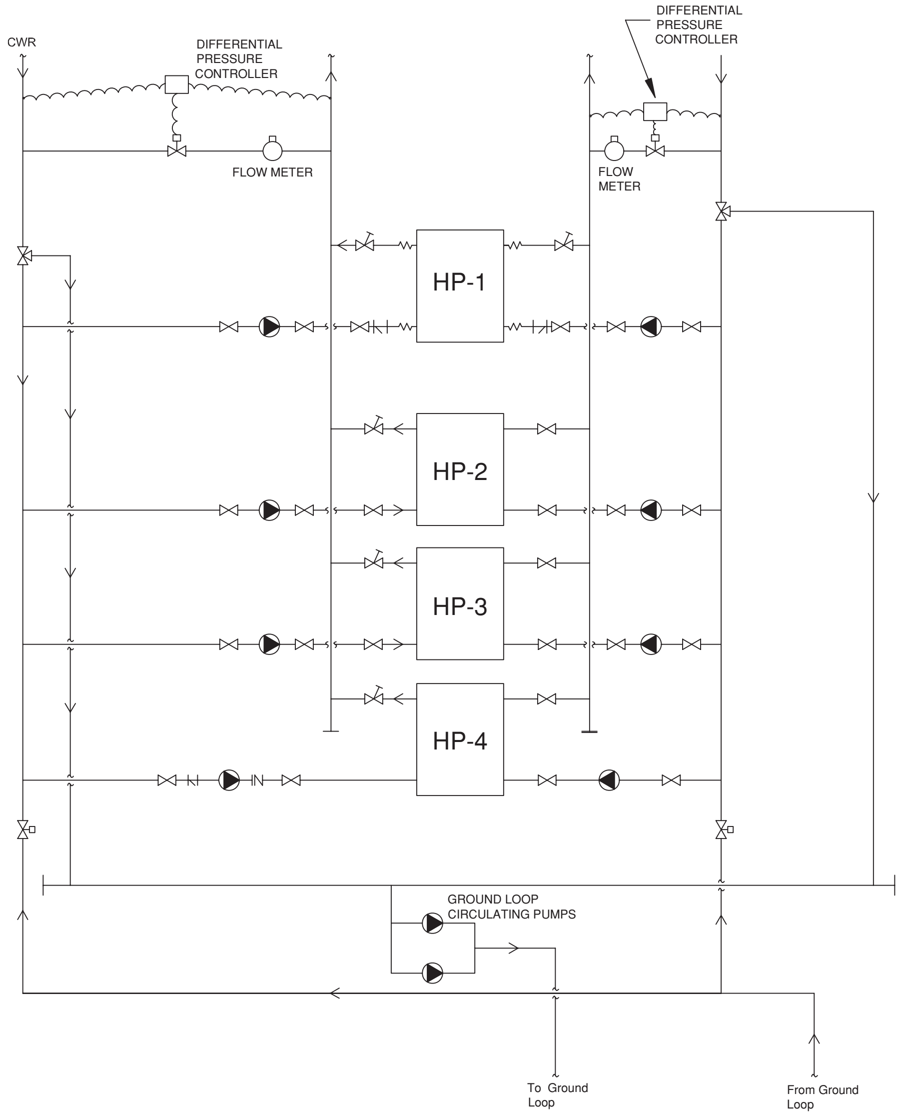

Figure 23. Central multiple heat pump system with ground loop and primary pumping

6.4. Some Recent Canadian Building Projects

6.4.1. PROJECTS

There are recent building projects in Canada that generally confirm the simulation results presented. Cost-effectiveness of some of these buildings is even greater than the simulated results due to savings in areas not modeled.

A brief summary of some recent projects is given, including both new and retrofit projects. Many projects have used the *Commercial Buildings Incentive Program (CBIP).* Natural Resources Canada offers a financial incentive for the incorporation of energy efficiency features in new commercial and institutional building designs. The objective is to encourage energy-efficient design practices and to permanently Improve the Canadian building design and construction industry. A financial incentive of up to $60,000 is awarded to building owners whose designs meet CBIP requirements. The program requirements are based on the Model National Energy Code for Buildings. An eligible building design must demonstrate a reduction in energy use by at least 25% when compared to the requirements of the MNECB. The program runs to March 2007.

6.4.2. TELUS BUILDING

The Telus Building in Vancouver at 550 Robson Street is on a corner of a city block of related Telus structures built from 1917 through the 1950s. The Telus Building is well known for its double skin. The Telus has about 25% of the floor area of this block. The buildings needed updating due to changing seismic and other building requirements and the changing nature of the communications business post deregulation. Conventional retrofit would have resulted in a building with 60% of the original floor space. Demolition of this building was considered. A design competition sought for an innovative retrofit solution maintaining the floor area and meeting current code requirements.

The winning design proposed that the brick cladding (no insulation) be removed exposing the concrete shell. A glass skin (double-glazed, fritted and frameless) was added on the two street faces. This layer is hung 1 m outside the shell. It extends onto city property. It features operable panels and fritted glass (on the #2 surface) to control solar glare. The original single-glazed windows remain.

There are dampers bottom and top of this cladding cavity to promote natural ventilation. A few integrated photo-voltaic panels are sufficient to power the fans (twelve $1/2$-HP motors) that assist ventilation through the double skin. There are tracks within the double skin that assist in the cleaning of surfaces #2 and #3. There is also a grid of fibre optic lights that blink periodically and change colour.

The building was strengthened by a bottom to top shear wall within the building and it has been left exposed. A commercial ground floor was also established. There was a mechanical room on the top floor. This has now been converted into a gym and immediately below are the executive offices. The original floor to ceiling height was 14–16 feet and a raised floor (18″) was introduced. It has wood core, metal-faced panels with a pressurized plenum below. Everything was raised 18″ including the stairwell (three risers were added) except for the washrooms, which are ramped. Heating is provided by abundant condenser water from an adjacent building. There are fan coil units on each floor.

The use of the building changed from mainly housing telephone exchange equipment to office space. The floor plate is 90 feet by 90 feet. Interior security railings were added to original double hung windows. We were told of frequent moves in the building. Costs were formerly \$4 to \$5 thousand per person per move and are now \$500 per person per move.

The adjacent building is on the site of the main telephone central for downtown Victoria. Slab cores showed very poorly mixed concrete from 1917 construction. It will be taken down to two floors and a 8-storey atrium will take its place. Acoustics are a concern. The Telus Building will be opened up to this atrium changing dramatically the present closed in feeling.

Occupants like the operable windows in the original and the new facade, but it is noisy with the windows opened. Lighting is good but acoustics are a problem. Rolling and moveable partitions are commonly used—usually without a ceiling.

Value of the retrofitted building is double the construction cost and Telus is considering selling and leasing back. Building was pre-LEED and might qualify as Gold Star.

6.4.3. VANCOUVER ISLAND TECHNOLOGY PARK

Vancouver Island Technology Park was built in 1977 as a hospital for the mentally and physically handicapped. It was demolished and rebuilt as a 165,000 square foot building. It reduced energy usage 42.5% below MNECB and was the first Canadian LEED Gold Building. It uses a water loop heat pump system (see S15 in Table 1.) and carbon dioxide monitoring as a control parameter. The parking lot could have been used (horizontal system) as the heat pump heating and cooling source (S17 instead of S15). This would have significantly increased the energy reduction.

Operable windows were part of the design, but eliminated in the "value engineering" phase. Fifty-four % of the building materials were purchased within 500 miles of the site and 35% fly ash concrete was used. There were extensive savings on storm water runoff using ponding, weirs and plantings on the extensive property to avoid large diameter piping.

An "invisible structure" was used in the parking lot replacing the conventional ashphalt surface. Grass was planted in the parking area and the driving area was left bare. The shade of the cars apparently promotes grass without additional watering. Reduced runoff leads to savings with storm drainage.

The invisible structure is more expensive but there are maintenance savings and capital savings for drainage.

Dual flush toilets were used and waterless urinals (falconwaterfree.com). Two urinal types were used. One with a cartridge lasting several weeks. The other requires the liquid to be added periodically by staff. The specific gravity is chosen so that urine sinks beneath.

Estimated $15–$20 thousand fee for the LEED documentation. Separating deconstruction and reuse from construction allows more detailed design and more detailed specs.

6.4.4. INFORMATION AND COMMUNICATIONS TECHNOLOGY (ICT) BUILDING [7, 8]

A team including Stantec Architecture, HOK and Barry Johns Architecture created the new Information and Communications Technology Building a striking addition to the University of Calgary campus. Faculty members of both the Computer Science and Electrical & Mechanical Engineering groups insisted on having operable windows. This desire for direct access to fresh air meant a conventional mechanical approach could not be used. The resulting system exposes the building's concrete for use as a heat sink with an embedded network of tubing. The slab absorbs the heat generated by a heavy concentration of computers and people. Chilled water is run through plastic piping embedded in the lower portion of each above-grade floor's concrete slab. The slab then acts as a radiant cooling source, primarily affecting the spaces below the slab, which must be exposed for the system to work. Fortunately, the ICT Building's design already called for open ceilings.

The ICT Building may be the first use of structural slab radiant cooling in Canada. Unlike radiant heating, radiant cooling is not commonly used in North America. It is not well understood and has been misapplied in the past. Slab radiation will meet half its cooling needs and traditional air-based ventilation the rest. As a result, the ventilation ducts, air-moving fans and related equipment will be half their normal size, resulting in significant energy saving and allowing each floor height to be reduced by 375 millimeters. Other energy savings will come from the slab system's cooling water, which will be used twice. The cooling water will first be used in the building's air handling system's cooling coils and then reused in the slab cooling system before it is returned to the chiller plant.

The decision to expose the concrete led to a natural design strategy of leaving all the building's materials and systems unconcealed. The ICT building opened in September 2001 and houses Computer Engineering with labs and offices. The offices are mainly on the east-west perimeter with labs and graduate student offices on the interior. There is an interior walkway linking the University and the ICT gets 7,000–8,000 people daily walking through it. The budget was based on an area of 15,000 m^2 but turned out at 18,000 m^2. The construction budget was $25 million and the total budget was $40 million. It came in at $700,000 under budget. The design was a 35% reduction from the MNECB and received $80,000 from CBIP. It was a Design-Build under Ellis Don with many budget cuts. One of these cuts was all the outside sun screening. Another concept dropped was displacement ventilation. Maintenance department was against raised floors.

The original concept was operable windows with natural ventilation shutting down the conventional cooling during appropriate conditions. There are two solar towers at North and South ends of the building with fan assist since the towers are not high enough to ventilate under all conditions. The natural ventilation comes through the office and down the corridors. The Building Automation System has low temperature sensors to assist in locating freezing danger from open windows during winter. While we were touring with the facilities manager we spotted an open window with outside temperature about –15 °C. The office was unoccupied and the thermal plume was quite visible. Window cranks are taken away from the offending office occupants if the low temperature alarm goes off.

Control in the perimeter offices is conventional with about one thermostat per every three offices. The open windows probably could be correlated with the two offices without a thermostat. A central heating and cooling plant supply the entire campus.

6.4.5. C. K. CHOI BUILDING, UNIVERSITY OF BRITISH COLUMBIA [3]

Reused heavy timbers from an adjacent building demolition were structural elements. Reused Vancouver brick pavers were used for the building veneer. More than 50% of the total materials are reused or recycled. It was designed to use 50% of the energy based on ASHRAE 90.1 Standard as a reference. It was the first University of British Columbia green building). A $100,000 new sewer line was originally required but waterless urinals and composting toilets with rainwater capture have eliminated this need. Operable twist and turn windows employed with natural ventilation using roof vents with fan assist eliminate mechanical cooling. Trickle air leakage under window ventilation is also employed.

6.4.6. CONCLUSIONS OF BUILDING PROJECTS

Buildings that use dramatically less energy and display improved indoor environmental conditions are needed to achieve sustainable buildings as the standard. This is especially so when post-Kyoto era objectives are decided.

Energy and cost reference levels are available in every country. How much better performing can buildings be? At what price? It has been shown that a level of 65% less energy is attainable with existing technologies and at reasonable cost. Natural energy, especially underground thermal energy storage or earth energy, can play a useful role in achieving these reductions. Thermal energy storage becomes a requirement if reductions beyond 65% are to be made at reasonable cost. Design simulations have been confirmed in practice for both new and retrofit buildings. New design concepts and control concepts need to be developed for the ultra-low buildings of the future.

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