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REPORT ON PRELIMINARY ASSESSMENT OF THE POTENTIAL APPLICATIONS OF GEOTHERMAL ENERGY (Western Canadian Sedimentary Basins) Phase One, and Two.

Sproule Associates Ltd. and Angus Butler Engineering (1980) Ltd.

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ABSTRACT

Three specific applications of geothermal energy from sedimentary basins were chosen from a wide variety of potential applications. These were 1) potash mine air heating in the Saskatoon area; 2) Commercial complex space heating in the Calgary area; and 3) district heating in the Grande Prairie area.

The costs of the available energy over a 30 year life are in the range $4.78 - $4.95 per GJ, but consideration of the utilisation factor increases this cost to $12.47 - $24.12 per GJ. These figures are in 1981 dollars, and make no allowance for inflation interest or capital or other variable economic factors.

RESUME

Trois usages spécifiques de l'énergie géothermique des bassins sédimentaires ont été choisis parmi une grande variété d'applications potentielles. Ces trois usages sont 1) le chauffage de l'air dans les mines de potasse de la région de Saskatoon; 2) chauffage de complexes commerciaux dans la région de Calgary; et 3) chauffage central de logements dans la région de Grande Prairie.

Le coût de l'énergie disponible au cours de 30 ans varie entre $4.78 et $4.95 par GJ. En considérant les facteurs de l'utilisation ce coût augmente à $12.47 - $24.12 par GJ. Ces coûts sont exprimés en dollars 1981 et ne tiennent pas compte de l'inflation, de l'intérêt ou du capital ou d'autres facteurs économiques variables.

REPORT ON PRELIMINARY ASSESSMENT
OF THE
POTENTIAL APPLICATIONS OF GEOTHERMAL ENERGY
(Western Canadian Sedimentary Basins)
PHASE ONE

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PHASE ONE

INTRODUCTION

The study on which this report is based has been carried out under Contract Serial Number OSQ80-00163 with the Department of Supply and Services.

The present report presents the results of Phase One of the Study. The remainder of the work will be the subject of a second report on Phase Two.

The object of Phase One was to study available data and to define site-specific locations where geothermal energy might be used and to recommend three of these locations for further study in Phase Two.

The work on Phase One has been carried out with the benefit of meetings with the Scientific Authority, Dr. A. Jessop, of the Earth Physics Branch of the Department of Energy Mines and Resources.

Phase One has been carried out in close collaboration with Angus Butler Engineering (1980) Ltd. of Edmonton, Alberta.

NATURE OF THE POTENTIAL RESOURCE

GENERAL

The purpose of this portion of the report is to outline the present state of knowledge with respect to potential geothermal resources in the Sedimentary Basin of Western Canada. In much of the report this is referred to simply as the "Basin".

The present report is intended not as a summation of geothermal knowledge but rather as a starting point for economic assessment of the potential resource. It does not, therefore, discuss theory of heat flow or heat flow patterns in the sedimentary basin but concentrates on presently available data which is pertinent to economic assessment.

Some rather basic concepts are outlined so that the report may be used by those without a geological or geophysical background.

The potential geothermal resources of the Western Canada Sedimentary Basin have only been investigated in the most preliminary manner.

Those investigations and studies which have been carried out, and those which are continuing, may be divided into two basic complimentary groups, although the two groups certainly overlap and each provides data concepts and interpretation fundamental to the continuity and success of the other.

The first group may be referred to as the mission-oriented basic research group while the second may be regarded as the applied research group. In the present compilation and interpretation, we are more concerned with the applied group, although the more fundamental studies certainly provide information essential to the study.

The mission-oriented research has included studies of geothermal gradients, conductivity of sedimentary rocks, heat sources, heat flow rates and patterns and total heat distribution in the sedimentary sequence essential to adequate study of the resources.

The applied research has been concentrated on actual heat sources that may become available for economic use in the short to medium term. This group of studies has concentrated on actual subsurface temperatures especially in porous beds from which hot water could be produced in quantity by available technology, on distribution of porous and permeable beds, water chemistry, and producing characteristics. One geothermal test well has been drilled, completed and partially tested on the campus of the University of Regina. Testing is not complete because a second well will be required for disposal of the large quantities of saline water which will be produced during a complete test.

Both groups of studies are in their early stages and much additional work is required to properly characterize and assess the potential resource.

DATA SOURCES AND LIMITATIONS

Both fields of research have had to base their studies largely on data provided by holes drilled by the oil and gas industry. While the many thousands of exploratory and development wells drilled by the oil and gas industry provide a vast amount of data, much of this information is of limited use in accurate assessment of geothermal potential.

Some of the reasons for this are summarized below:

1) Drilling operations which involve the circulation of drilling mud generally tend to cool the rock and a long time is required for rock in the immediate vicinity of the test hole to return to normal temperature. Bottom hole temperature measurements are usually taken shortly after circulation of drilling fluid ceases so that recorded temperatures are usually lower than normal temperatures.
2) Temperature measurements at the well-site have not always been given the care which would result in more accurate data.
3) The oil and gas industry has not usually been interested in the producing capability of porous and permeable rocks containing water only. Because oil and gas traps generally occur at the top of porous and permeable sequences, it is only these upper portions of aquifers which have usually been tested. In most cases even these sections are not tested unless there is some evidence of the presence of oil or gas. This means that the major porous and permeable aquifers, which form the best potential source of hot waters, have seldom been tested.

4) Very few of the tests which have been run are of long enough duration to establish water producing characteristics.

5) Formation water sampling and analysis has frequently not been adequate for the work required for geothermal studies. Apart from the fact that tests of short duration may not have produced representative samples of formation water, sampling has rarely been done in a manner that will provide for the retention of dissolved gases, particularly Oxygen, Methane and Hydrogen Sulphide which are very important in estimating costs involved in handling warm waters. The vast majority of available analyses only report determinations of major ions, namely:

Cations	Anions
Sodium and Potassium	Chloride
Calcium	Sulphate
Magnesium	Bicarbonate
Iron	Carbonate

Even so, in many cases, Sodium and Potassium have been determined by difference so that the accuracy of analyses cannot be checked by balancing cations and anions.

6) Drilling and testing has naturally concentrated on those areas and stratigraphic units which are known to contain oil or gas on a regional basis. This means that some of the major aquifers, especially the deepest basal aquifers such as those of the Cambrian and Ordovician where the

highest temperatures will be found, have been tested only very rarely.

In spite of the limitations of the data there is still enough information to permit a general initial interpretation of the geothermal resource potential. It must be stressed that only initial interpretations are possible.

HEAT SOURCES

Natural heat is stored in, and moving through, all rocks and vast amounts of heat exist in the earth's crust. The problem in using this heat as an energy source is in removing it in some reasonably concentrated manner.

The igneous and metamorphic rocks of such areas as the Canadian Shield contain little or no porosity and there is not, at present, any effective way of removing heat in significant quantities.

Sedimentary rocks, such as those of the Western Canadian Sedimentary Basin, may be porous and permeable, although only a relatively small portion of most sedimentary sequences contains important porosity and permeability.

Porosity in sedimentary rocks is always fluid filled, the fluids being oil, gas or water. The contained fluids are effectively at the temperature of the containing rock. Some of the heat in the sedimentary sequence may therefore be removed by removing the contained fluids. For present purposes, we are concerned only with the water.

The availability of water from any sedimentary sequence is dependant on the porosity and permeability.

Porosity is a measure usually, expressed in percent, of the void space in the rock which is filled with water. Porosity may vary greatly ranging from zero to perhaps 40 percent in extreme cases, but does not usually exceed perhaps 25 percent except very locally. A working range of porosities for permeable sections might be from five to 20 percent.

Permeability is a measure of the connection between pore spaces in a rock and determines the producibility. Rocks can be quite porous but have very limited permeability so that production is very slow. Especially in fractured reservoirs, permeability can be high but porosity may be low, giving a limited reservoir.

It is necessary to locate reservoirs with good porosity and good permeability for high rates of water production. Such reservoirs will have to be explored for and certainly are not present in all areas.

TEMPERATURES

Except for the near surface area, temperatures within the earth's crust increase with depth. The rate of increase with depth, the geothermal gradient, varies from area to area and depends on a number of factors such as rock type.

Available data from the Western Canadian Sedimentary Basin indicates that geothermal gradients generally vary between about 27 mK/m (15°F/1000 ft.) and 40 mK/m (22°F/1000 ft.). An average value of 33 mK/m (18°F/1000 ft.) may be considered for the entire Basin. Areas of higher gradients naturally give higher temperatures at the same depths. Maps showing interpreted geothermal gradients for those areas of the Basin where sufficient data are available have been prepared by Dr. A. Jessop of EMR.

These maps show the highest gradients in the Basin to be in northern British Columbia and northwestern Alberta and in parts of southern Saskatchewan. These highest gradients are over 40 mK/m. For most of the area the gradients range from about 25 to 35 mK/m.

Because of the increase of temperature with depth, one of the most important factors controlling temperature in any porous and permeable rock sequence is the depth to that sequence. The thickness of the entire sedimentary sequence is therefore an indication of the maximum temperatures that may be expected at the base of the sedimentary sequence. In the Western Canadian Sedimentary Basin this thickness of sediments ranges from zero at the edge to over 4,500 m (15,000 ft.) in west central Alberta near the edge of the Foothills Disturbed belt. Figure 1 is a sketch map illustrating the thickness of the sedimentary sequence in the Basin. Because the vast majority of the original data were recorded in feet, this unit of measurement is used on the map.

Although factors other than geothermal gradient and depth, such as stratigraphy, heat source, hydrodynamic conditions and surface temperature may affect temperatures at depth, for much of the area of current interest the main factors determining the average temperature to be expected are depth and geothermal gradient (the geothermal gradient is, of course, strongly affected by some of the factors listed above).

Figure 3 shows interpreted maximum bottom-hole temperature ranges in the Basin.

WATER CHEMISTRY

The chemistry of subsurface waters may have an adverse effect on the practicality of the use of such waters as a heat source.

High salinities may cause problems of corrosion and precipitation, with respect to the equipment required for production, use and disposal of water.

Unfavourable chemistry may cause plugging problems when waters are re-injected into the subsurface even if injection is into the producing formation (almost all deep subsurface waters are sufficiently saline that they cannot be disposed of on the surface and must be re-injected into the subsurface). Dissolved gases such as Oxygen, Methane and Hydrogen Sulphide can have highly corrosive effects.

As stated earlier, adequate water analyses are very rare for the Basin.

The available information indicates that in much of Alberta, waters from the deeper Paleozoic beds are likely to be very saline with total dissolved solids usually well in excess of 100,000 ppm and reaching much higher to 200,000 or 300,000 ppm or even higher.

Many deep Alberta waters contain significant amounts of Calcium and Magnesium, up to the order of 100,000 ppm Calcium and 10,000 to 15,000 ppm Magnesium. The main Anion is usually Chloride.

Generally in Saskatchewan the situation is somewhat different. An area in southern Saskatchewan near the Third Meridian is characterized by relatively fresh waters, 10,000 ppm total solids or less, even in the deepest beds. Salinities tend to increase radially as the edge of the Prairie Evaporite Salt is approached and may reach very high values, close to saturation with respect to Sodium Chloride. Many of Saskatchewan subsurface waters appear to owe their salinity to solution of halite and have Sodium and Chloride as their main constituents.

The limited information available indicates that waters from British Columbia may tend to be somewhat fresher than those from Alberta but saline contents are still high.

Although quantitative data are very limited, Hydrogen Sulphide appears to be quite common in many of the deeper Devonian waters of Alberta. (The Devonian Formations are some of the more important potential aquifers in Alberta.) Even when it is not noted in available standard oil field water analyses, the possible presence of small quantities of Hydrogen Sulphide should be suspected in Devonian and Mississippian waters in Alberta. It may also be present in Cambrian waters in Alberta.

Hydrogen Sulphide is seldom reported from the deeper Saskatchewan waters but detailed analyses of water from the University of Regina geothermal test well demonstrated that about 20 ppm of Hydrogen Sulphide was present.

Rather surprisingly, the water from the Regina test well also contained one ppm of Oxygen. There is every little data on Oxygen content of deep waters.

Methane or other hydrocarbons may be present in all subsurface waters.

POTENTIAL RESERVOIRS

Without detailed geological studies, only limited comments can be made on the distribution of reservoirs adequate for the production of large quantities of water.

The producibility of large amounts of water depends on porosity and permeability of the rock as well as other factors such as reservoir pressure and the continuity of porous and permeable reservoirs over considerable distances to provide drainage area and recharge of the area in the immediate vicinity of the well bore. If there is not continuity of reservoir, even though there may be adequate porosity and permeability in the immediate vicinity of a well bore, the producing area will not be recharged and production rates will fall.

There is very little published information on the occurrence of major continuous porous and permeable intervals for most of the Western Canadian Basin.

Some broad assessments may be made on the bases of previous work and general stratigraphic knowledge.

In the Saskatchewan portion of the Basin, the most prospective stratigraphic sequence is formed by Deadwood and Winnipeg formations of Cambrian and Ordovician age. These units often contain sandstones with good reservoir characteristics.

As these beds are followed into southern Alberta, reservoir characteristics tend to deteriorate. Locally there may be good Cambrian reservoirs above the basement in southern Alberta, but they are not nearly so widespread as in southern Saskatchewan.

The following paragraphs are quoted from the Sproule "Report on Study of Geothermal Resources in Western Canadian Sedimentary Basins Phase One". They summarize interpretations of prospective reservoirs and include comments on the temperatures which may be anticipated on the basis of present knowledge. The locations of cross-sections referred to are shown on Figure 2.

"In western Alberta and northwestern British Columbia, the deepest potential producing zones are in the basal clastic zones of the Middle Devonian Lower Elk Point Group and of the Cambrian. These clastic beds tend to be of limited lateral extent and their occurrence cannot be predicted with accuracy.

The Gilwood sandstone of the Middle Devonian Elk Point Group, although fairly thin, can be a prolific producer of water. The occurrence of this zone below 10,000 feet is mainly restricted to west-central Alberta and is illustrated on Cross-Section E-E'.

Sandstone beds of the Stephen and Cathedral formations of Cambrian age are also present in the area of Cross-Section E-E'. These beds are considered to have local reservoir potential. The number of wells penetrating sediments of Cambrian age in the deeper parts of the basin is limited and in most areas very little is known about the distribution and reservoir potential of these beds.

In western Alberta, northeastern British Columbia, and the southern part of the Northwest Territories, the most important deep reservoirs, on a regional basis, are considered to be in the reef complexes of Upper and Middle Devonian age.

The Elk Point Group Keg River Formation in northwestern Alberta forms pinnacle reefs with good reservoir potential. This zone is illustrated in

Section H-H'. Available temperature data indicate that water temperatures in these reservoirs are probably in the range of 200°F to 250°F. In northeastern British Columbia, a continuous reef development is present from the Upper Elk Point Group, which includes the Keg River, Pine Point, and Presqu'ile reefs, into the overlying Slave Point Formation. These reefs are illustrated on Cross-Section I-I' and J-J'. As indicated by the drill stem tests from certain of the wells illustrated on the cross-sections, significant reservoirs are present. Information available to us indicates that water temperatures in these reservoirs may range from 200°F to 300°F.

The higher temperatures in the area of Cross-Sections I-I' and J-J', as compared with Cross-Section H-H', are partly due to the greater depths of the porous zones but there may also be a regional temperature increase not related to depth in this area (increased geothermal gradient).

The Beaverhill Lake Formation contains reef reservoirs in the Swan Hills Member in west-central Alberta, as illustrated on Cross-Section E-E'. These reefs, although thinner and somewhat less widespread than those in the Elk Point Group discussed above, are considered to be significant reservoirs in the area of this cross-section. Good water recoveries from drill stem tests are illustrated on the cross-section but information available to us indicates that water temperatures may be in the order of 200°F or less. The Beaverhill Lake also contains reefs in the area of Cross-Section D-D'. In this area these reefs may be continuous into the Leduc Formation.

In western Alberta, in the area of Cross-Sections C-C' and D-D', reefs of the Upper Devonian Leduc Formation offer a good potential for deep reservoirs capable of significant water production. The results of drill stem tests from the wells illustrated on the cross-sections indicate that significant reservoirs are present. The available data indicate that water temperatures in these reservoirs may range from 250°F to 300°F. Stratigraphic depths in the area of Cross-Sections C-C' and D-D' are considerably greater than in the area of Cross-Section E-E' referred to above.

Carbonate beds of the Winterburn and Wabamun groups overlie the Beaverhill Lake section.

Rocks of these groups, or their equivalent in northeastern British Columbia, have, for the most part, limited reservoir potential. The wells on the cross-sections do not show significant reservoirs although porous beds could be present in local areas.

The Mississippian carbonates, especially the Debolt Formation (equivalent to the Turner Valley and Mounthead formations in southwestern Alberta) and the Pekisko Formation, may contain reservoir beds. In west-central and southwestern Alberta, these zones may be present at depths in excess of 10,000 feet and may be potential reservoirs for warm waters. Cross-Sections B-B', C-C', and D-D' illustrate the potential of the Mississippian beds. Available information indicates that water temperatures are generally in the order of 200°F in the deeper areas. In other areas, Mississippian beds are considered to be too shallow to be a source of hot water."

Figure 1 also shows a breakdown into areas in which certain maximum temperatures may be anticipated. It should be stressed that there are temperatures at the lowest depth for which we have information, usually near the base of the sedimentary sequence. Adequate reservoirs will not necessarily be found at these depths but may be considerably shallower. Locally, warmer areas will be found.

SUMMARY

In summary, the requirements for commercial production and use of warm water and the present state of knowledge may be listed as follows:

1) Adequate temperature - controlled by source of heat and heat flow but most largely by depth. Only a relatively small part of the Basin appears to have temperatures of present interest.
2) Adequate reservoirs controlled by stratigraphy. Adequate reservoirs will be more difficult to define than will adequate temperatures.
3) Water Chemistry - most Basin water is highly saline with well over 50,000 ppm total solids. In Saskatchewan many waters contain mostly Sodium Chloride. In British Columbia and Alberta there is a much higher percentage of Calcium and Magnessium Chloride. Hydrogen Sulphide is expected to be common in British Columbia and Alberta waters and may be found in all areas.

GENERIC TYPES OF APPLICATIONS

GENERAL

In various parts of the world, low-temperature geothermal resources have been used for a variety of applications ranging from residential, commercial and industrial space heating through chemical processing and drying to fish hatcheries.

In our considerations, we have attempted to restrict ourselves to applications which are established or foreseen in Western Canada and at the same time to use our knowledge of geology and the geography of the potential resource to eliminate areas which did not appear satisfactory. Many applications which have been used in other areas have had to be eliminated because there was no forseeable practical use in Western Canada, because producing costs were obviously too high, because other forms of heat were readily available or for other reasons.

A number of applications which initially appeared to have a potential were initially considered and then rejected for a variety of reasons. Some of these are briefly discussed in the following parts of this section. Some of these uses may become worthy of more detailed consideration in the future when economic or technical factors change.

APPLICATIONS CONSIDERED BUT FOUND WANTING

Some of the generic types of industrial, commercial and agricultural establishments and applications which were considered, but found to be unattractive in the present market, for geothermal heat are briefly discussed in the following sections.

In each case there is a recognized potential for the use of low grade heat, but for economic, technical or current acceptability, the geothermal type of application was not found to be attractive at this time. In the future this may well change and future reviews of each application may provide an opportunity for the use of geothermal heat.

In some cases the temperature of the geothermal heat was too low for the site specific application being considered. In other cases the available evidence indicated that it was very doubtful that adequate amounts of hot water were available.

Greenhouse Heating

The use of geothermal heat for greenhouse heating could be practical in most areas of the prairies under certain conditions. A greenhouse could benefit for much of the year from the use of low grade heat, for space heating, for pre-heating of the make-up air necessary to pressurize the building to prevent the ingress of freezing air into the growing area in winter, for preheating the water used for feeding the plants and for humidification.

The site requirements for a greenhouse are not critical. A greenhouse can be located adjacent to any source of low grade heat. At this time, a number of greenhouses have been located in Western Canada near industrial plants, pipeline pumping stations, and other sources of low grade heat that is available at minimum cost.

The capital costs for a geothermal installation with supply and injection wells, pumps and heat exchangers would not appear to be competitive with other sources of essentially free low grade waste heat from industrial processes at this time.

Geothermal heat would be technically but not economically feasible at present for greenhouse heating at this time.

Grain Drying

Inland grain terminals require low temperature heat for drying grain for storage or to meet export specifications. The normal supply air temperature to the driers for the different grains would be as follows:

Corn	150°F entering air temperature
Grain for food	180°F entering air temperature
Grain for seed	120°F entering air temperature
Grain for malting	120°F entering air temperature

Any drier application would be required to dry all types of grain for all purposes so the system would have to be designed for 180°F entering air temperature to the drier.

Only very deep sedimentary rock formations in the prairies would produce a sufficiently high temperature of geothermal water for use in grain drying applications. This in essence means western Alberta, northeastern British Columbia and the Peace River area would be suitable for the use of geothermal heat for grain drying.

Because of the limited geographic opportunity for the use of geothermal heat for grain drying in these parts of the prairies, an in-depth study of this application was not undertaken.

Livestock Feeding Stations

The use of geothermal heat in agricultural buildings was considered. It was found that this subject was controversial and open to many questions of an agricultural and animal husbandry nature which are outside the scope of this report.

A great deal of research is being undertaken to determine the metabolic rates of various types and breeds of farm animals under various environmental conditions. As this work progresses and is correlated into accepted forms, the use of heating buildings for livestock feeding may be accepted as a general practice on the prairies.

At this time we question if geothermal heat could compete with the biomass heat available in the form of manure in most agricultural feedlot locations.

Forest Products

The lumber, pulp and paper, plywood and chipboard industries based on the use of forest products are making progress in the utilization of all bark and waste products for the generation of heat and in some cases the generation of electrical power. It is questionable if the waste from these operations will meet all their fuel requirements in the future, as alternate uses for wood material are developed.

Although there are a number of forest industries which are located in areas where geothermal heat would likely be available we do not feel that any serious consideration to the use of geothermal heat can or would be given by the industry until the program to fully utilize the available wood wastes is well advanced or completed.

In the future, the development of by-products from wood may make wood waste too valuable for use as a fuel. At that time the use of geothermal heat could be considered for preheating the large volumes of process water and ventilation air required for paper mills and preheating of drying air in wood kilns.

Airport Runways

Interest has been expressed in work undertaken in Japan for the utilization of geothermal heat in roadways and airport strips for the removal of snow during the winter. The weather conditions in the area of the Western Canadian Sedimentary Basin are more severe than Japan. For Canada, very large heat flows through expensive systems would be required to be effective.

In Canada, we use systems for heating ramps in parking areas or the steps and entrances of prestige buildings, quite extensively. Generally, hot glycol is circulated in pipes imbedded in the pavement or step surfaces. These are special areas and the cost is considered acceptable for a specialized use.

Heavy Oil Industry

The heavy asphalt-based oil found in the Lloydminster and other adjacent fields requires heating and/or dilution with a lighter oil to permit pumping or processing of these oils. Unfortunately, the sedimentary basin is shallow in the area where heavy oil is found and the temperature of available geothermal water was considered to be too low for effective heating of the heavy oils.

Cement Plants

Two large primary cement plants are located in areas of the Western Sedimentary Basin under consideration in this study. The potential for utilizing geothermal heat in the future at these plants was investigated.

The wet grinding cycle was initially used for these plants. Fairly large volumes of preheated ventilation air was required for the mill room to absorb the moisture released from the grinding process and to prevent the ingress of freezing air into the mill room.

The dry grinding cycle for cement manufacture offers very substantial power savings over the wet grinding cycle and consequently is being used on any expansions to these plants. Likely the existing mill rooms will also be converted to the dry grinding cycle sometime in the future. The process air required for dry grinding of cement needs no preheating before introduction into the mills. There is no water vapour release to the mill room. Consequently, the heat required for ventilation air is greatly reduced and in all likelihood can be supplied by equipment heat losses. The mill room ventilation does not represent a large potential user of low grade geothermal heat.

In the kiln area of the cement plant, there are substantial quantities of low grade heat available from the kiln exhaust gases and the hot product discharging from the kilns. This heat is being investigated and in some places utilized to preheat the combustion air for the kilns or for building ventilation.

Although the cement plants are a large industry, their potential for utilizing low temperature geothermal heat seems to be minimal at this time.

Absorption Chillers

Absorption chillers are widely used in the building industry to cool water to as low as 42°F (5.55°C) for the use in air conditioning equipment. The absorption chiller is a hermetically sealed machine which utilizes the differences in vapour pressures of various concentrations of lithium bromide brine to transfer heat from the chilled water circuit to the waste heat or condensing water circuit. Pumps are used to circulate the brine solutions within the machine but the principle energy source for the heat transfer is provided by steam or hot water at about 250°F (121°C). This is used in the generator section to produce the enriched brine solution. A fuller explanation of this very interesting machine is available from manufacturers' literature. It is sufficient to say that water can be cooled to a low temperature by the use of heat in an absorption chiller.

Unfortunately, for this study, the lowest acceptable steam or hot water temperature suitable for the economically available absorption machines is 220°F (104.5°C). In the area under study it would appear that only in the northeastern part of British Columbia are there geothermal sources of water available at a sufficiently high temperature to be of use in the commercially available absorption chiller machine. There are few buildings in that area which could utilize or need the air conditioning available from this energy source.

Possibly in the future absorption chillers using a different heat transfer medium will be available to utilize lower grade heat from waste streams or geothermal sources.

Heat Pumps

Heat pumps are refrigeration machines which extract heat from a low temperature heat source and discharge the heat from the machine at an elevated temperature more suitable for use in building heating systems. Electricity is used in most machines to power the machine. C.O.P.'s (Coefficient of Performance) of 3 to 5 can be achieved with suitable system design and equipment selection. Otherwise for every unit of electricity expended 3 to 4 times as much heat can be generated at a high enough temperature for use in a building heating system by the extraction of heat from a low grade (low temperature) heat source.

In the geothermal heating systems installed at Creil in France, heat pumps are used to extract the maximum benefits from the geothermal water. With heat pumps they can cool the geothermal water to (50°F) 10°C before pumping it to the injection well.

The use of heat pumps has not been considered in this study but their use is not discounted in any way for future applications.

In the selected site specific applications recommended for study in detail for this report, it is possible to reduce the geothermal water to an acceptable low temperature before pumping it to the injection well with the systems designed to preheat ventilation air from sub zero temperatures.

FACTORS WHICH WILL CONTROL ECONOMIC USE

The most important factor affecting the use of geothermal waters in Western Canada at this time is cost relative to the cost of competing energy sources.

At the present, data on the probable costs of geothermal energy have not been developed. The second phase of the current study will attempt to develop costs for selected site-specific applications. Until this has been done it is impossible to make comparisons even though some data on present costs of competing energy sources may be available.

Certain current costs are available for other sources such as oil, natural gas, coal, hydro-electric power, etc. These must be escalated to provide future comparative costs. Because the escalation rate will depend on a number of unpredictable factors, political as well as economic, the escalated costs will have limited accuracy.

If, for example, the escalation rate for oil or natural gas depended solely on drilling and production costs, then it might reasonably be assumed that the escalation rates for geothermal would be very close to those for oil or natural gas.

Other factors will almost certainly affect oil and gas selling prices and availability so that prices for these sources of energy may escalate more rapidly than costs of geothermal energy.

Future conservation regulations for non-renewable sources, particularily oil and gas, may not only increase the price of these sources but may result in controls restricting their use for heating purposes. Such cost increases or controls could place geothermal energy in a more favourable position.

Environmental controls may also affect the use of fossil fuels in the future and again may lead to restrictions on their use of requirements for expensive anti-pollution installations, increasing costs. Geothermal waters will have to be disposed of from the beginning so that probable future increased concerns for environmental contamination should not affect geothermal energy as much as they might affect fossil fuels such as soft coal.

They are no current regulations controlling the use or costs of geothermal heat. It may well be that owners of the resource (generally assumed to be government) may institute royalties, taxes or other levies which will affect the cost to the ultimate user. For the present study we have assumed that any such charges would be minimal as an encouragement to industry to use this form of energy and charges have been ignored in our calculations.

Until more tests are carried out there are many other unknowns which affect the accuracy of economic analyses of geothermal and conventional heat sources.

These include such factors as producibility, costs of exploration, costs of well completion, costs of operation. Data on these factors will only be obtained as test installations are completed and operated.

For the present we have assumed relatively small escalation in operating costs for a geothermal installation. There is a total escalation of operating costs for a conventional system. The potential user may well choose to accept higher initial capital costs for a geothermal installation rather than face the uncertainty of escalation of conventional fuel costs.

Existing oil or gas wells which are reaching the end of their effective production life may be suitable for conversion to the use in geothermal installations. These would be special and fortunate occurrences but the potential should not be overlooked as substantial costs savings could be gained especially in the stages of testing and developing costs.

The potential owners' interest and financial viability must be considered in the selection of potential applications for the use of geothermal heat. There will be risk involved and potential users must be in a position to carry that risk. Enthusiasm must be backed by solid financial resources on new types of installations since the lack of financial depth could cause failure and could destroy public interest for an otherwise sound technical installation.

Some of the factors we have considered in selecting and recommending site-specific locations for the Second Phase of this study are listed below:

- Geology of the area included anticipated temperature, anticipated porosity and permeability of potential producing zones and disposal zones and the chemistry of subsurface waters.
- Total heat load required for the installation.
- Space availability for the geothermal wells and drilling operations.
- Routing of pipelines to the geothermal collection and injection wells.
- Yearly utilization factor based on operating cycles and climatic data.
- Potential for thermal storage and/or peak load auxiliary heat to achieve the maximum economic utilization factor.
- Jurisdictional and proprietary authority as it affects the access and physical installation.
- Availability of equipment of the size and type that will likely be required.

- Reliability factor required for the type of installation proposed and the need for auxiliary systems if necessary.
- The age and service life of existing heating equipment and the owner's budget predictions for the replacement of this equipment.
- Corrosion allowances for the selection of equipment and pipe.
- Alternate source of waste or heat available from other sources in the vicinity of a geothermal installation.
- The suitability of existing building heating system for conversion to the use of geothermal heat.
- Methods of handling the various gases that may be present in the geothermal water.

CONCLUSIONS

On the basis of our work to date we recommend the following site-specific locations for study in the Second Phase of this project.

The sites have been chosen to represent different geological areas and, as far as possible, different geographic situations.

We believe that each offers realistic technical potential for the use of geothermal energy.

1. Mine Air Heating for a Potash Mine - Saskatoon Area, Saskatchewan
2. Commercial Building Complex - Immediately West of Calgary, Alberta
    - Space Heating
    - Domestic and process water heating
    - Ventilation air preheating
3. Commercial Building Complex - Grand Prairie, Alberta
    - Space heating
    - Domestic and process water heating
    - Ventilation air preheating

THE ASSOCIATION OF
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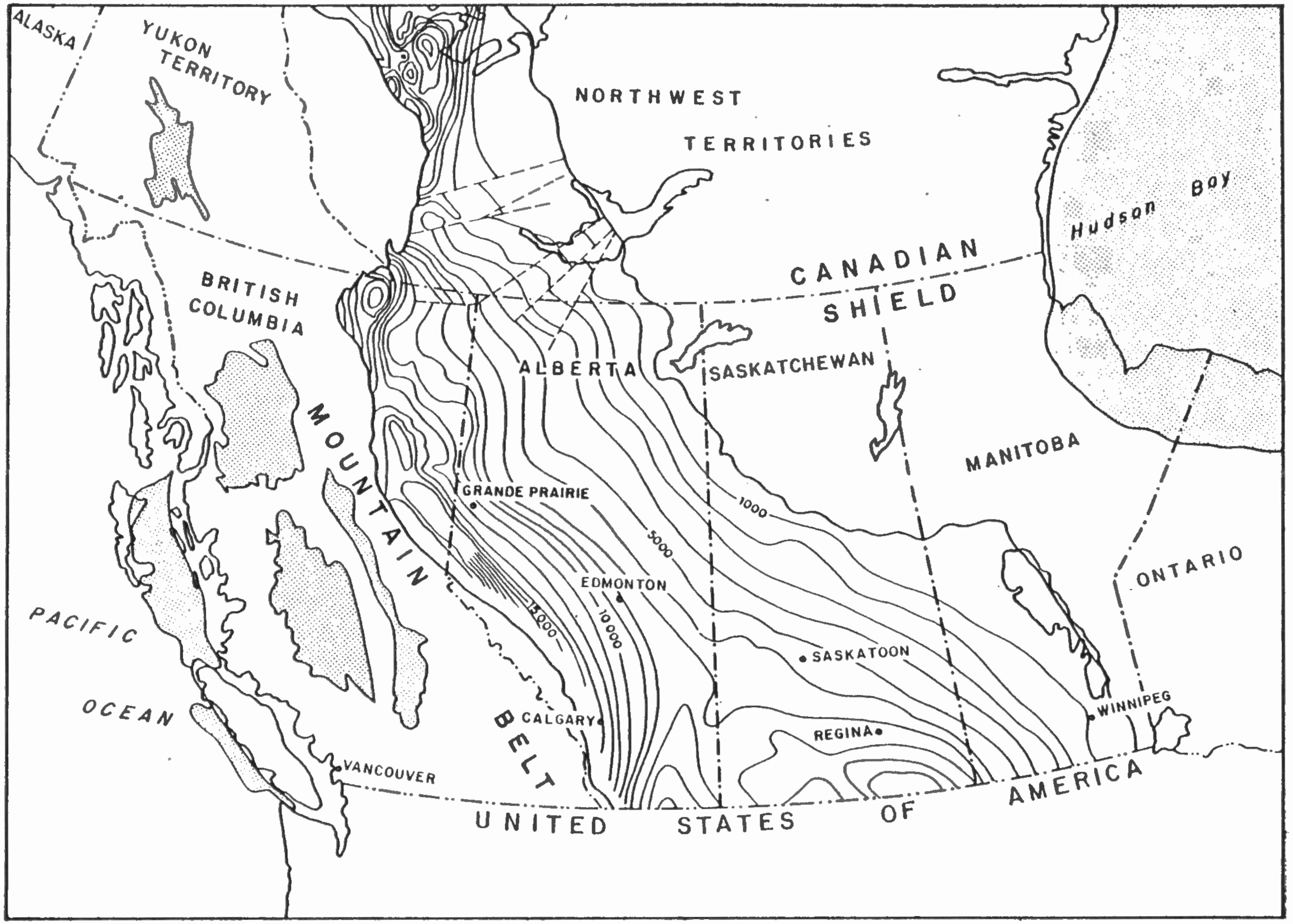

FIGURE - 1

SKETCH MAP
WESTERN CANADIAN SEDIMENTARY BASIN
SHOWING
THICKNESS OF SEDIMENTS
Contour Interval: 1000 Feet

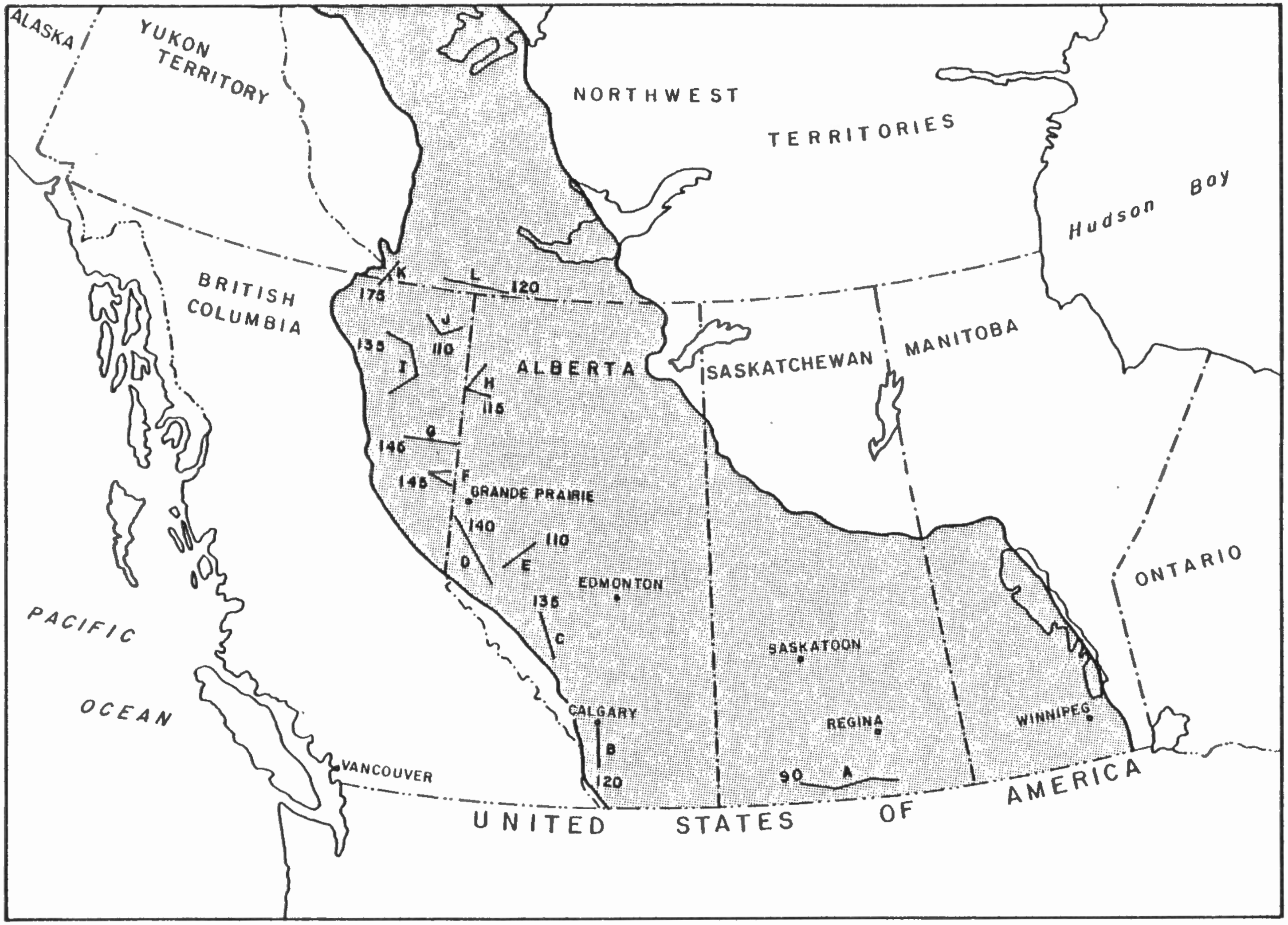

FIGURE - 2

WESTERN CANADIAN SEDIMENTARY BASIN

GEOTHERMAL INVESTIGATIONS

SHOWING

LINES OF CROSS-SECTION

LEGEND

——— Line of Cross-Section, A— Reference Letter, 90— Maximum Reported Temperature 0° C.

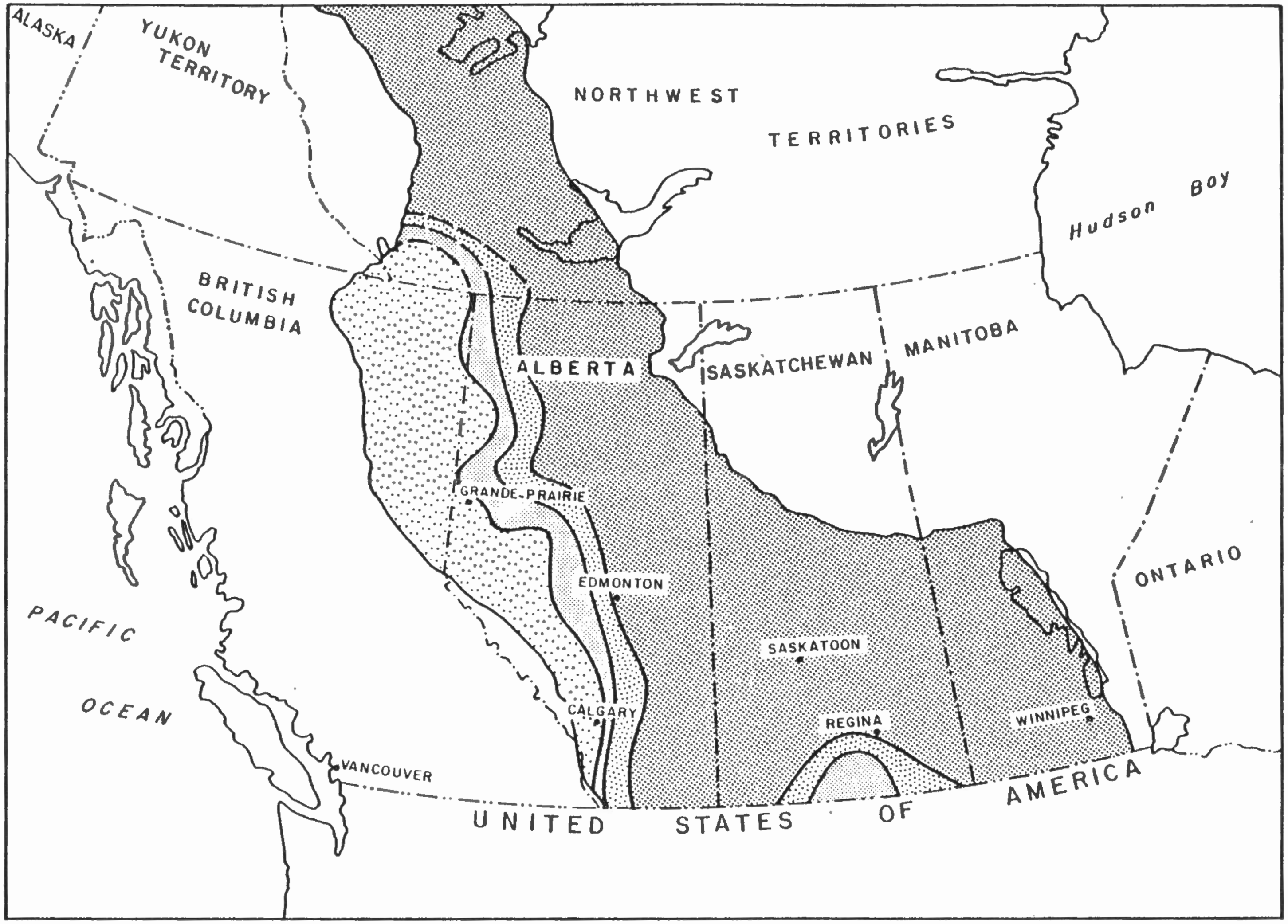

FIGURE – 3

WESTERN CANADIAN SEDIMENTARY BASIN

GEOTHERMAL INVESTIGATIONS

SHOWING

ANTICIPATED MAXIMUM SUBSURFACE TEMPERATURES

LEGEND

▩ <150° F (65°C)

▦ 150° F – 175° F (65°C – 79°C)

▒ 175° F – 200° F (79°C – 93°C)

░ >200° F (93°C)

REPORT ON PRELIMINARY ASSESSMENT OF THE POTENTIAL APPLICATIONS OF GEOTHERMAL ENERGY

(Western Canadian Sedimentary Basin)

PHASE TWO

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AND

SPROULE ASSOCIATES LIMITED

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REPORT ON PRELIMINARY ASSESSMENT OF THE POTENTIAL APPLICATIONS OF GEOTHERMAL ENERGY

(Western Canadian Sedimentary Basin)

ABSTRACT

Phase One

The major parameters of the geothermal resource in the Western Canadian Sedimentary Basin are reviewed with particular reference to geological factors such as depth, temperature and water supply. Only a relatively small portion of the Basin in southern Saskatchewan, western Alberta and northeastern British Columbia has temperatures over 65°C. Adequate reservoirs will be more difficult to define than will adequate temperatures.

A number of generic types of applications are reviewed as are factors which are expected to control economic use.

Site-specific applications for further study are recommended.

Phase Two

Preliminary engineering and economic analyses are presented for three site-specific applications, namely:

1. Saskatoon Area, Saskatchewan - Potash Mine Air Heating.
2. Calgary Area, Alberta - Commercial Complex.
3. Grande Prairie Area, Alberta - District Heating.

Capital and operating costs are presented for a thirty-year life for the complete installation to the user connection to the primary heat exchanger.

Engineering design criteria and flow sheets are developed for geothermal energy applications at the selected sites. Potential yearly utilization factors were calculated.

Undiscounted costs for supply of geothermal energy in \$ per 10^9 joules are developed and presented.

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REPORT ON PRELIMINARY ASSESSMENT OF THE POTENTIAL APPLICATIONS OF GEOTHERMAL ENERGY

(Western Canadian Sedimentary Basin)

PHASE TWO

INTRODUCTION

The study on which this report is based has been carried out under Contract Serial Number 0SQ80-00163 with the Department of Supply and Services.

The present report presents the results of Phase Two of the study. A report on Phase One was submitted earlier.

The object of Phase Two was to develop life costs for selected site-specific locations for the use of geothermal energy.

Both phases of the work were carried out with the benefit of meetings with the Scientific Authority, Dr. A. Jessop of the Earth Physics Branch of the Department of Energy Mines and Resources.

Both phases of the work have been carried out in close collaboration with Angus Butler Engineering (1980) Ltd. of Edmonton, Alberta.

SUMMARY AND CONCLUSIONS

Based on the work carried out in Phase One, three site-specific applications for assessment of potential applications for geothermal energy were chosen in consultation with the Scientific Authority.

The applications chosen were:

1. Saskatoon Area - Potash Mine Air Heating
2. Calgary Area - Commercial Complex
3. Grande Prairie Area - District Heating

Capital and operating costs were developed for each application to provide 30-year life costs.

These costs include all the equipment up to the user connections to the primary heat exchanger.

The conclusions are summarized in the table below:

	Saskatoon Area	Calgary Area	Grande Prairie Area
No. of well systems	1	2	1
Well Depth, Feet	5,300	10,500	11,000
Metres	1,770	3,200	3,350
Production Rate, Bbls/Day	10,000	10,000	10,000
Estimated Temperature	46°C	96°C	110°C
Capital Costs, \$ M	2,590	7,246	4,750
Operating Costs, 30-year life, \$ M	11,376	19,548	21,960
Total Life Costs, \$ M	13,966	26,794	26,710
Total Energy Available, 10^9 Joules	2,909,000	5,610,000	5,402,000
30-Year Life Time Cost, \$/10^9 Joules Available Energy	\$ 4.80	\$ 4.78	\$ 4.95

The above life costs are for available energy. Studies of the related applications show that due to variable loads, there will not be full utilization of available energy.

For the selected applications, utilization factors have been calculated.

When these factors are incorporated into the results, the costs are shown in the table below:

	Saskatoon Area	Calgary Area	Grande Prairie Area
Total Energy Available, Joules x 10^9	2,909,000	5,610,000	5,402,000
Utilization Factor, %	38.5	19.8	36.7
Useable Energy, Joules x 10^9	1,120,000	1,111,000	1,983,000
30-Year Life Time Costs, \$/10^9 Joules	\$ 12.47	\$ 24.12	\$ 13.47

The energy costs, in dollars per 10^9 joules, are not discounted to reflect present worth, nor were costs escalated beyond 1981. There is no allowance for interest or payout on capital or other variable economic factors. There is no allowance for exploration risk. These are a matter of interpretation and users of the basic data should provide their own factors appropriate to their studies.

Factors which would encourage the use of geothermal energy in the Sedimentary Basins of Western Canada include the following:

1. Increased prices of energy from other sources.
2. Conservation regulations for non-renewable energy sources, particularly oil and natural gas.
3. Environmental restrictions affecting the use of fossil fuels.

4. Development of long-term contracts for the use of geothermal heat.
5. Development of appropriate regulations and controls by the authorities with jurisdiction.
6. Selection of large installations which would have the potential for fully utilizing the quantity of geothermal heat available from each well.

Technical factors which would improve the yearly utilization of a geothermal heating system would be:

1. Use of thermal storage to accommodate daily fluctuations in load.
2. Use of auxiliary heat to accommodate the very heavy peak heating loads in the extreme cold weather.
3. Development of an absorption chiller for summer air conditioning service which would give acceptable performance with the temperature of water available from a geothermal source.
4. Selection of an application with large heating loads that are independent of the outside air temperature. An example would be domestic water heating.

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SELECTION OF SITE-SPECIFIC LOCATIONS

GENERAL

The Phase One report was reviewed at a meeting held in the Calgary office of Sproule Associates Limited. Present at the meeting were Dr. A. M. Jessop, the Scientific Authority, of the Department of Energy Mines and Resources, Mr. H. A. Gorrell, P. Geol., of Sproule Associates Limited, and Mr. J. Sworder, P. Eng., of Angus Butler Engineering (1980) Ltd., of Edmonton. Other Sproule staff, including Mr. F. O'Shea and Mr. G. Robinson, P. Eng., attended portions of the meeting.

The meeting reviewed the Phase One report on this project along with other pertinent material, including the background material provided by the Department of Energy Mines and Resources. Other material from our files, including data on subsurface temperatures, subsurface water chemistry, and drill stem test results, was used as required, as was the specialized knowledge of each of the participants.

It was necessary to outline several systems for the possible use of geothermal heat, past the primary heat exchanger, in order to satisfy ourselves of the engineering practicability of these uses of the resource. These "system outlines" are discussed later in this report.

In the selection of the three site-specific applications, every effort was made to select areas with differing geological and geographic conditions. It was agreed that the applications selected would be those for which present information indicated the possibility of a practical use in the foreseeable future.

The site-specific locations selected for further study were those recommended in the Phase One report, namely:

1. Mine Air Heating for a Potash Mine - Saskatoon Area, Saskatchewan.
2. Commercial Building Complex - Immediately West of Calgary, Alberta.
3. District Heating - Grande Prairie, Alberta.

These site-specific locations were approved by the Scientific Authority. The reader is referred to the Phase One report for discussion of several other applications which were considered but which were rejected for various reasons.

The geological and geographic reasons for the selection of the three areas are summarized in the following sections of the report.

SASKATOON AREA

The Saskatoon area was chosen because, although water temperatures are not particularly high, the data indicated a good probability of being able to produce large amounts of water from the Cambrian Deadwood Formation at depths of approximately 5,500 feet and because our investigations indicated that the potash mines in the Saskatoon area might be able to make economic use of geothermal heat.

The thickness of the Deadwood Formation in the Saskatoon area varies but may reach a total thickness of 1,000 feet or more and contain significant porous intervals.

Drill stem tests in the area have given large water recoveries in relatively short intervals of time.

We believe that if a sufficiently thick section were perforated, it should be possible to produce in the order of 10,000 barrels per day of water from a single well.

Temperatures in the Deadwood in the vicinity of Saskatoon are expected to be in the order of 115°F (46°C) to 120°F (49°C).

Deadwood water is very saline. One analysis is given below:

	ppm		ppm
Na	107711	Cl	179718
K	1448	SO_4	288
Ca	3339	CO_3	-
Mg	1803	HCO_3	332

TOTAL SOLIDS - 295,699

Some H_2S may be present.

CALGARY AREA

The Calgary area was chosen as an example because the temperature of potential reservoir beds is significantly higher than is the case in the Saskatoon area and because Calgary is an area where commercial or industrial uses for geothermal energy should be readily available if it proves economic. The unfavourable factors for the Calgary area lie in the apparent paucity of thick porous and permeable beds at adequate depth.

We believe that production rates of up to 5,000 barrels per day may be expected from the Elkton Member of the Turner Valley Formation of Mississippian age and/or from the Crossfield Member of the Devonian Wabamun Formation. Porosity and permeability in both these units is quite variable, and very careful exploration studies would be required. There would still be a considerable risk that porosity and permeability adequate for production and disposal would not be obtained on a first well.

For our analysis, we have assumed two wells producing 5,000 barrels per day each from depths of about 10,500 feet and two injections wells.

Temperatures in the range of 190°F (88°C) to 205°F (96°C) are indicated. Two typical water analyses are given below.

Crossfield Member

	ppm		ppm
Ca	192	Cl	20,896
Mg	?	SO_4	6,600
Na + K	18,239	HCO_3	3,636

H_2S - present and hydrocarbon gases may be present.

TOTAL SOLIDS - 50,563 ppm

Elkton Member

	ppm		ppm
Ca	1,904	Cl	35,145
Mg	185	SO_4	2,602
Na + K	22,149	HCO_3	1,703

H_2S - present and hydrocarbon gases may be present.

TOTAL SOLIDS - 63,688 ppm

GRANDE PRAIRIE AREA

The Grande Prairie area was chosen as an example because the available evidence indicates the waters from the lower part of the Devonian section and possibly from Cambrian beds will have significantly higher temperatures than those of the Calgary area and because the evidence also indicates that there are very good prospects for producing large volumes of water from the Devonian Leduc Formation and possibly from the Cambrian section. Several other areas in western Alberta and northeastern British Columbia have similar prospects but the fact that Grand Prairie has shown considerable growth in the last few years indicated that prospects for use of geothermal resources in this locality were better than in most other areas in this region.

Although data are limited, we anticipate that production rates in the order of 10,000 barrels per day could be obtained from the Leduc Formation. Rates could be higher.

We estimate temperatures in the order of 230°F (110°C) at depths of about 11,000 feet.

The following water analysis is considered to approximate average conditions in the Devonian in this area, but more saline water could be encountered.

	ppm		ppm
Ca	11,300	Cl	84,200
Mg	1,200	SO_4	61
Na + K	39,900	HCO_3	1,420

TOTAL SOLIDS - 138,101 ppm

H_2S and hydrocarbon gases may be expected.

PRELIMINARY ENGINEERING AND ECONOMIC ANALYSES

GENERAL

Using our knowledge of the geology of each of the three site-specific application areas and our experience in drilling and testing deep wells in Western Canada, preliminary designs for producing and injection wells were prepared for each of the areas.

Costs were estimated for the geothermal energy supply system up to the user connections to the primary heat exchangers.

Capital and operating costs are treated separately below.

ESTIMATES OF CAPITAL COSTS

For each of the site-specific locations, costs were estimated for the necessary systems up to the user connections into the primary heat exchangers. These costs included drilling and completion of both producing and injection wells, controls and pipelines between the producing and disposal wells. They also include the necessary controls and the primary heat exchangers.

For the estimation of costs for the drilling of the water producing and injection wells, drilling contractors with suitably sized oil well drilling equipment were contacted and the applicable costs were supplied by them. Service companies provided costs for such items as cement and cementing, mud, coring, logging, testing, etc. Local equipment suppliers provided costs for casing, wellhead equipment, submersible water pumps, water injection pumps, etc. Calgary Power supplied estimates for the provision of adequately sized electrical power substations, as well as an estimate of power costs.

Costs supplied by third parties were adjusted on the basis of our own experience where necessary.

The costs of the appropriate primary heat exchangers were obtained from the manufacturers for the flow rates and temperatures determined for the selected site-specific applications.

All of the costs are in terms of 1981 dollars, and are considered to be reasonably accurate estimates. The costs for the injection wells are slightly lower than those for their companion producing wells due to lesser in-hole activity contemplated during their drilling.

The capital costs for each of the site-specific applications are summarized in the table below.

	Saskatoon	Calgary	Grande Prairie
Depth, feet	5,300	10,500	11,000
Depth, metres	1,770	3,200	3,350
Drill and complete water producing well, $ M	1,225	3,594*	2,243
Drill and complete water injection well, $ M	1,125	3,232*	2,289
Pipeline - 1 mile of 6" line, buried at $30,000 per inch/mile, $ M	180	360*	180
Heat Exchangers, $ M	30	50	38
Total Capital Costs, $ M	2,590	7,246	4,750

---

* Two wells.

Details of the well costs are included in Appendix A.

ESTIMATES OF OPERATING COSTS

Operating costs were estimated, based on the projected power requirements, the likely equipment repair and maintenance needs and on the anticipated supervision required. Estimated repair costs were based on experience and information from suppliers. These costs were held constant throughout the 30 year life of the supply systems.

The operating costs for each system, including producing and disposal wells, are summarized below:

Saskatoon Area	$31,600 per month
Calgary Area (2 systems)	$54,300 per month
Grande Prairie Area	$61,000 per month

Details are given in Appendix C.

Data used in establishing surface water pump requirements are included in Appendix B.

ENERGY SUPPLY COSTS

Capital and operating costs for each site-specific location may then be summarized as follows:

	Saskatoon Area	Calgary Area (2 systems)	Grande Prairie Area
	$ M	$ M	$ M
Capital Costs	2,590	7,246	4,750
Operating Costs, 30 Years	11,376	19,548	21,960
Total Cost, 30 Years	13,966	26,794	26,710

The amount of heat available from the systems was calculated. It was assumed that there would be no decline in production.

The 30 year life costs for the systems are shown below:

	Saskatoon (1 system)	Calgary (2 systems)	Grande Prairie (1 system)
Production, Bbls/Day	10,000	10,000	10,000
Temperature, Initial	115°F (46°C)	205°F (96°C)	230°F (110°C)
Temperature, Final	55°F (13°C)	70°F (21°C)	100°F (38°C)
Temperature, Drop	60°F (33°C)	135°F (75°C)	130°F (72°C)
Available Energy Per Year, BTU	91.98×10^9	177.39×10^9	170.82×10^9
Available Energy for Life of System = 30 years, BTU	$2,759 \times 10^9$	$5,321 \times 10^9$	$5,123 \times 10^9$
Available Energy Life of System = 30 years 10^9 Joules	2,909,000	5,610,000	5,402,000
Life Time Cost Per 10^9 Joules	$ 4.80	$ 4.78	$ 4.95

It should be noted that not all of the extracted heat from each system is considered to be useable, because of the peculiarities of the projected application at each chosen site.

In our studies on concepts of Heat Utilization Systems, given later in the report, the utilization factors for the site-specific applications chosen have been calculated. Using these factors, the costs for the useable energy at these sites become:

	Saskatoon	Calgary	Grande Prairie
Available Energy, 10^9 Joules	2,909,000	5,610,000	5,402,000
Utilization Factor	38.5%	19.8%	36.7%
Useable Energy, 10^9 Joules	1,120,000	1,111,000	1,983,000
Lifetime Cost Per 10^9 Joules	$ 12.47	$ 24.12	$ 13.47

It must be stressed that these costs apply only if the suggested utilization factors are employed. Increasing the utilization can decrease unit energy costs.

The energy supply costs, in dollars per 10^9 joules, are not discounted to reflect present worth, nor were costs escalated beyond 1981. No sale value was assigned to the supplied energy. A dramatic reduction in the cost of the supplied energy would be apparent if operating costs were escalated for the years following 1981, if a sale value were assigned to the supplied energy, and if a reasonable discount factor were applied to the generated net revenue to reflect present worth values.

The above cost analyses do not include allowances for escalation of operating costs, interest and payout on capital and other variable economic factors. These are a matter of interpretation and users of the basic data provided can utilize factors pertinent to their own studies.

There is no comparison with costs or future costs of alternate resources since these costs are also subject to unknown factors.

No allowance has been made for exploration costs. Like any subsurface prospecting, there is always the risk that the first, or any, well may not provide the required production.

Although extensive geological studies using available data can greatly reduce the exploration risk, they cannot remove it entirely.

We believe that, for the examples used, detailed studies of available data reduce risks in the Saskatoon and Grande Prairie areas but that there would be significant risk in the Calgary area.

Estimated current "dry hole" costs for the three areas are given below for information.

Saskatoon	- $ 665,000
Calgary	- $ 993,000
Grande Prairie	- $1,249,000

More detailed information on dry hole costs is given in Appendix A.

CONCEPTS FOR HEAT UTILIZATION SYSTEMS

We considered it essential that we develop certain system utilization concepts to define the type of system required up to the stage of the primary heat exchanger and to make some reasonable assessment of the applications proposed for the specific sites under study.

These included determination of adequacy of suggested pumping rates, development of realistic utilization factors and sizing and costing of the necessary primary heat exchanger.

These utilization concepts are outlined in the following pages. Diagrams of suggested systems are included.

We appreciate that alternate systems for heat utilization may be and likely will be developed with further investigations into the application of this source of heat.

EQUIPMENT DESCRIPTIONS AND SELECTION CRITERIA

The proposed systems utilize equipment commercially available and in common use for the specific applications. This brief description of the equipment and a comment on the performance rating is provided as back-up material.

Plate Heat Exchanger

All liquid-to-liquid heat exchangers would be of the multi-plate design. This type was chosen because it provides full counter flow heat transfer and can therefore achieve very efficient performance with approach temperatures in the order of 5°F to 10°F (2.8°C to 5.6°C). Because the temperature of the geothermal water is relatively low, it is essential that a unit with this performance be selected.

The geothermal heat installation in Paris, France, utilizes plate heat exchangers supplied by Alfa-Laval, and these would appear to have given satisfactory service.

The plate heat exchangers for removing heat from the geothermal water have been selected and priced for the operating temperatures and flows given on the flow diagram for each site-specific application. All units were priced on the basis of 316 Stainless Steel plates with gasket material to suit the application. Pressure drops through the heat exchangers were below 20 psig (137.9 KN/m^2) and in most cases 5 psig (34.5 KN/m^2).

Because plate heat exchangers are only available in specific sizes, it would be desirable on an application to investigate the cost effectiveness of several sizes for slightly different operating temperatures and flows.

Ventilation Air Heating Coils

The ventilation air heating coils would be of a commercial quality, finned tube type of heat exchanger selected for glycol to air heat transfer. In order to fully utilize the available heat in the geothermal water through effective heat exchange in the plate heat exchanger, it is necessary to limit the flow of glycol to not more than twice the flow rate of the heating water. This means that the heating coils, in most cases, require the use of a half circuit arrangement to achieve acceptable glycol velocity in the tubes. The use of turbulators in the tubes was not considered in order to keep the pressure drop low and to avoid potential start-up pumping problems in the glycol loop.

The glycol loop would be sealed after initial venting with system pressure changes accommodated by means of the expansion tank shown on the sketches.

Glycol to ventilation air heating coils have been used for many years and are finding greater acceptance recently because the danger of damage through freezing is eliminated.

Building Radiation Heaters

The radiation heating used in most buildings comes in various configurations such as baseboard heaters, force flow cabinet heaters which incorporate a fan to move air over the element, unit heaters and the reheat coils used to temper ventilation air. The common procedure is to rate these units for 200°F (93.4°C) hot water with a 20°F (11.1°C) temperature drop through the unit. To more fully utilize the geothermal heat, it would be necessary to select this unit for 190°F (87.8°C) entering water temperature with a 40°F (22.2°C) temperature drop through the unit. This would decrease the rating performance by about 30 percent, but this can be compensated for in a new building by installing larger units at nominal overall costs.

Dishwashers

Many apartment buildings and all hotels will be built with dishwashers installed. To be effective, an automatic dishwasher requires water at 180°F (82.2°C). Therefore, some of the proposed systems given on the sketches allow for domestic water to be heated to 180°F.

Domestic Water Heaters

The flow requirements for domestic hot water will vary a great deal over the course of a day. The geothermal heat would be available at a constant rate over the full day. Therefore, it would be necessary to install an adequately sized storage tank for the domestic hot water to accommodate the fluctuating demand.

In the proposed systems, a small circulating pump is shown on the flow diagrams to provide for circulation of domestic water through the heat exchanger.

Pipeline

The supply well and the injection well for the geothermal water would be located about one mile apart so the reinjected cool water would not influence the supply water temperature. A coated high pressure steel buried pipeline has been priced to connect the two wells in the closed geothermal water loop.

Down Well Supply Pump

A downhole pump will be installed in the well, at a depth to be determined by testing, to provide the necessary draw down on the formation to produce the forecast water volumes and to overcome the friction in the downhole production tubing, fittings and plate heat exchanger.

Injection Pump

For injecting the cooled geothermal water back into the original supply formation, a surface mounted pump would be used. Prices were obtained on an electrically driven multi-plunger, high pressure positive displacement pump of a type commonly used for waterflood injection systems in the oil industry.

GEOTHERMAL HEAT UTILIZATION

To investigate the technical suitability and to calculate the yearly utilization factor for heating systems designed to use the low temperature heat available from geothermal water, flow sheets for various applications have been developed and equipment selected. The flow sheets with liquid flows and temperatures are given in this report.

Geothermal heat has been considered as the principal source of heat for all applications. Basically geothermal heat would provide all the heat required with the exception of the mine air heating plant for the Saskatoon area discussed below. This decision means that the utilization factors are low and may cast unfavourable light on the value of geothermal heat utilization.

A more favourable analysis might be achieved if larger energy requirement loads were available and if systems could be designed with the "base load" heating to be provided by geothermal heat with supplementary heat from gas or oil fired boilers being required in winter for short periods of time of maximum heating demand when outside temperatures were very cold.

Long term climatic data indicates that temperatures below -10°F (-23.4°C) occurred on the average for only 25 days per season in Edmonton. If the 30 percent of the installed heating capacity required to accommodate these very low outside temperatures could be provided from other heat sources, the utilization factor for geothermal heat would be greatly improved.

The Mine Air Heating system proposed for Saskatoon is just such a case. The air volume of 200,000 CFM (94.39 m^3/second) is determined by the mine requirements. The available heat from geothermal water would only raise this volume of air from 13.6°F (-10.2°C) to the supply air temperature required of 55°F (30.6°C). Therefore, the system was designed for the use of supplementary heat from the steam heating system at times when the outside temperature was below 13.6°F (-10.2°C).

Surveys of existing buildings and past designs were undertaken to establish realistic loads for the types of application considered. There is a wide variance between different designs, and we expect this pattern will be accentuated by recent efforts towards better heat utilization in buildings. We feel the split of heating loads for the proposed systems is reasonable, but these would change for specific applications.

System flow sheets have been developed for all proposed applications and included in this report. Liquid flows and operating temperatures are shown for the maximum heat demand on the systems at the design outside temperature of -40°F (-40°C).

To develop the flow sheets, selection of all the heat transfer equipment was undertaken to assure that the systems would be practical and could be utilized should the economics permit. This was done to validate the proposed systems and to obtain realistic flow temperatures for the selection of the primary plate type heat exchanger used to extract heat from the geothermal water so that a realistic price could be included in the total capital and operating costs called for in Item 6 of the request.

Climatic data was obtained from the Edmonton office of the Atmospheric Environment Services of Environment Canada. Data on the degree F days per year to 65°F (18.3°C) and 55°F (12.8°C) were used in the calculations of the heat utilized for the full year for each application. This provided information on the percent of available heat utilized by the systems within the degree of accuracy required.

For design of a new building or the review of a specific existing building's heating systems, more detailed information on temperature changes on an hour-by-hour basis is available in conjunction with various computer software packages developed for the analysis of heating and cooling loads in buildings. The degree of accuracy provided by such analyses was not within the scope or intent of this report or in keeping with the estimates made for the proposed systems.

The thermal storage of heat is recommended and would prove of real value by levelling the hour-by-hour fluctuations in heat demand in a building.

This would be important because the geothermal heat is available at a constant rate and could not accommodate rapid changes in demand. Also, the effective use of thermal storage would permit a higher maximum load to be supplied by a geothermal source. This would enhance the economic analysis for the utilization of geothermal heat.

Pumping costs for the circulation of the geothermal water are large. Because the pumping pressure would be primarily in the form of static lift in the supply well or back pressure in the injection well, little advantage would be gained by using variable speed pumps to vary the flow in accordance with heating demand. It would be better to use thermal storage of the heat utilization system liquid so the geothermal water pumping units could be shut down for some of the day to save the pumping costs involved.

The yearly heat utilization factor has been calculated for each system proposed and for the total installation where more than one heating system is utilized for geothermal installation. The results of these calculations are given on the enclosed sheets with the flow diagrams involved.

A short description of each system and an explanation of the factors considered is necessary along with the system flow sheets.

Radiant Heating

Radiant heating is widely used in buildings to provide the heat lost from the building envelope and at outside door openings to temper any drafts of air entering the building when the doors are opened. Hot water and occasionally steam is used in a closed loop system for heating the building. In the flow diagrams, the building heating system water would be heated in a plate type heat exchanger by the geothermal water and circulated throughout the building.

Under no circumstances would we recommend that the geothermal water be circulated through the building heating systems, even though this would give a more favourable heat transfer. The geothermal water is saline in nature, and would cause rapid deterioration of standard radiant heating systems.

The proposed systems shown on the flow sheets utilize lower temperature water than normal for radiant heating systems so the heating units would have to be sized about 30 percent larger than normal practice.

Radiant heating demand varies as the outside temperature and does not provide a good yearly utilization factor.

Domestic Water Heating

The demand for domestic water fluctuates widely over the course of a day for every installation, and the total demand will vary from one type of building to another. Also, domestic water is required at different temperatures from 110°F (43.4°C) for bathrooms to 180°F (82.2°C) for kitchens and dishwashers. It has been assumed that all hotels and new higher class apartment buildings would have dishwashers installed.

Thermal storage of hot domestic water is quite feasible and economical and is necessary for the effective use of geothermal heat.

Domestic hot water is required on a year-round basis and therefore provides an opportunity for a good yearly utilization factor. We would consider the heating of domestic water as the primary consideration for geothermal heat in any building system.

Preheating of Ventilation Air

There will be a certain amount of air infiltration and exfiltration in all buildings with the volume of air being dependent on how the outer shell of the building is sealed, the exposure to wind, the pressures developed by the wind passage around the building plus the negative or positive air pressures developed in the building by stack effect and/or ventilation systems. Ventilation exhaust requirements are clearly defined by code for certain areas such as washrooms and kitchens of public buildings. All in all, there will be a substantial flow of air into and out of a building that must be heated in the passage.

In a cold climate, it is desirable for the ventilation air to be preheated and distributed throughout the building to prevent the ingress of cold air at unwanted places. In general, the total heat consumption for preheating the ventilation air for a building is the same as the heat that would be required to warm the outside air that enters the building by infiltration.

We recommend the use of preheated ventilation air for buildings because it provides a much better working condition in the occupied space. Also, much lower temperature heat can be used for preheating fresh cold outside air than is acceptable for space heating. In the proposed systems, we are able to heat ventilation air with heat as low as 145°F (62.8°C) using a hot water to glycol to air system. In several of the proposed installations, the geothermal water is first used to heat the radiant heating system water and then to heat the glycol for the preheating of the ventilation air.

We would recommend that the preheating of ventilation air is a secondary consideration in a building for the utilization of geothermal heat.

Industrial Process Heat

It would be desirable to use the available heat from a geothermal source in some industrial process with a steady year-round requirement. We investigated various potential applications but found that the industries had quantities of unused low grade heat that they have no need for or have found no economical way of using. As fuel prices increase, the energy conservation efforts will be intensified, and economical opportunities will be realized to use this waste heat from their processes.

The first priority of industry will be to utilize their own plant waste low grade heat. Geothermal heat would be a secondary consideration.

The potential for year-round utilization of geothermal heat in an industrial process justifies a continued search for a suitable application.

SITE-SPECIFIC APPLICATIONS

Included in this report are flow diagrams showing liquid flows and temperatures for various systems plus the summary sheets of the yearly heat utilization, yearly available heat and the utilization percentage. A brief explanation of each site-specific application is required.

Mine Air Heating - Saskatoon

Although the geothermal water temperature would be rather low at 115°F (46.1°C), the mine air heating application can make very good use of this heat during the winter season. The utilization factor is good because of the 24 hour per day operation and the use of auxiliary heat for outdoor temperatures below 13.6°F (-10.2°C).

Since there is no climatic data readily available for the degree days below 13.6°F (-10.2°C), it was necessary to estimate the percentage of time that the temperature would be above or below 13.6°F and therefore the length of time that the full capacity of the geothermal heat was fully utilized. To adjust for this in our total yearly heat calculations, we reduce the quantity of geothermal heat utilized by 10 percent. A computer analysis based on actual hour-by-hour temperatures would give a more exact answer, but the above should provide the order-of-magnitude results desired.

Calgary - Commercial Complex

The city of Calgary is large enough to support large-sized commercial complexes which could utilize the available heat from a geothermal installation. The analysis was made for a shopping mall with some office space included. The heat available would provide for a total complex of from 700,000 ft.^{2} (65,032 m^2) to 1,000,000 ft.^{2} (92,903 m^2). This would be a larger regional or small major shopping centre complex.

Unfortunately, the utilization factor for such a complex proved to be not too attractive because of a number of factors.

- Low weekly utilization (78 hours per week).
- Extremely high lighting loads which provide much of the space heating in many areas.
- Very low domestic water consumption.
- Low ventilation air supply temperatures to accommodate the heat release from the lights.
- Reasonable but not excessive fresh air requirements.

The very size of shopping centres required to utilize the available geothermal heat would be a deterrent to its use for such an application. There would be only a few of this large size in any city. Therefore, it was not reasonable to consider a larger complex which would use auxiliary heat in the very cold weather and/or thermal storage to achieve a better utilization factor.

This points out that, for purely commercial complexes, very large developments would be necessary to utilize geothermal heat and that in all likelihood these should be built in conjunction with residential uses in a central heating system.

Grande Prairie District Heating

The city of Grande Prairie is experiencing rapid growth but would not support the size of the commercial complex considered for Calgary. The high temperature, 230°F (110°C), of the geothermal water and its apparent availability in this area were reasons enough to try and find a worthwhile use for this heat.

The major industrial plants in this area are a pulp and paper mill and a number of wood processing plants. These are considered to have enough wood wastes to meet heating needs.

Therefore, we choose to investigate the use of a central heating system to provide the needed heat for a variety of buildings of types suitable for and likely to be built in the city of Grande Prairie. The buildings considered in the study were a hotel of about 200 beds, a commercial complex (shopping centre) of around 200,000 ft.^{2} and three apartment buildings.

The geothermal water supply temperature is high enough to provide an acceptable temperature for the water circulated in the district system. A two pipe system would be required so the return temperatures of the district heating systems could be as low as possible.

No thermal storage was considered.

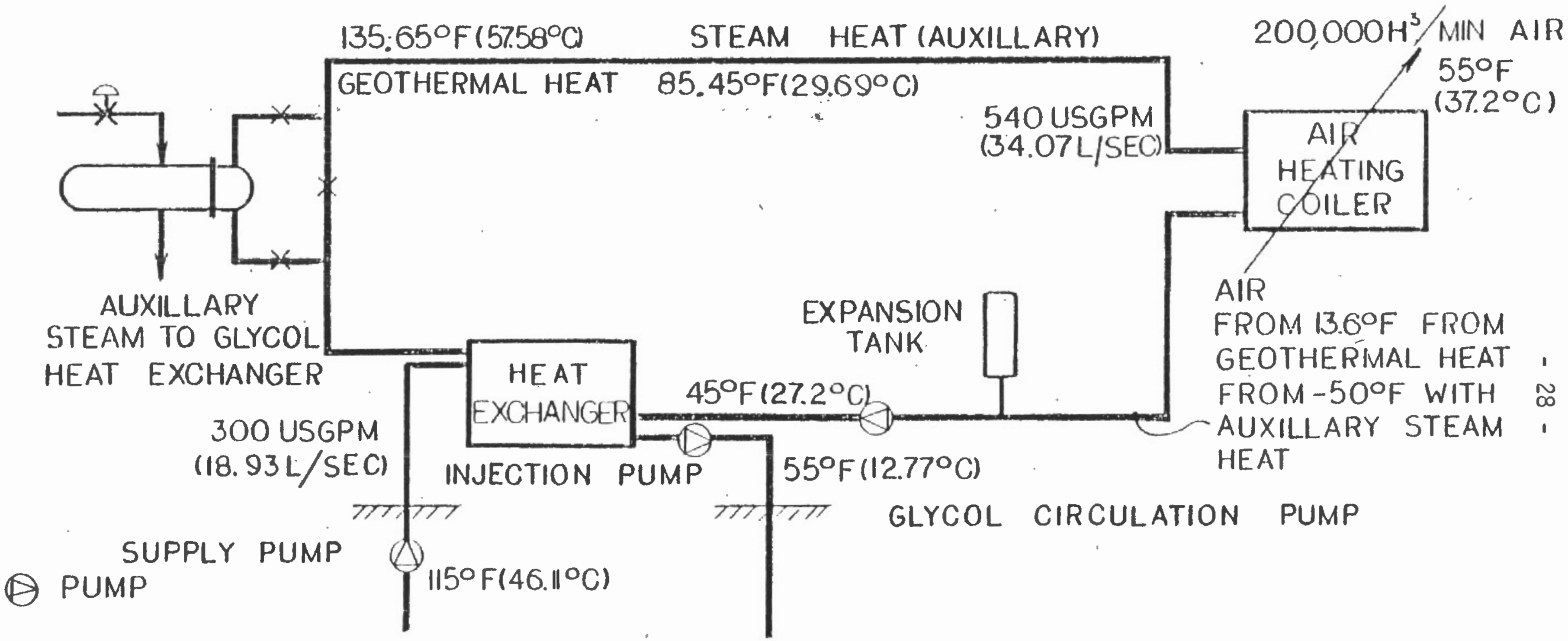
No auxiliary heat for peak load periods was considered.

If thermal storage and auxiliary heat for peak loads was considered, a larger number of buildings could be supplied and a much better utilization factor achieved.

Also, no absorption cooling for the summer months' air conditioning load was considered for the hotel and commercial complex. This would be a reasonable summer load providing the owners and designers of the building were willing to accept a much lower output from the absorption chillers due to the reduced temperature heat source.

We feel in an area with geothermal water at or above 230°F (110°C), the central heating system approach to the utilization of geothermal heat is technically attractive. The economic validity requires further detailed analysis of the potential markets for the heat. In all likelihood, this would only be acceptable with today's economics for a new green field development in a rapidly expanding city.

MINE AIR HEATING — SASKATOON



TOTAL GEOTHERMAL HEAT AVAILABLE	91.98×10^9 BTU	96.98 KJ
UTILIZED	35.458×10^9 BTU	37.38 KJ
AVAILABLE HEAT YEARLY UTILIZATION	38.55%	
TOTAL HEAT REQUIRED FOR MINE AIR	8004°F DAYS/YEAR	
GEOTHERMAL HEAT UTILIZED	6796°F DAYS/YEAR	
NEEDED HEAT YEARLY UTILIZATION	84.9%	

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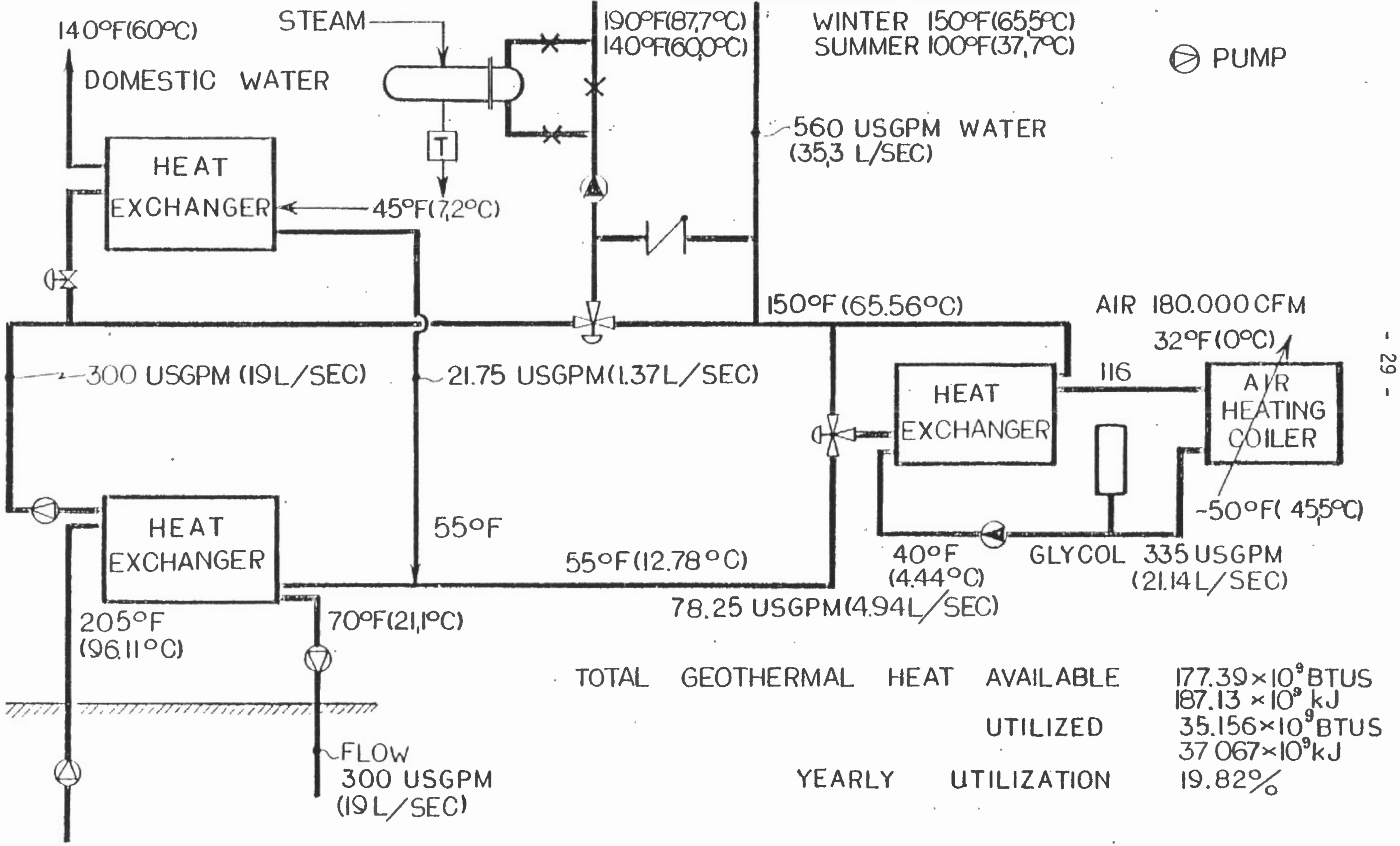
CALGARY—COMMERCIAL COMPLEX



TOTAL GEOTHERMAL HEAT AVAILABLE	177.39×10^9 BTUS 187.13×10^9 kJ
UTILIZED	35.156×10^9 BTUS $37\,067\times10^9$ kJ
YEARLY UTILIZATION	19.82%

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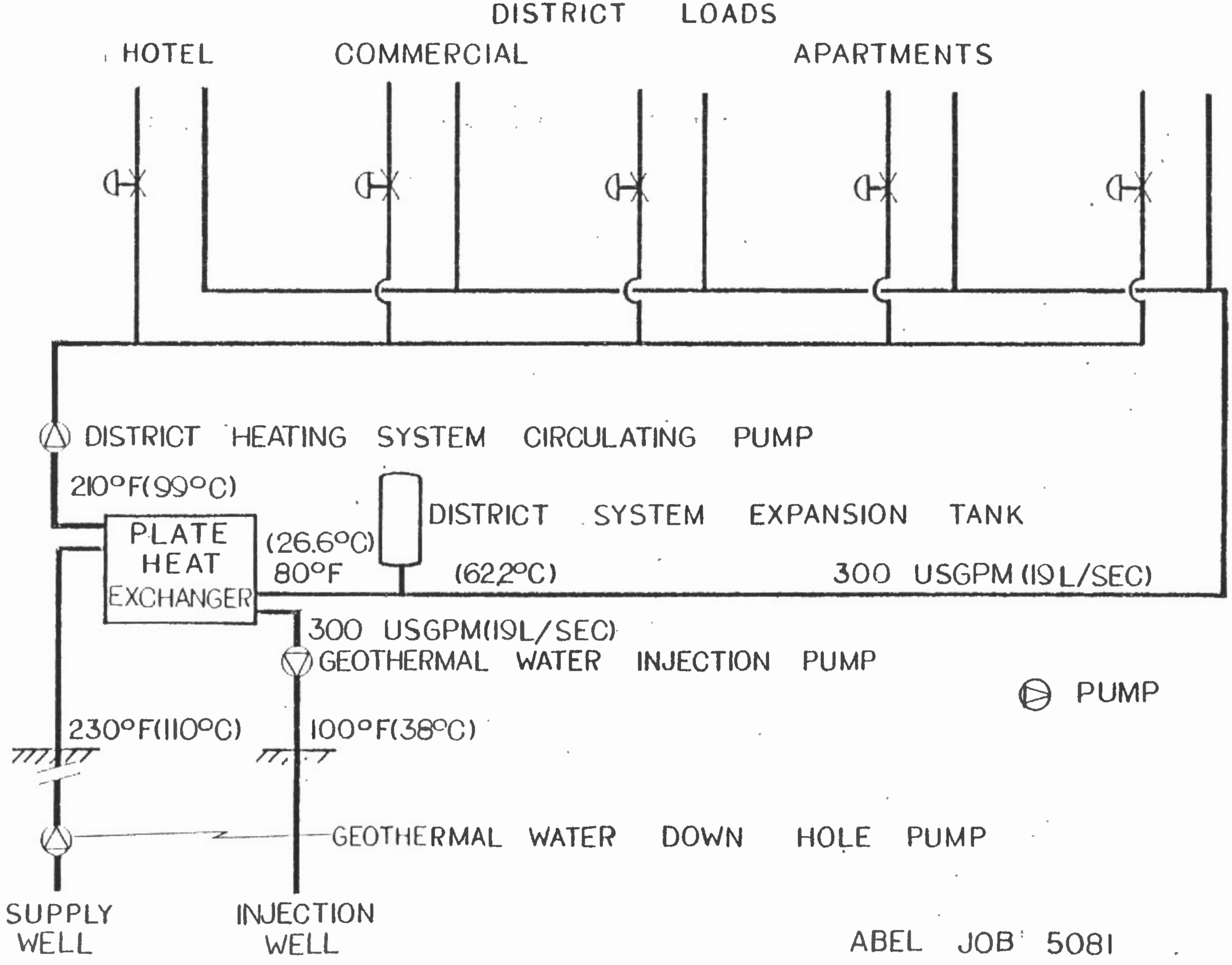
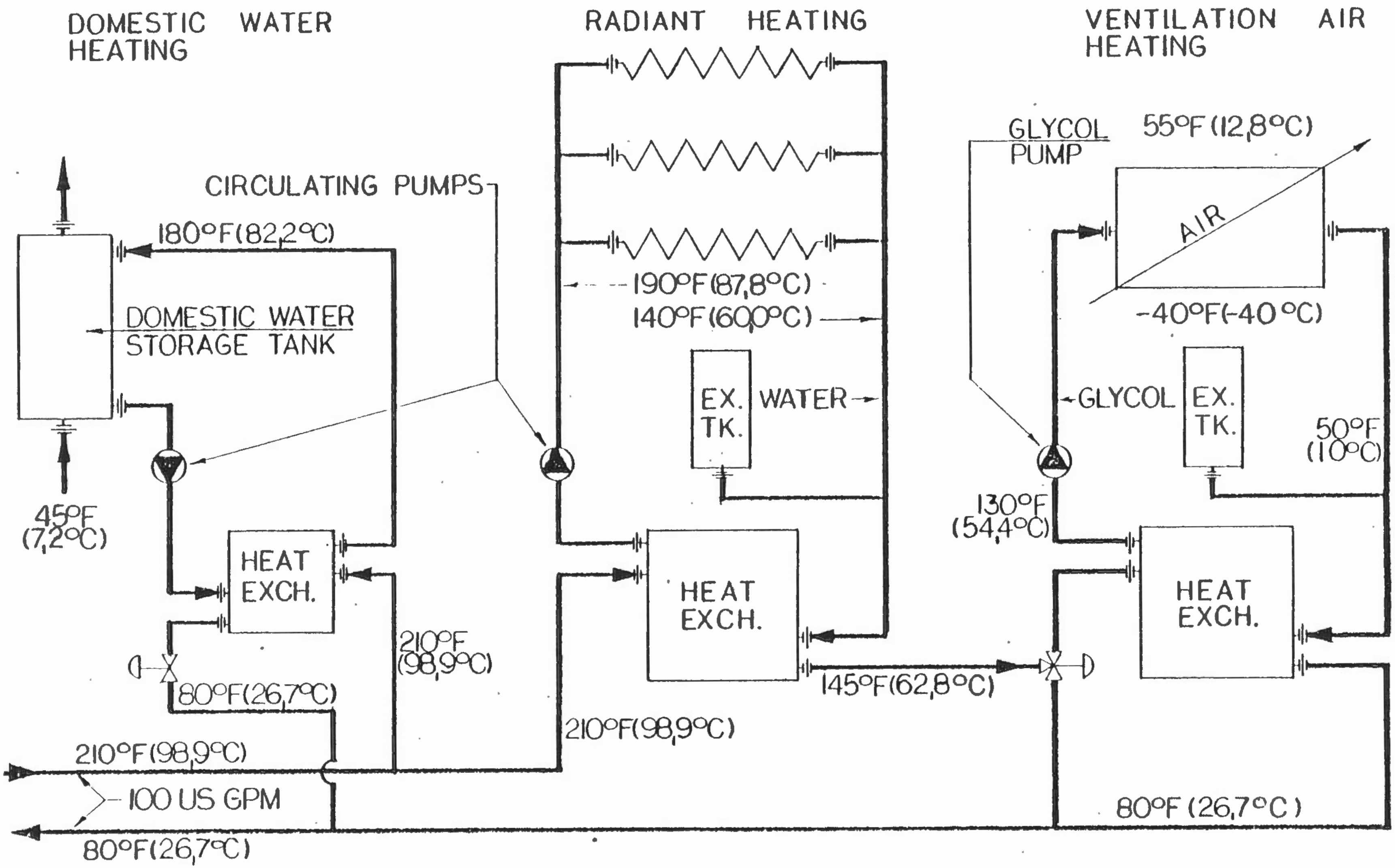
GRAND PRAIRIE DISTRICT HEATING SYSTEM



GRANDE PRAIRIE DISTRICT HEATING SYSTEM

Total Yearly Heat - Utilized			
	Hotel	24.4060×10^9 Btus.	23.624 kJ
	Commercial Building	8.5545×10^9 Btus.	9.019 kJ
	Apartment (c/w ventilation)	12.3078×10^9 Btus.	12.977 kJ
		12.3078×10^9 Btus.	12.977 kJ
	Apartment (no ventilation)	7.1006×10^9 Btus.	7.487 kJ
		62.6767×10^9 Btus.	66.084
Total Available Heat		170.82×10^9	180.104 kJ
Yearly Utilization		36.69%	36.69%

HOTEL



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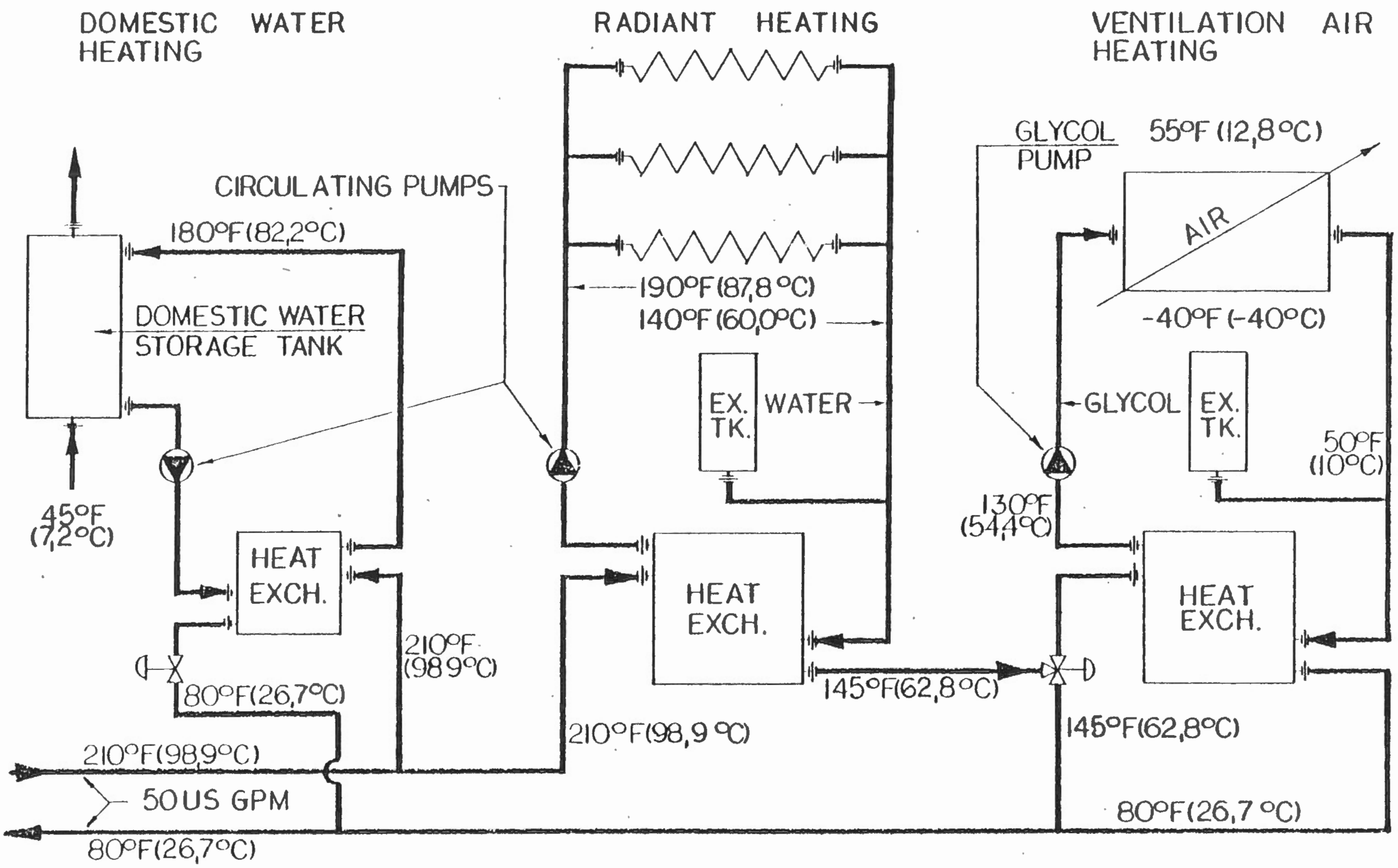
HOTEL

		Domestic Water	Radiant Heating	Ventilation Air
% Total Load		30%	35%	35%
District Heating		210°F to 80°F 98.9°C to 26.7°C	210°F to 145°F 98.9°C to 62.8°C	145°F to 80°F 62.8°C to 26.7°C
System Liquid		Domestic Water	Circulated Water	Glycol
System Temperature		45°F to 190°F 7.2°C to 82.2°C	190°F to 140°F 87.8°C to 60°C	130°F to 50°F 54.4°C to 10°C
Air Temperature		- -	- -	-40°F to 55°F -40°C to 12.8°C
Duration		Full Cacapity 12 hr/d ½ Capacity 12 hr/d	°F days to 65°F (18.3°C)	°F day to 55°F (12.8°C 16 hr/d full capacity 8 hr/d ½ capacity
Yearly Heat:	Btus.	12.811×10^9	5.787×10^9	3.808×10^9
	kJ	13.507×10^9	6.101×10^9	4.015×10^9
Total Yearly Heat:	Utilized	22.406 Btus/year	23.624 kJ/year	
	Available	56.940 Btus/year	60.035 kJ/year	
	Utilization	39.35%		

COMMERCIAL BUILDING

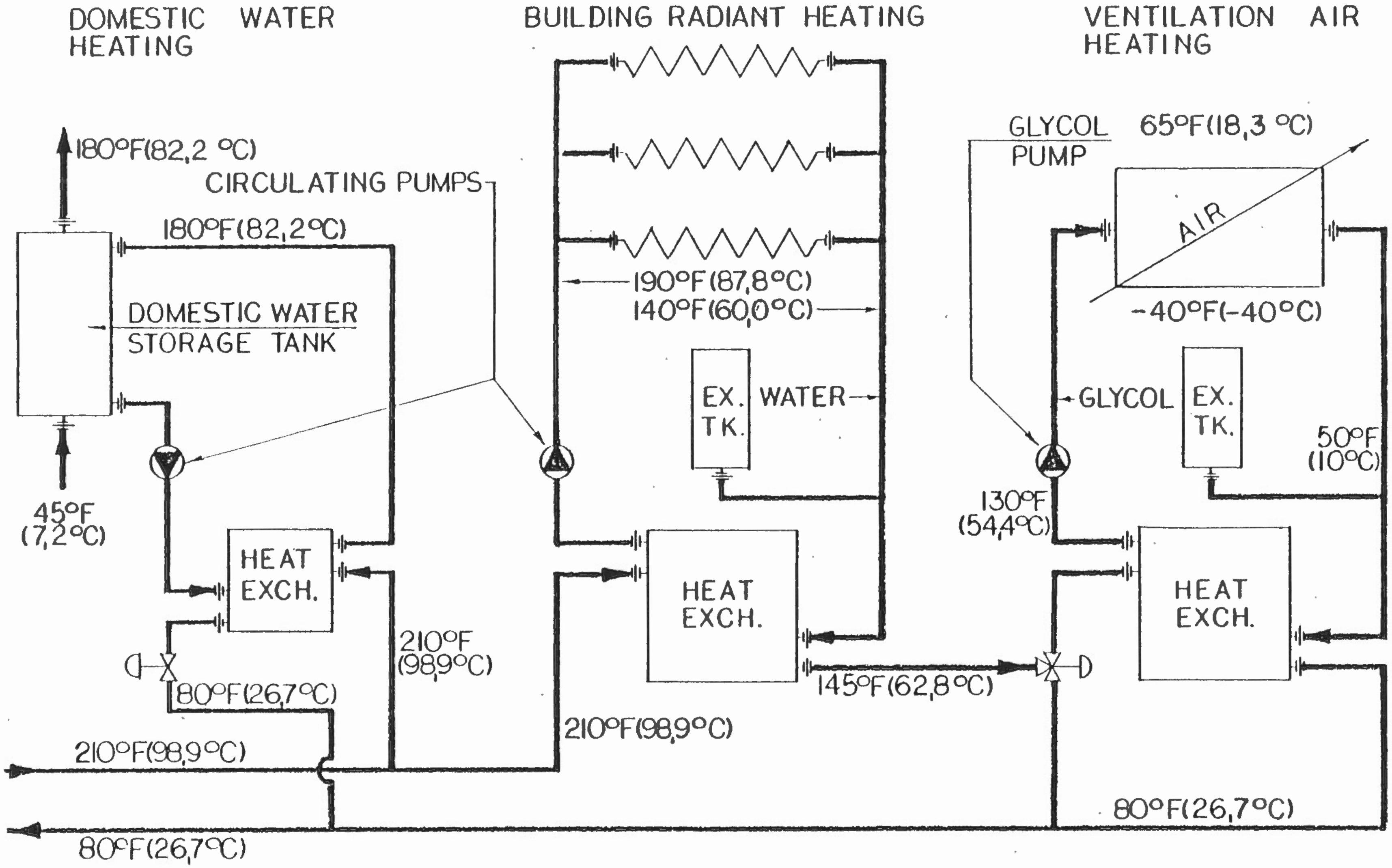


COMMERICAL BUILDING

		Domestic Water	Radiant Heating	Ventilation Air
% Load		10	45	45
District Heating		210°F to 80°F 98.9°C to 26.7°C	210°F to 145°F 98.9°C to 62.8°C	145°F to 80°F 62.8°C to 26.7°C
System Liquid		Domestic Water	Circulated Water	Glycol
System Temperature		45°F to 180°F 7.2°C to 82.2°C	190°F to 140°F 87.8°C to 60°C	130°F to 50°F 54.4°C to 10°C
Air Temperature		- -	- -	-40°F to 55°F -40°C to 12.8°C
Duration		78 hr./wk.	Degree days to 65°F (18.3°C)	78 hr./wk. Degree day to 55°F (12.8°C)
Yearly Heat:	Btus.	2.6364×10^9	3.3069×10^9	2.6112×10^9
	kJ	2.7797×10^9	3.3866×10^9	2.7531×10^9

Total Yearly Heat:	Utilized	8.5545×10^9	Btus/year	9.019×10^9	kJ/year
	Available	28.47×10^9	Btus/year	30.017×10^9	kJ/year
	Yearly Utilization	30.05%			

APARTMENT WITH VENTILATION AIR HEATING



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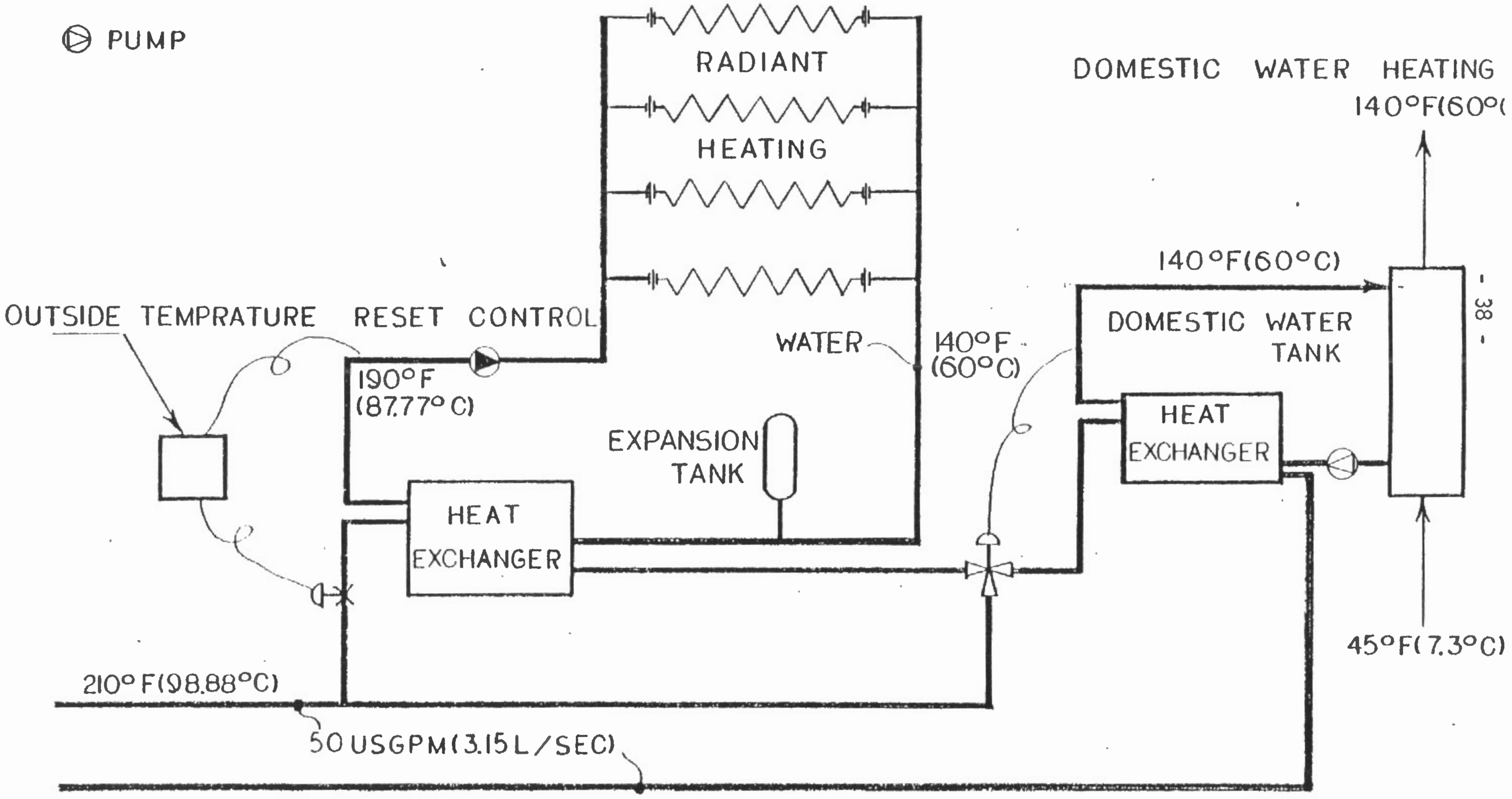
APARTMENT WITH VENTILATION AIR HEATING

		Domestic Water	Radiant Heating	Ventilation Air
% Total Load		20%	40%	40%
District Heating		210°F to 80°F 98.9°C to 26.7°C	210°F to 145°F 98.9°C to 62.8°C	145°F to 80°F 62.8°C to 26.7°C
System Liquid		Domestic Water	Circulated Water	Glycol
System Temperature		45°F to 180°F 7.2°C to 82.2°C	190°F to 140°F 87.8°C to 60°C	130°F to 50°F 54.4°C to 10°C
Air Temperature		- -	- -	-40°F to 65°F -40°C to 18.3°C
Duration/Year		365 days	Degree Days to 65°F (18.3°C)	
Yearly Heat:	Btus.	5.694 x 10^9	3.3069 x 10^9	3.3069 x 10^9
	kJ.	6.003 x 10^9	3.4866 x 10^9	3.4866 x 10^9
Total Yearly Heat:	Utilized	12.3078 x 10^9	Btus/year	12.9767 kJ.
	Available	28.47 x 10^9	Btus./year	30.0173 kJ.
	Utilization	43.23%		

APARTMENT



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APARTMENT BUILDING

		Radiant Heating		Domestic Water	
% of Load		80%		20%	
District Heating		210°F to 150°F 98.9°C to 65.5°C		150°F to 135°F 65.5°C to 52.2°C	
System Liquid		Circulated Water		Domestic Water	
System Temperature		190°F to 140°F 87.8°C to 60°C		45°F to 140°F 7.2°C to 60°C	
Duration		Degree days to 6.5°F		365 days	
Yearly:	Btus.	3.8156×10^9		3.285×10^9	
	kJ.	4.0229×10^9		3.464×10^9	
Total Yearly Heat:	Utilized	7.1006×10^9	Btus.	7.4865×10^9	kJ.
	Available	28.47×10^9	Btus.	30.0173×10^9	kJ.
	Utilization	24.94%			

APPENDIX A

PRODUCING WELL COST ESTIMATE FORM

DATE: Mar 16/81 AREA: Saskatoon FORMATION: Cambrian DEPTH: 1770 m 5800 ft. Water

REMARKS: Estimates in 1981 dollars

A.	DRILLING COSTS		
1.	Surface Costs	M $	30
2.	Footage 1770 meters at $ 9M per day x 31 days		279
3.	Mud Costs		125
4. (a)	Surface Casing 180 meters of 339.73 mm O.D.@ $98/m.		18
(b)	Cement, cementing and casing equipment 180 x 7$/m		1
5.	Coring 91 meters.		15
6.	Logging		25
7.	Drill Stem Tests: (3) tests		20
8.	Rig time for testing and logging Included above		-
9.	Supervision 31 x 600		19
10.	Other - mobilize		89
10A	Bits		14
11.	Contingencies - 20%		
	TOTAL, A		635
B.	ABANDONMENT COSTS	M $	30
	TOTAL DRY HOLE COSTS (A + B)	M $	665
C.	COMPLETION COSTS		
1. (a)	Production Casing 1770 meters of 177.8 mm O.D. x 55.00/m	M $	98
(b)	Cement, cementing, casing equipment @ 12.5 $/m		22
2. (a)	Rig time for completing well - 2 days @ 9M$/d		18
(b)	Perforating - 10 m @ 375/m		4
(c)	Acid	Est.	-
(d)	Fracturing		50
3. (a)	Wellhead		10
(b)	Tubing 1770 meters of 114.3 mm O.D. @ 15.00/m		27
4.	Supervision 4 @ 600		2
5.	Other - pump test		50
6.	Contingencies - 20%		
	TOTAL, C.	M $	281
	TOTAL, WATER WELL (A + C)	M $	916
D.	LEASE EQUIPMENT COSTS		
1.	To place well on pump - pump	M $	264
2.	Battery Cost - power facilities		55
3.	Gas Treating Equipment		
4.	Other - rig time, labour, supervision		20
5.	Contingencies - 20%		
	TOTAL, D	M $	339
	TOTAL COST OF COMPLETED WELL AND PRODUCTION EQUIPMENT (A+C+D)	M $	1,255

APPENDIX A

PRODUCING WELL COST ESTIMATE FORM

DATE: Mar. 16/81 AREA: Calgary FORMATION: Devonian DEPTH: 3,200 m 10,500 ft Water

REMARKS: Estimates in 1981 dollars

A. DRILLING COSTS		
1. Surface Costs	M$	30
2. Footage 3200 meters at $ 9.5M$ per day x 60 days		570
3. Mud Costs		82
4. (a) Surface Casing 320 meters of 339.73 mm O.D. @$98/m		32
(b) Cement, cementing and casing equipment 320 m @ 11.50/m		4
5. Coring 91 meters. @ 165/m ex rig costs		15
6. Logging		55
7. Drill Stem Tests: ( ) tests		30
8. Rig time for testing and logging Included above		-
9. Supervision 60 x 600		36
10. Other - mobilize		59
10A Bits		40
11. Contingencies - 20%		
TOTAL, A		953
B. ABANDONMENT COSTS	M$	40
TOTAL DRY HOLE COSTS (A + B)	M$	993
C. COMPLETION COSTS		
1. (a) Production Casing 3200 meters of 177.8 mm O.D. @$55/m	M$	176
(b) Cement, cementing, casing equipment @ 20 $/m		64
2. (a) Rig time for completing well 2 days @ 9.5 M$/day		19
(b) Perforating		4
(c) Acid	)	
(d) Fracturing	)	100
3. (a) Wellhead		10
(b) Tubing 3200 meters of 114.3 mm O.D. @ $15/m		48
4. Supervision 4 days @ $600/day		2
5. Other - pump test		50
6. Contingencies - 20%		
TOTAL, C.	M$	473
TOTAL, WATER WELL (A + C)	M$	1,426
D. LEASE EQUIPMENT COSTS		
1. To place well on pump - pump	M$	296
2. Battery Cost - power system		55
3. Gas Treating Equipment		-
4. Other - rig time, labour, supervision		20
5. Contingencies - 20%		
TOTAL, D	M$	371
TOTAL COST OF COMPLETED WELL AND PRODUCTION EQUIPMENT (A+C+D)	M$	1,797

APPENDIX A

PRODUCING WELL COST ESTIMATE FORM

DATE: Mar 16/81 AREA: Grande Prairie FORMATION: Devonian-Cambrian DEPTH: 3,350 m 11,000 ft Water

REMARKS: Estimates in 1981 dollars

A.	**DRILLING COSTS**		
1.	Surface Costs	M$	30
2.	Footage 3350 meters at $ 10M per day x 75 days		750
3.	Mud Costs		136
4.	(a) Surface Casing 335 meters of 339.73 mm O.D. @$98/m		33
	(b) Cement, cementing and casing equipment 335 m @ $12/m		4
5.	Coring 91 meters. @ 165.00/m ex rig costs		15
6.	Logging		51
7.	Drill Stem Tests: ( ) tests		30
8.	Rig time for testing and logging Included above		-
9.	Supervision - 75 days @ $600/day		45
10.	Other - mobilize		64
10A	Bits		41
11.	Contingencies - 20%		
	TOTAL, A		1,199
B.	**ABANDONMENT COSTS**	M$	50
	TOTAL DRY HOLE COSTS (A + B)	M$	1,249
C.	**COMPLETION COSTS**		
1.	(a) Production Casing 3350 meters of 177.8 mm O.D. x $55/m	M$	184
	(b) Cement, cementing, casing equipment @ 21$/m		70
2.	(a) Rig time for completing well 2 days @ 10M$/day		20
	(b) Perforating		4
	(c) Acid		-
	(d) Fracturing		100
3.	(a) Wellhead		10
	(b) Tubing 3350 meters of 114.3 mm O.D. @ 15.00/m		50
4.	Supervision 4 days @ 600/day		2
5.	Other - pump test		50
6.	Contingencies - 20%		
	TOTAL, C.	M$	490
	TOTAL, WATER WELL (A + C)	M$	1,689
D.	**LEASE EQUIPMENT COSTS**		
1.	To place well on pump - pump	M$	454
2.	Battery Cost - power system - 700 HP @ 1,000/HP		70
3.	Gas Treating Equipment		-
4.	Other - rig time, labour, supervision		30
5.	Contingencies - 20%		
	TOTAL, D	M$	554
	TOTAL COST OF COMPLETED WELL AND PRODUCTION EQUIPMENT (A+C+D)	M$	2,243

APPENDIX A

INJECTION WELL COST ESTIMATE FORM

DATE: Mar. 18/81 AREA: Saskatoon FORMATION: Cambrian DEPTH: 1770 m. 5800 ft. Water

REMARKS: Estimates in 1981 dollars

A. DRILLING COSTS		
1. Surface Costs	M $	30
2. Footage 1770 meters at $ 9M per day x 31 days		279
3. Mud Costs		125
4. (a) Surface Casing 180 meters of 339.73 mm O.D.@ $98/m.		18
(b) Cement, cementing and casing equipment 180 x 7$/m		1
5. Coring _____ meters.		
6. Logging		25
7. Drill Stem Tests: (2) tests		15
8. Rig time for testing and logging Included above		-
9. Supervision		19
10. Other - mobilize		89
10A Bits		14
11. Contingencies - 20%		
TOTAL, A		615
B. ABANDONMENT COSTS	M $	
TOTAL DRY HOLE COSTS (A + B)	M $	615
C. COMPLETION COSTS		
1. (a) Production Casing 1770 meters of 177.8 mm O.D. x 55.00/m.	M $	98
(b) Cement, cementing, casing equipment @ 12.5$/m		22
2. (a) Rig time for completing well - 2 days @ 9M$/m		18
(b) Perforating - 10 m @ 375/m	Est.	4
(c) Acid		-
(d) Fracturing		50
3. (a) Wellhead		10
(b) Tubing 1770 meters of 114.3 mm O.D.		27
4. Supervision 4 @ 600		2
5. Other - packer		10
6. Contingencies - 20%		
TOTAL, C.	M $	241
TOTAL, WATER WELL (A + C)	M $	856
D. LEASE EQUIPMENT COSTS		
1. To place well on pump	M $	194
2. Battery Cost - power facilities		55
3. Gas Treating Equipment		
4. Other - rig time, labour, supervision		20
5. Contingencies - 20%		
TOTAL, D	M $	269
TOTAL COST OF COMPLETED WELL AND PRODUCTION EQUIPMENT (A+C+D)	M $	1,125

APPENDIX A

INJECTION WELL COST ESTIMATE FORM

3,200 m
DATE: Mar 18/81 AREA: Calgary FORMATION: Devonian DEPTH: 10,500 ft. Water
REMARKS: Estimates in 1981 dollars

A.	DRILLING COSTS		
1.	Surface Costs	$	30
2.	Footage 3200 meters at $ 9.5M$ per day x 60 days		570
3.	Mud Costs		82
4.	(a) Surface Casing 320 meters of 339.73 mm O.D. @$98/m		32
	(b) Cement, cementing and casing equipment 320 m @ 11.50/m		4
5.	Coring ____ meters.		
6.	Logging		55
7.	Drill Stem Tests: (2) tests		15
8.	Rig time for testing and logging Included above		-
9.	Supervision 60 x 600		36
10.	Other - mobilize		59
10A	Bits		40
11.	Contingencies - 20%		
	TOTAL, A		923
B.	ABANDONMENT COSTS	$	
	TOTAL DRY HOLE COSTS (A + B)	$	923
C.	COMPLETION COSTS		
1.	(a) Production Casing 3200 meters of 177.8 mm O.D. @$55/m	$	176
	(b) Cement, cementing, casing equipment @ 20 $/m		64
2.	(a) Rig time for completing well 2 days @ 9.5 M$/day		19
	(b) Perforating		4
	(c) Acid		)
	(d) Fracturing		) 100
3.	(a) Wellhead		10
	(b) Tubing 3200 meters of 114.3 mm O.D. @ $15/m		48
4.	Supervision 4 days @ $600/day		2
5.	Other - packer		10
6.	Contingencies - 20%		
	TOTAL, C.	$	433
	TOTAL, WATER WELL (A + C)	$	1,356
D.	LEASE EQUIPMENT COSTS		
1.	To place well on pump	$	190
2.	Battery Cost		55
3.	Gas Treating Equipment		-
4.	Other		20
5.	Contingencies - 20%		
	TOTAL, D	$	265
	TOTAL COST OF COMPLETED WELL AND PRODUCTION EQUIPMENT (A+C+D)	$	1,621

INJECTION WELL COST ESTIMATE FORM

DATE: Mar 18/81 AREA: Grande Prairie FORMATION: Devonian-Cambrain DEPTH: 3,350 m 11,000 ft Water

REMARKS: Estimated in 1981 dollars

A. DRILLING COSTS	
1. Surface Costs	$ 30
2. Footage 3350 meters at $ 10M per day x 75 days	750
3. Mud Costs	136
4. (a) Surface Casing 335 meters of 339.73 mm O.D. @$98/m	33
(b) Cement, cementing and casing equipment 335 m @ $12/m	4
5. Coring ____ meters.	
6. Logging	51
7. Drill Stem Tests: (2) tests	15
8. Rig time for testing and logging	-
9. Supervision - 75 days @ $600/day	45
10. Other - mobilize	64
10A Bits	41
11. Contingencies - 20%	
TOTAL, A	1,169
B. ABANDONMENT COSTS	$
TOTAL DRY HOLE COSTS (A + B)	$ 1,169
C. COMPLETION COSTS	
1. (a) Production Casing 3350 meters of 177.8 mm O.D. x $55/m	$ 184
(b) Cement, cementing, casing equipment @ 21$/m	70
2. (a) Rig time for completing well 2 days @ 10M$/day	20
(b) Perforating	4
(c) Acid	-
(d) Fracturing	100
3. (a) Wellhead	10
(b) Tubing 3350 meters of 114.3 mm O.D. @ 15.00/m	50
4. Supervision 4 days @ 600/day	2
5. Other - packer	10
6. Contingencies - 20%	
TOTAL, C.	$ 450
TOTAL, WATER WELL (A + C)	$ 1,619
D. LEASE EQUIPMENT COSTS	
1. To place well on pump	$ 570
2. Battery Cost	70
3. Gas Treating Equipment	-
4. Other	30
5. Contingencies - 20%	
TOTAL, D	$ 670
TOTAL COST OF COMPLETED WELL AND PRODUCTION EQUIPMENT (A+C+D)	$ 2,289

APPENDIX B

Approximate Surface Water Pump Requirements

	Saskatoon	Calgary	Grande Prairie
Pump discharge pressure required (p. 2)	2,500	3,000	4,000
Q - b/d	10,000	5,000	10,000
Q - Usgpm	292	146	292
H HP required = $\frac{P \times Q}{1715}$	426	255	681
Pump efficiency - Est.	0.85	0.85	0.85
Input HP	501	300	801

APPENDIX B

Work Notes Regarding Pumping

	Saskatoon	Calgary	Grand Prairie
depth - ft	5,800	10,500	11,000
Q - b/d	10,000	5,000	10,000
Reservoir pressure - psia	2,535	4,000	4,500
Water density	1.1	1.1	1.1
Hydrostatic gradient - Psi/ft	0.477	0.477	0.477
Pump set depth - assumed - ft	5,300	10,000	10,500
Assumed pumping fluid level + 200'	5,100	9,800	10,300
Static back pressure on formation - psia	335	335	335
ΔP, formation to fluid level	2,200	3,665	4,165
P/I - b/d/psia drawdown	4.546	1.364	2.401
Injectivity index - as above	4.5	1.4	2.4
For Injection:			
ΔP required to inject required volume	2,222 psi	3,571	4,167
Reservoir pressure - psia	2,535	4,000	4,500
Pressure required @ perforation	4,757	7,571	8,667
Hydrostatic pressure @ TD minus 100 ft	2,717	4,961	5,200
Wellhead pressure - less friction loss in tubing	2,040	2,610	3,467
Friction loss in tubing - 4.5" Nominal (4" ID)	20#/1,000' = 116	5.5#/1,000' = 58	20#/1,000' = 220
Wellhead pressure required	2,156	2,668	3,687
Pipe - 1 mile x 6" nominal - Friction Loss - psia	16	5	16
Pump discharge pressure required ≈	2,172	2,673	3,703
say	2,500 psi	3,000	4,000

APPENDIX C

OPERATING COST ESTIMATE - SASKATOON

	$/Month
1) Power Consumption - *	
a) Submersible pump motor - 756 HP @ 13.33/HP/month	10,100
b) Surface pump motor, lights, controls, etc. 600 HP @ 13.33/HP/month	8,000
TOTAL power	18,100
2) Down hole submersible repairs - 107,000	8,900
3) Surface pump repairs - 10% of initial cost/yr	1,600
4) Well operating and monitoring cost - approx. $3,000/mo	3,000
TOTAL ESTIMATED OPERATING EXPENSES - EACH WELL	31,600

* Power Costs - Electric - ± $8,000/month for 600 HP or $13.33/HP/mo.

APPENDIX C

OPERATING COST ESTIMATE - CALGARY 2 WELLS

	$/Month
1) Power Consumption -	
a) Submersible pump motor 660 x 2 = 1,320 HP @ 13.33/HP/month	17,600
b) Surface pump motor, lights, controls, etc. 375 x 2 = 750 HP	10,000
TOTAL power	27,600
2) Down hole submersible repairs - 105,000 x 2 = 210,000/yr	17,500
3) Surface pump repairs - 10% of Cost = 0.10 (190,000 x 2)	3,200
4) Well operating and monitoring cost - approx. $3,000/mo x 2	6,000
TOTAL ESTIMATED OPERATING EXPENSES - EACH WELL	54,300

APPENDIX C

OPERATING COST ESTIMATE - GRANDE PRAIRIE

	$/Month
1) Power Consumption -	
a) Submersible pump motor 1,342 HP @ 13.33/HP/month	17,900
b) Surface pump motor, lights, controls, etc. 1,000 HP @ 13.33/HP/month	13,300
TOTAL power	31,200
2) Down hole submersible repairs - 264,000/yr	22,000
3) Surface pump repairs - 10% of Initial Cost	4,800
4) Well operating and monitoring cost - approx. $3,000/month	3,000
TOTAL ESTIMATED OPERATING EXPENSES - EACH WELL	61,000