

GEOTHERMAL ENERGY FROM OLD MINES AT SPRINGHILL, NOVA SCOTIA, CANADA

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Key words:

Direct use, heat pumps, flooded mines, economy, environment benefit

ABSTRACT

Flooded former coal-mines of Springhill, Nova Scotia, contain about 4,000,000 m³ of water which is recovered at the surface at a temperature of about 18°C. The heat in the water is derived from the normal heat of the rocks, and the contribution from chemical heating is negligible. Water is used as the input to heat pumps for heating and cooling industrial buildings. Annual heat exchange with the mine by the largest user puts more heat into the mine in summer than is taken out in winter. Other buildings may be a small net drain of heat, so that many systems could operate indefinitely, without significant depletion of the heat source. Initial costs of heat-pump installation are higher than the costs of conventional oil furnaces, but in Springhill operating costs of geothermal heating are substantially lower than heating by fuel oil. There is a net saving in the emission of carbon dioxide to the atmosphere.

1. INTRODUCTION

Coal mining began at Springhill, Nova Scotia, in 1872 and continued as the primary industry of the town until 1958, when the last of a series of rock-bursts prompted the final closing of the mines. After closure the mines were allowed to fill with water. With the main industry removed, the town entered a period of economic readjustment and had to strive to develop new industries. The rapidly rising cost of oil-based energy from 1973 to 1980 added a major impediment to economic recovery.

In 1985 the Town began to explore the idea of taking water from the flooded mines to feed heat-pumps for space heating. A feasibility study concluded that the idea was sound and that the system was capable of providing energy at a substantial saving over conventional hydrocarbon sources. By May 1994 there were eight users of the geothermal resource, including Ropak Can-Am Ltd, a plastics manufacturing company, MBB Ltd, a boiler-maker, Pizza Delight Ltd, a pizza restaurant, and Surette Battery Ltd, a lead battery manufacturer.

2. THE TOWN AND THE MINES

The Springhill area lies on the flanks of the Athol Syncline. The mines follow several parallel coal seams. Surface outcrops are curved, and all seams dip in a generally westerly direction, at about 30° near the surface and at an angle decreasing to about 24° at the furthest point of mining. Seams are numbered from 1 to 7, but in the order of commercial development rather than any geometrical order. A cross section through the seams is shown in Figure 1. The greatest depth of the mines below the surface is about 1350 m (McInnes et al., Appx. G).

Figure 2 shows the relative position of the town over the coal outcrops and the mine workings. Only the largest workings, in Seams 2, 3 and 7, are shown. The lowest levels of mine

workings, in Seams 6 and 7, begin under the town, but the shallowest level begins on the western edge of the town. All levels follow the seams and dip to the west and all are interconnected.

Only the western part of Springhill is located directly over mine workings. The industrial park is the part best located to use the mine-water resource, having a choice of several levels of the mine from which to draw water or in which to reinject. The western part of the town, including the area around the Town Hall is limited to levels 6 and 7 for direct vertical access. The eastern part of the town has no mine workings below it. Horizontal distribution of mine water on the surface to the eastern part of the town is technically possible, but it may not be economically feasible.

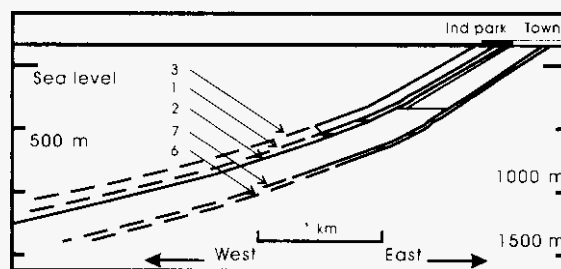


Figure 1. Vertical section through the coal seams and Town of Springhill. Continuous lines indicate mines and dashed lines indicate unmined extensions. Thin lines indicate connections between the levels. Diagram redrawn from McInnes et al., 1959.

3. ENERGY CAPACITY OF THE MINES

The thermal capacity of the water in the mines depends on volume and temperature. Temperature of the water depends on geothermal gradient, heat exchange with the walls, and circulation. Two methods have been used to derive an estimate of the total volume of water-filled space in the mines. In the first method an estimate was made of the area mined in each seam, which was multiplied by the average thickness of the seam to give a volume. This volume was then adjusted for subsidence of the roof and for the angle of the workings. In the areas mined by "room and pillar" methods, where the pillars have been left in place, open spaces probably survive either as left or with rock debris on the floor. Convergence of the roof as a whole with the floor has probably been small, so that the mined space probably remains filled with water. Roof falls blocking the floor area are compensated by corresponding voids in the roof. Where the pillars have been removed the roof has probably collapsed to be supported by the rubble on the floor. In the areas mined by "longwall" methods convergence of roof and floor has probably occurred, but the "chocks" (timbered

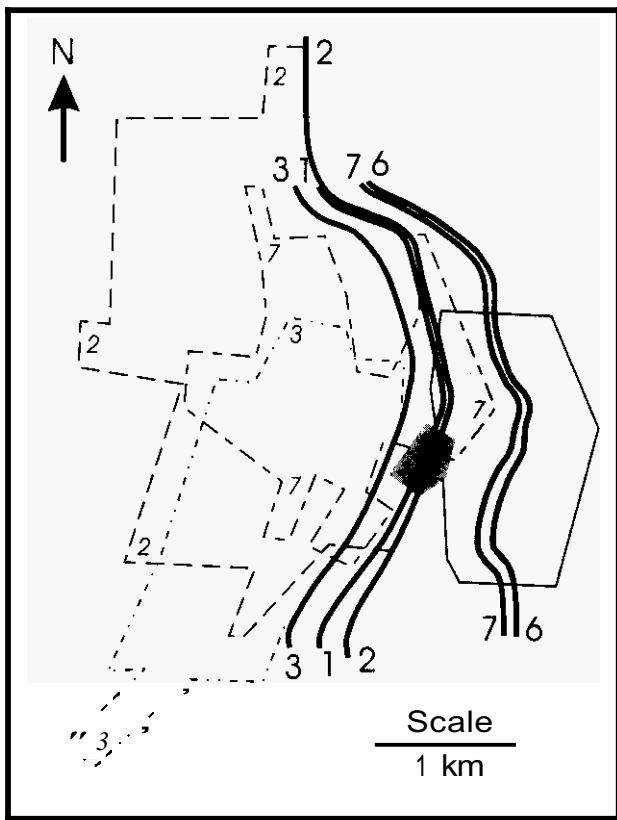


Figure 2. Map showing relative position of town over mines. Coal outcrops are shown by heavy lines, extent of mining operations in three of the seams is shown by dashed lines, with the numbers of the seams indicated. The Town of Springhill and the Springhill Industrial Park are indicated by light and dark shading.

to be near this temperature. These observations imply a temperature of about 26°C at the maximum depth of the mines.

The ability of deep water to circulate widely through the mine depends on the presence of connecting channels and the driving influence of incoming water. The several levels of the mines are known to have been interconnected, but the present state of ventilation-control doors and blockage due to roof-falls is unknown. The tunnels and mined areas probably still provide channels for water movement.

Water temperature up to 20°C has been observed at the surface, which is well above the ground temperature. There are three possible mechanisms that could produce this anomalous temperature. These are convective overturn of the water in the mines, water flow from greater depth forced by water entering the mines, and chemical reactions, mainly oxidation, within the mines.

Convective overturn is governed by the temperature gradient, the size of the channels, and the properties of the water. The theory of convective overturn in vertical boreholes has been examined by Krige (1939). For a small borehole of radius 25 mm, filled with reasonably clean water at 10 to 20°C, the temperature gradient must be over 50 mK/m before convection will occur. In a vertical mine shaft, where the radius is of the order of 1 m, the limiting gradient is of the order of 0.1 mK/m. This is less than a normal geothermal gradient by two orders of magnitude, and thus unforced convective mixing is possible in all unobstructed vertical mine shafts. Convection will also occur in other, non-vertical, workings provided that they are inclined by about 10° or more, and provided that obstructions such as ventilation-control doors or rock-falls do not prevent free circulation.

In the area around Springhill there are many natural springs, including one at a high elevation in the centre of the Town. This shows that there is a supply of recharge water and that hydraulic potential of the area is high enough to provide a driving force for circulation in the mines. At the mine museum in Springhill

roof supports), their rock fill, and rock falling from the roof has probably assured that space for water flow remains. In all three mining systems it is assumed that the space remaining is 25% of the volume calculated from the product of the mined area and the thickness of the seam, an estimate regarded as conservative. The total volume of the flooded mines is calculated by this method to be $4.2 \times 10^6 \text{ m}^3$.

The second method of calculation uses data on total coal production from the Report of Mines (Nova Scotia Department of Mines, 1978). By assuming a density of 1500 kg/m^3 these figures have been converted into volume, and the same factor of 25% has been used to account for subsidence. Production figures are given by the mine rather than by the seam, and there is not an exact correspondence. The total volume calculated by this method is $3.7 \times 10^6 \text{ m}^3$.

These two estimates are in good agreement. The mean of the two estimates is $4 \times 10^6 \text{ m}^3$ and this will be taken as the best estimate of the volume of water in the mines at present.

Terrestrial heat flow and geothermal gradient have not been measured in the immediate area of Springhill, but there are measurements near Wallace and on Prince Edward Island, all to the northeast, as shown in Figure 3. Temperature gradients from all these sites are in the range 14 to 17 mK/m, with an average of about 15 mK/m. Equilibrium surface temperature, the temperature with which deep gradients are in approximate equilibrium, is about 6°C. (Jessop and Judge, 1971, Hyndman et al., 1979, Drury et al., 1987). Present surface temperatures, below the depth of significant seasonal variation, are in the range 7 to 8°C, and waters near the surface would be expected

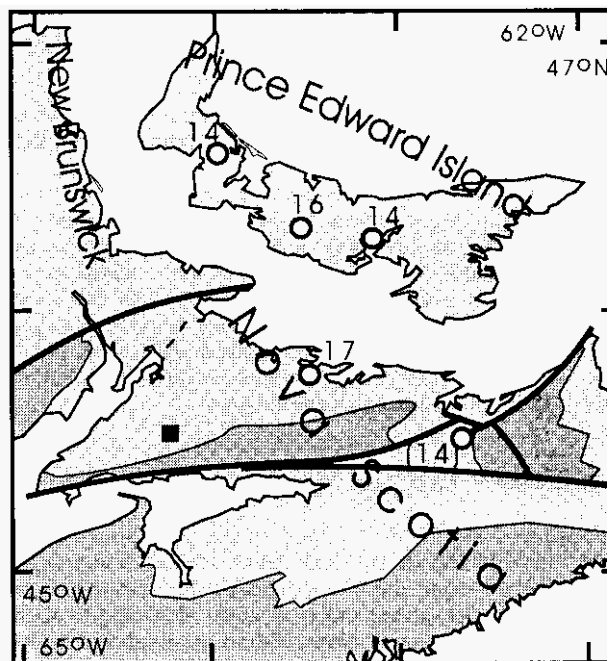


Figure 3. Geothermal regime at Springhill. Light shading indicates areas of Carboniferous or later sedimentary rocks. Site of Springhill is shown by a black square. Sites of geothermal measurement are shown by open circles with values of geothermal gradient in mK/m.

on the site of the Syndicate Mine, water is pumped from the mine at up to 1000 m³/day, in order to keep a small part of the mine open and accessible to visitors. The water level is kept at 50 m below the local surface, or at an elevation of 100 m above sea level. This water is replaced in the mines by water entering from fractures in the rock at unknown depths. The level maintained at the museum probably controls the level in the entire mine system. The museum is at about the same elevation as the Ropak Pan-Am plant, which is already using the mine-water, and the Town Hall, which is one of a group of buildings where mine-water may be used in the future.

It has been postulated that some of the heat in the water comes from oxidation of minerals by oxygen dissolved in the water. Jacques Whitford & Associates (1987) reported an oxygen content of the water pumped from the mine of approximately 0.05 mg/l. For a simple calculation we assume that the water originates as meteoric water with a saturation level of 8.5 mg/l of dissolved oxygen and that the reduction to the level observed in the mine water is caused by oxidation of pyrite in the mine. The heat produced by this process would be 15.7 J/m³ of water, resulting in a temperature increase of the water of 0.004 K. Once the oxygen available in the water is used up in this process the heating ceases, and generation of heat will resume only as fresh water enters the mine and is itself heated by the same amount. Since virtually all the heat generated by oxidation is taken by the water, and only a small amount resides in the rock, there is no significant accumulation of heat from this cause. This is an insignificant heat source compared with the magnitude of the observed temperature anomaly.

The anomalous temperatures are probably caused by a combination of convective mixing and forced water circulation throughout most of the mine. Convection alone tends to produce a water temperature approaching an average value, between the temperatures at the deepest and shallowest parts and weighted by the relative volume of the workings throughout the depth range. Neglecting the distribution of volume by depth, this average temperature is about 17°C, and water is expected to approach this temperature throughout the mine after an initial period of convective adjustment. This temperature is close to the 18°C reached in the pump test reported by Jacques Whitford & Associates (1987) and by Ropak Can-Am in the first year of operation.

As described above the total volume of water in the mine workings remaining after subsidence is estimated to be about 4 x 10⁶ m³. This volume of water, if cooled by 15 K, would yield 250 x 10¹² J or 70 GWh. This temperature drop implies the return of water to the mine at 3°C and thus represents the total heat reasonably accessible to heat pumps. This result takes no account of recharge of water or of heat exchange from the rock to the water. The transfer of heat from the walls of the mines is a slow process and will maintain the heat content of the water over a long period of time, perhaps hundreds of years.

4. DATA FROM THE FIRST APPLICATION

Ropak Can-Am Ltd have supplied detailed information on the first year of operation of the geothermal system and some further data on total energy usage. The company is situated in the industrial park on the west side of Springhill. The building has been assembled in three stages and in 1992 had a total area of 14,000 m², comprising an old part of 1600 m² and new parts of 6700 m² added in 1989 and a further 5700 m² added later. Space in the building is used for plastic moulding manufacturing, storage for raw materials or completed goods awaiting shipment, and a small office area. The heat pumps are suspended from the ceiling, and so do not take up floor space. The pipes for water intake and outlet, with associated meters and controls, take up a space of about 1 m by 4 m, adjacent to

one wall. Each heat pump has a motor rated at 5 horse-power (3.73 kW). In addition to space heating the heat pumps supply heat for the domestic hot water supply, but this is assumed to be negligible in comparison.

Figure 4 shows the temperatures of the intake and outlet water streams and the calculated heat drawn from the mine water over a period from 22 March 1989 to 6 March 1990. This period includes the initial heating of the new part of the building and the move of some machinery from the old part into the new part. Thus it does not represent a complete year of operation under the operating conditions later established. Early points at days 24 and 84 are not consistent with the remainder and probably represent highly abnormal conditions of building completion. Routine measurements, at weekly intervals, were made from 11 July 1989, day 113 to 6 March 1990, day 352. This period of 239 days provides the only data suitable for analysis.

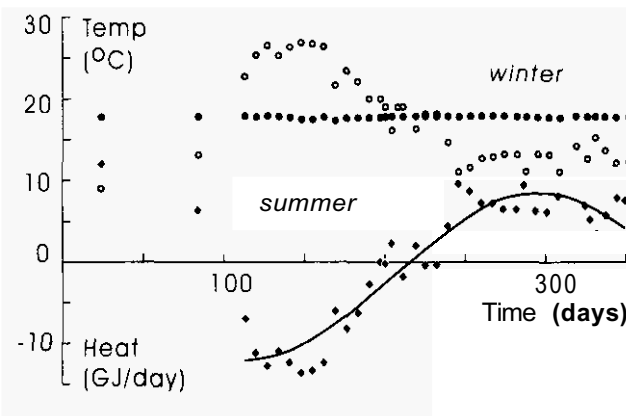


Figure 4. Plot of temperatures and energy use at the Ropak Can-Am building. Inlet and outlet temperatures are indicated by solid and open squares respectively. Energy taken from the mine water is indicated by solid diamonds. The two vertical scales have the same numerical values.

The inlet temperature of the water is constant at 17.9°C. The outlet temperature varies through the year, from a minimum of 11.1°C in the winter heating cycle to a maximum of 26.7°C in the summer cooling cycle. The rate of extraction of heat from the water is proportional to the product of the flow rate and the difference between the intake and outlet temperatures. The maximum heat per day taken from the water in the winter was 9.6 GJ/day (111 kW) and the maximum returned to the water in the summer was 13.7 GJ/day (159 kW). Over the 239 days the total heat exchanged with the water was 1640 GJ, but the net heat taken from the mine was 50 GJ, for an average of 0.2 GJ/day (2.5 kW).

An extrapolation of the data to a period of one year has been achieved by fitting a sine curve, constrained to a period of one year, but otherwise fitted by the method of least squares. The result of this analysis is a draw on the mine of 890 GJ and a return to the mine of 1550 GJ, for a total of 2440 GJ exchanged and a net heat input to the mine of 660 GJ. Neither method represents a full year of operation under normal conditions, because of the short data sequence and the concurrent growth of operations. However, it is safe to assume that the heat production by machinery inside the building was not less after normal operations were achieved than before, and that the annual exchange of heat tends to put heat into the mine rather than take it out.

Detailed records in the first year show electrical power consumption of 259 MWh over a period of 239 days, a rate of

395 MWh/year. The eleven heat pumps working at their rated capacity would have used 985 kWh/day or 235 MWh in these 239 days. The maximum electrical energy usage recorded during the cooling cycle was 1780 kWh/day and during the heating cycle was 1736 kWh/day, but the maximum heating occurred over the holiday season when manufacturing machines were shut down and conditions were abnormal. The next highest heating load was 1687 kWh/day for a few days in early February. These figures do not break down the power usage into the parts used by the heat pumps and by the manufacturing process. However, the minimum power usage recorded is 329 kWh/day, in late October, when the load of the heat pumps is very small. We may make a first assumption that the power used for purposes other than the heat pumps was 300 kWh/day, which leaves a total of 187 MWh (677 GJ) used by the heat pumps over the 239 days. This implies an average coefficient of performance of 2.4. Since the maximum daily power use exceeds the maximum heat-pump power by nearly 800 kWh, the assumed figure of 300 kWh/day is probably too low. If we take the median figure of 550 kWh/day for uses other than the heat pumps, the balance left for the heat pumps is 128 MWh (460 GJ) and the coefficient of performance is 3.6, which is a more reasonable figure for heat pumps working under these conditions.

The figures on which these calculations are based are for a non-standard period of time, and they are not adequate as a base for the calculations without some significant assumptions. Thus the ability of these results to represent the established operating conditions is subject to errors that may be up to 25%

Net heat exchange with the mine-water by the Ropak Can-Am system over the first year of operation is small compared with the total amount of heat exchanged by the system. Thus the water in the mine workings acts more in the manner of a large reservoir of heat that is drawn on and replenished seasonally, rather than as a depletable resource. At present the water is returned to a level different from which it is taken. This system was designed to ensure that the water would not return quickly to the production well. The constant production temperature shows that this objective has been achieved. It is probable that mixing of the water and circulation within the mines will prevent any significant change in temperature of the intake water for many years

Although the Ropak Can-Am system puts heat into the mine, other buildings without the industrial heat generation, such as offices and churches, will probably take heat from the mine. It is possible to imagine an enhanced water circulation system whereby the water would be recovered repeatedly on a six-month cycle. This would provide that the water cooled by the winter heating and returned by the reinjection well would be in a position to be recovered by the production well for the following summer cooling cycle. Since the conditions for flow and patterns of circulation in the mines are unknown, it would be virtually impossible to determine the relative locations of single-direction production and reinjection wells to achieve return of the water on the six-month cycle required. The same effect could possibly be achieved by a reversal of the production and reinjection wells on a six-month cycle. This would require static conditions in the mine, and there is a good chance that reinjected water would be removed by unknown circulation patterns before the time for recovery. The cost of such a system might not justify the extra efficiency to be obtained.

The net annual heat drain by Ropak Can-Am is negative and has been calculated above to be about 660 GJ. The accessible heat in the water of the mines has been estimated earlier to be 250 TJ, based on a temperature change of 15 K. The annual exchange of this one installation is thus less than the accessible heat by a factor of 400. This calculation takes no account of heat exchange between the water and the mine walls or of heat brought in by groundwater circulation. For practical purposes

this present heat exchange and several others of similar magnitude could be supported for long periods in comparison with the life of the buildings.

5. ECONOMIC BENEFITS

Costs for heating the old part of the Ropak Can-Am building of 1600 m² were about \$25,000 per year, using conventional oil furnaces. This was projected to an anticipated annual cost of \$125,000 per year for the total 8300 m² heating the total building after the addition of 1989. Since the new building was planned to be more energy efficient, this figure is too high, perhaps by a factor of 2 or more.

The capital cost of the heat pump system and the two wells was \$110,000, 20% higher than the estimated cost of conventional oil furnaces. However, the maintenance costs are considerably lower. Good temperature and humidity control provided by the heat pump system removes the need for dehumidifiers on each of the machines, at a capital cost of \$15,000 for each of twelve machines. Thus in this particular application the entire capital cost of the heating system, not just the incremental cost of the heat pumps, is more than compensated by this saving alone.

The data for the 239 days in the first year of operation show a total cost of electrical power of \$16,400. If we divide this cost in the proportion for heat pumps and other uses as derived above for the electrical energy, we find that the heating cost of \$11,840 for the 239 days or \$18,000/year. This is less than the annual heating cost for the original small building.

In the complete building of 1991, with sixteen heat pumps, and a total area of 14,000 m², the company estimates that the geothermal system saves \$160,000 per year over the equivalent oil-fired furnace system. (MacKinnon, personal communication). Disregarding the saving associated with the dehumidification, the pay-back period of the extra capital cost was thus well under one year for this installation. If the conventional dehumidification costs are also included in the calculation the payback period is virtually instantaneous.

There are non-monetary benefits in addition to the savings in energy costs: the clean operation now permits the company to make food containers: and working conditions are much better than before, particularly in the summer, because of the cooling provided by the geothermal system.

6. ENVIRONMENTAL BENEFITS

The extraction of energy from mine water, which is immediately returned to the mine, produces no combustion gasses and leaves no chemical residue on the surface. This energy source, when in routine use, produces no harm to the local environment. In the event of a break in a pipe, permitting the release of water, the potential damage would be limited to any damage caused by the water and any impurities. At Springhill the water pumped from the mine at the museum is discharged into the local surface drainage, and it is presumably of surface-water quality. Thus the potential far environmental damage by a break is limited to physical damage by the water itself.

The electrical energy used to run the heat pumps is less environmentally benign. Much of the power used in the Atlantic Provinces is generated by coal-burning generators. Data from the first 239 days of operation imply a consumption of 128 MWh, which is a rate of about 195 MWh/yr or 700 GJ/yr. The energy equivalent of 1 TJ is 36 Tonnes of coal (British Petroleum, 1992). Assuming a conversion efficiency of 20%, it requires 126 Tonnes/yr of coal to produce the energy. Assuming that the coal is 80% carbon, the electrical generation releases

about 370 Tonnes/yr of carbon dioxide into the atmosphere. There is some emission of sulphur and nitrogen oxides in addition to or instead of some of the carbon dioxide. If the coefficient of performance of the heat pumps is 3.6 this use of electrical energy saves a further emission of 960 Tonnes/yr of carbon dioxide.

The use of more electrical energy would not be the chosen alternative heating system if the geothermal system were not available. Without the geothermal system the building would be heated by fuel oil and cooling in the summer would be by air conditioning. The positive heating of the building during winter took 890 GJ from the mine water, and, with a coefficient of performance of 3.6, put 3.2 TJ of heat into the building. Since 1 TJ is equivalent to 170 barrels of oil, this heating would require 540 barrels, and with a heating efficiency of 50% would use 1080 barrels or 160 Tonnes. Assuming that the oil is 85% carbon, this would release 500 Tonnes of carbon dioxide into the atmosphere. With oil-fired heating in winter the cooling part of the annual cycle would be run by electrically driven air-conditioners, which would release 240 Tonnes of carbon dioxide, calculated from the fraction of the electrical energy used by the geothermal system for cooling. However, without the geothermal water the air conditioning would probably use external air as the heat sink and the efficiency would be substantially lower than at present, resulting in higher electrical usage.

The carbon dioxide emissions necessary to provide the same benefits are thus 370 Tonnes/yr for the geothermal system and at least 740 Tonnes/yr for a system of oil heating and conventional air conditioning. Although this is a very small quantity in comparison with the national emission of gas into the atmosphere, it is a small contribution to environmental responsibility that is profitable for the operator and is reproducible in many other locations.

7. POTENTIAL FOR OTHER LOCATIONS

An inventory of abandoned mines in the provinces of Nova Scotia and Quebec has been performed under contract to the Geological Survey of Canada and CANMET (Arkay, 1992). It was found that much of the requisite information already exists in provincial records, but not necessarily in a form readily applicable to the assessment of geothermal resources. It was also observed that only two provinces within Canada, British Columbia and Nova Scotia have legislation that defines and regulates geothermal resources, and that the British Columbia legislation specifically excludes resources at a temperature less than 80°C. Thus only Nova Scotia has legislation to define and regulate low-temperature geothermal resources. The absence of current legislation inhibits potential developers. A clear definition of ownership of a resource and the regulations under which it may be developed are much preferred to a situation where there matters are undefined and where other, possibly multiple and conflicting, sets of regulations must be observed. Furthermore, the enactment of legislation prior to development is desirable since otherwise the developer runs a risk that regulations may be changed after considerable time and money has been expended.

There are many abandoned mines in Nova Scotia and Quebec. Some of them are very small, and the smallest have not been included in the inventory. Others are large and have considerable volumes of water in them. The temperature of the water in a mine is a function of the maximum depth of the mine and the geothermal gradient. The Springhill mines combine great depth of 1325 m and modest geothermal gradient of 15 mK/m to produce a water temperature of 18°C. In the other areas of the Atlantic region the geothermal gradient is similar.

and mines of similar depth would be expected to show about the same water temperature. In tectonically younger areas, such as British Columbia, where geothermal gradients are generally higher than in Nova Scotia, shallower mines would be expected to contain water of useful temperature. In the Precambrian Shield, where geothermal gradients may be as low as 12 mK/m, and the surface temperature may be lower than at Springhill, water temperatures will be correspondingly lower.

The geothermal potential of each flooded mine is a subject for individual study. However, a market in close proximity to the energy source is needed before any individual mine can be of economic interest.

8. CONCLUSIONS

Geothermal energy from the waters of an abandoned mine is capable of providing heating and cooling for large buildings through the use of heat pumps. Because the water in a mine circulates by convection, shallow wells produce water of a temperature significantly higher than groundwater of the same depth.

One company, Ropak Can-Am Ltd, has made substantial savings in the cost of heating and cooling their building. The geothermal system has provided working conditions much better than were experienced in the old part of the building that was heated, but not cooled, by oil furnaces. Other users report substantial savings and improvements in conditions.

The Ropak Can-Am building, averaged over an annual cycle, puts heat into the mines, but other buildings will probably take heat from the mines.

In addition to the economic savings, the geothermal system provides substantial reductions in the release of carbon dioxide to the atmosphere, and thus is environmentally attractive.

There are many flooded and abandoned mines in Canada and elsewhere many of which would have geothermal potential if the user were located close to the workings. Legislation defining and regulating such resources is still lacking in all Canadian provinces except Nova Scotia.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of Len McKinnon, who provided the data from the Ropak Can-Am plant on which much of this paper is based, and C. Kavanaugh, who provided estimates of the mined volumes of the seams.

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