

HEAT-PUMPING TECHNOLOGIES RESEARCH AND DEVELOPMENT IN CANADA—PAST, PRESENT, AND FUTURE

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ABSTRACT

In Canada during the past two decades a very significant level of resources has been directed towards targeted R&D activities in the area of heat pumping technologies. These activities have been conducted under separate but complementary programs operated mostly by laboratories and research centers located in government departments, universities, and power utilities, supplemented by studies and software development produced by independent research consultants. Relevant output and material generated by the various organizations have been well documented in numerous publications, including refereed papers in technical journals, conference proceedings, and reports to collaborating partners/clients. The measure of Canada's commitment to sharing of R&D information on this technology is also reflected by its consistent participation in international joint research projects (Annexes) operated by the International Energy Agency (IEA) Heat Pump Programme. Specifically over the past 20 years Canada has been involved in at least 15 Annexes covering a broad range of technical input, and has taken the lead role in three of those projects.

The results obtained and information gathered from these activities have provided a comprehensive source of knowledge and a wealth of experience to draw upon. Based on this solid foundation the ongoing R&D related effort is focused on areas of technology that are relevant to Canada, especially applications in refrigeration and ground source heat pump installations.

Key Words: *heat pump, refrigeration, refrigerant, energy efficiency, climate change*

1 INTRODUCTION

Starting in the late 1980s a program of research, development and demonstration was initiated at the National Research Council Canada (NRC) with support from Natural Resources Canada (NRCan) to explore the potential of high temperature heat pumps capable of steam generation for utilization in industrial applications, especially pulp and paper mills. Challenges involved the identification of a suitable and environmentally acceptable high temperature working fluid/oil combination capable of long-term stability under harsh operating conditions.

In 1990 NRCan's CANMET Energy Technology Centre - Varennnes (CETC-Varennnes) initiated a R&D program on advanced heat pumps (absorption and chemical systems). The R&D activities were funded by the Program of Energy Research and Development (PERD) managed by NRCan, and undertaken in partnership with several Canadian utility companies. In 1999, following NRCan's orientation to reach mid-term impact goals and make a significant market change in Canada, CETC-Varennnes initiated a major R&D and Deployment program in refrigeration, in partnership with the sector stakeholders. The program is a good example of a fully integrated effort carried out by a multidisciplinary team of research scientists, engineers and technicians.

Ground source heat pump (GSHP) system can be a rational technology choice for space heating and cooling requirements in Canada, given the seasonal temperature variations and the country's

predominately higher heating load. However the market penetration has been very low so far, impeded primarily by the often-higher initial installation costs and a lack of awareness of the benefits of the technology. These issues have been studied by various researchers in Canada and work continues to address some of these impediments by developing improved design techniques, better models for heat exchanger sizing, as well as increased monitoring of new installations to optimize performance.

Under the terms of the Montreal Protocol and subsequent Amendments adopted in the 1990s worldwide regulatory measures were implemented requiring the phase-out of ozone depleting substances including CFC and HCFC refrigerants, and accelerated target dates for elimination of CFCs were established in Canada and several other countries. The urgency of these commitments provided the impetus for the establishment of a broad based R&D strategy aimed at identifying environmentally acceptable alternative working fluids capable of providing satisfactory thermodynamic performance in refrigeration, air-conditioning and heat pump equipment. This program was in force for approximately 10 years, ending in 2000. During that time NRC provided the main focus of activity, with collaboration and additional technical expertise from partners in industry, university, and consulting organizations.

This paper contains a brief overview of the above activities related to heat pumping technologies.

2 HIGH-TEMPERATURE HEAT PUMPS

Industries such as pulp and paper and petrochemicals reject large quantities of waste hot water in the 55°C to 80°C temperature range, and typically require steam at temperatures above 120°C. Industrial high temperature heat pumps offer the potential to recover waste heat to produce low pressure steam or heat other process fluids, and in so doing can reduce the amount of energy consumed in industrial boilers or furnaces and lead to a reduction in emissions of greenhouse gases that contribute to global warming.

NRC collaborated with DuPont Canada and NRCan to design, construct and test a prototype steam generating heat pump (SGHP) test facility. The SGHP was a single stage vapour compression type system with an output capacity of about 45 kW. The heat pump package contained a reciprocating compressor driven by an electric motor, and a shell and tube type evaporator and condenser. The heat source was provided by a hot water loop with the temperature controlled in a range of 55°C to 70°C. Saturated steam was produced in the 102°C to 135°C temperature range. At that time R-123 was selected as the heat pump working fluid, in combination with a synthetic hydrocarbon lubricating oil (Mobil SHC-234). A complete description of the test facility, testing procedures and results were reported (Linton and Smale 1991).

The basic objective of the test program was to establish the feasibility of using R-123 as a high temperature heat pump working fluid. The related research and development tasks included:

- (i) evaluation of the long term stability of refrigerant R-123 and synthetic lubricating oil Mobil SHC-234 under high temperature operating conditions
- (ii) provision of actual heat pump performance data for various operating conditions
- (iii) establishment of the durability of heat pump components during high temperature operation
- (iv) identification of design changes and operating problems on the test facility prior to potential construction of an industrial scale unit

Tests conducted over 7012 hours of operation up to a maximum refrigerant discharge temperature of 153°C showed that R-123 and SHC-234 oil remained stable in contact with the materials normally found in industrial heat pumps. Periodic chemical analysis of refrigerant and oil samples showed no signs of contamination, oxidation, or any other types of deterioration. Example results showed a coefficient of

performance (COP) of 4.2 for a typical refrigerant temperature lift of 56°C, going down to COP of 2.9 for refrigerant temperature lift of 77.6°C. It was observed that the COP could be improved by optimizing the design for a specific operating condition, and by selecting a correctly sized compressor drive motor.

3 GROUND-SOURCE HEAT PUMPS

3.1 Software Development

GS2000 is a software program developed by Caneta Research Inc. for sizing of in-ground heat exchangers for ground source heat pumps. Development work on GS2000 began in 1991, when it became clear that many existing methods for sizing resulted in oversized heat exchangers by as much as 90% (ASHRAE Transactions –NY-91-17-5). As the capital cost of ground-source systems is highly sensitive to the length of trench or borehole required, industry design methods needed to be more accurate than those reported. Heat transfer between the ground and a buried heat exchanger is a very difficult process to model. The model needs to predict how soil thermal properties, soil density, soil moisture content, soil temperature distribution, heat exchanger material, pipe diameter, heat exchanger fluid properties, fluid film resistance all affect the performance of the heat exchanger. A method published by the National Water Well Association (NWWA) involved the cylindrical heat source solution to the heat conduction equation. This approach accounted for some of the important parameters and also involved fewer simplifying assumptions than the existing industry methods and was chosen as the basis of the algorithm for GS2000. With funding support from NRCan, Version 1 became available in 1995. This version was capable of sizing both vertical and horizontal heat exchangers. More than one ground layer for vertical heat exchangers could be specified, and the thermal properties of a number of pre-defined soil/rock types could be included. Ground temperature thermal data needed by the program was provided for 129 locations in North America.

By 1996, it became evident that a new version of GS2000 was needed, as there had been a number of advances in the industry in heat exchanger design and installation procedures. Improvements in Version 2 included the ability to model helical spiral (slinky) heat exchangers, supplemental heat rejecters (i.e. cooling towers), multiple borehole fields, and the effects of grouting on heat transfer. This version also had the capability to account for building peak load impact on heat exchanger sizing, plus a number of other improvements. GS2000 measured up well in a comparative model evaluation/validation exercise undertaken by Oak Ridge National Laboratory in 1999 and 2000 (Shonder 2000). The comparison tested six computer models and compared them for accuracy and consistency against benchmarks based on calibrated simulation models.

By 2000, under license to NRCan, Caneta had distributed over 200 copies of Versions 1 and 2 to engineers and others throughout Canada and the US. The program is now freely available and can be downloaded from the Internet site of NRCan's CANMET Energy Technology Centre-Ottawa (CETC-Ottawa).

3.2 GSHP Development and Demonstration

Work in this area has been undertaken mostly by research groups affiliated with electric utilities in Canada. With electric baseboard heating being used in over two million homes in Canada the option of replacement with GSHP systems offers the opportunity for flattening of the utility's electrical loads and improved demand management with a steadier electrical throughput in the transmission lines. The consumer also benefits from having a reliable alternative heat source and low operating costs.

3.2.1 Ontario Hydro

Stimulated by the above motivation Ontario Hydro was previously a very active player in this area, and between 1991 and 1994 an estimated 6,700 residential GSHPs were installed in the province under the Ontario Hydro Power Saver Heat Pump Program (Caneta 2004). The Program involved co-operative efforts between the Canadian Earth Energy Association (CEEAA), the federal and provincial government and Ontario Hydro to improve product performance and installation. Cash incentives, a subsidized loan and joint promotional efforts by Ontario Hydro and industry were offered. However the use of incentives attracted the involvement of some dealers/contractors who were not familiar or knowledgeable of GSHP design/installation techniques. This resulted in many warranty problems. The largest problem involved inadequate heat exchanger sizing. The CSA (Canadian Standards Association) Standard C445 required the GSHP system to meet 70% of the design-heating load (including hot water in many cases). The amount of ground heat exchanger surface was not specified. Some contractors did not properly size the ground heat exchanger - generally undersizing it - which led to lower heating capacity, reduced savings on heating, and under-performing units. Ontario Hydro claimed that about 34 MW of demand reduction had been achieved by the Program, but it was recognized that there was a need to have a longer term program strategy and a better management of the end of the Program to address warranty related issues.

3.2.2 Hydro-Québec

In the province of Québec the *Laboratoire des Technologies de l'Énergie* (LTE) at Hydro-Québec has maintained a strong activity in this area for more than 15 years, and has promoted several high efficiency technologies including heat pumps, geothermal systems, and thermal storage. The main approach of LTE has been to contribute to the development and laboratory/in-field demonstration of the most promising and efficient technologies suited to the Canadian cold climate, mostly in collaboration with different private and public partners.

In the general field of heat pumps research, LTE has actively contributed to the development and field testing of dual-energy residential heat pumps with integrated fossil back-up capabilities, an innovative exhaust air heat recovery heat pump for hospitals, and laboratory and industrial-scale high temperature heat pumps for wood drying applications.

Specifically in the area of GSHP technology applications LTE has been involved in:

- demonstration of residential, commercial and institutional buildings, containing open and closed-loop systems with horizontal and vertical conventional heat exchangers (schools, offices, hospitals, cinemas, hotels, restaurants)
- development of residential and small industrial/agricultural direct expansion, mono-fluid heat pumps with horizontal ground heat exchangers, radiant floor heating, hot water preheating and exhaust air heat recovery (pig nursery, greenhouse)
- Current LTE applied research projects are aimed at:
- developing a new, integrated GSHP heating and cooling system for the most common greenhouses sold in Canada (including floor heating, direct air cooling, heat recovery and seasonal energy storage)
- optimization of a vertical direct expansion (DX) ground source heat pump
- design strategies to reduce the total initial costs of geothermal systems

3.3 GSHP Deployment - The Canadian GeoExchange Coalition

The Canadian GeoExchange Coalition was established in 2002. It is dedicated to the creation of a large, competitive, self-sustaining market for geothermal heating and cooling systems (“geoexchange”) in both the residential and commercial HVAC markets of Canada. In this transformed market, consumers and business owners will be aware of and consider clean, renewable geoexchange technology on par with

other kinds of high-end heating and cooling systems. The Coalition has been established to achieve four primary objectives:

1. Expand the market in Canada for geoechange products and services;
2. Facilitate business development in a way that complements the participants' core business;
3. Promote the Coalition's contribution to the Canadian economy through increased sales revenues, jobs creation, and enhanced export opportunities; and,
4. Improve environmental performance, including the reduction of greenhouse gas emissions.

The Coalition has three major sets of strategies:

- Overcoming market barriers;
- Serving as a vital information source;
- Delivering value to partners and allies.

4 REFRIGERATION

Work in this area has been undertaken mostly by CETC-Varennnes (<http://cetc-varennnes.nrcan.gc.ca>) through a refrigeration program established for the supermarket, ice rink and curling sectors. These three sectors offer similar contexts, favourable to the establishment of energy efficient technologies and practices. In all three cases, the buildings are very energy intensive, present zones that are simultaneously cooled and heated, and can be heated through the recovery of the thermal energy released by the refrigeration system. Moreover, the refrigeration system contains high charges of refrigerant and offers the opportunity to be better adapted to the Canadian climate, thus resulting in substantial energy savings. CETC-Varennnes' refrigeration program aims to develop knowledge, increase expertise, build capacity and demonstrate innovative measures and practices in order to improve the energy efficiency and reduce synthetic refrigerant charges and leaks in refrigeration systems and support the Canadian industry. The program is undertaken in strong partnership with the private and public sectors to ensure innovation, as well as knowledge and technology transfer. It is the only major refrigeration program in Canada and is well balanced between research, development, demonstration, and deployment activities.

The deployment program, the Refrigeration Action Program for Buildings (RAPB), is funded by the Canadian Climate Change Action Plan and is carried out in partnership with refrigeration stakeholders (consultants, manufacturers and associations), utilities and provincial organizations. This deployment program has the potential of reducing the energy consumption by 1755 GWh eq./year and the greenhouse gas (GHG) emissions by 1.6 Mt eq. CO₂/year in ice and curling rinks and supermarkets in Canada by 2012. The activities aim at increasing the capacity in the sector in order to reduce the energy consumption as well as the synthetic refrigerant charges and leaks of supermarkets, ice and curling rinks. This is accomplished by providing stakeholders with tools and knowledge to better design and operate new integrated Heating, Ventilation, Air Conditioning & Refrigeration (HVAC&R) systems and to retrofit the existing ones.

As per the demonstration activities, 8 projects are currently underway: 7 ice rinks and one supermarket. A second supermarket showcase is under way and should be done by the end of 2005. The main common characteristics of these projects are the adoption of energy efficient and environmentally sound technologies as well as the integration of the HVAC with the refrigeration system (thermo-frigo-pump).

CETC-Varennnes' R&D program in refrigeration aims to develop scientific knowledge and innovative technologies, to increase expertise in refrigeration and to support the deployment program. This program is carried out in collaboration with the Universities of Sherbrooke (THERMAUS group) and Concordia (Building Department). These three institutions established a collaborative partnership for R&D activities four years ago and have since been working together on research projects on ice rinks and

supermarkets. Among these collaborative activities we can mention a research contract awarded by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) to develop and verify methods for determining ice sheet cooling loads as well a 3 year funding for a research project (Development of tools for the design and operation of ice rink HVAC&R systems) granted by NSERC (Natural Sciences and Engineering Research Council of Canada). CETC-Varennnes has also participated in the IEA Annex 26 (Advanced Supermarket Refrigeration/ Heat Recovery Systems).

The R&D program has three main activity areas:

- Energy efficiency improvement;
- Synthetic refrigerant charge reduction;
- Adaptation to Canadian climatic conditions.

In order to carry out these activities CETC-Varennnes has a well-instrumented testing facility (3 test-benches in operation as well as calorimetric and psychrometric chambers) that allows the execution of tests in accordance with ASHRAE standards. It has also a calibration laboratory and a computing center (state of the art computers and software programs like PHOENICS, TRNSYS, DOE2.1).

4.1 Energy Efficiency Improvement

The main activities in this area are the development and validation of simulation and design tools for ice rink buildings and innovative refrigeration systems.

Two ice rink simulation tools have been developed and have been continuously improved: a DOE2.1 energy analysis model and a Computing Fluid Dynamics (CFD) model. A third one has been developed using TRNSYS and is being validated presently.

In order to develop the DOE 2.1 model for ice rinks, some changes had to be introduced in the original DOE2.1 code and new algorithms have been incorporated to it: ice load, chiller and pumps, heat recovery, domestic hot water, hot and cold storage systems. The model was validated with data from an ice skating ice rink commonly found in Québec. Eight fact sheets presenting the influence of new practices and technologies on the building overall energy consumption were developed, based on simulations carried out for a typical ice rink

A 2-D CFD model (PHOENICS) aimed at understanding and optimizing thermal and air flows in ice rinks have been developed and validated. The validation was carried out with data from field measurements performed at an ice rink in the Montreal region. A new version (3-D) is under development. One of the major scientific contributions of this activity is the detailed radiation module that has been developed and integrated to the CFD code. A sensitivity analysis has been conducted with the last version of the model and new fact sheets and energy efficiency guidelines are being developed.

A well instrumented ice rink prototype has also been built in order to help validate the model and get a better understanding of the heat and mass transfer phenomena that take place between the air and the ice. The prototype is functional and tests have been performed since October 2004.

As per the innovative refrigeration systems, a lot of effort has been deployed in order to better understand and improve the efficiency of ejectors. The use of an ejector to produce a refrigeration effect has the objective of either replacing the compressor or supplementing it in refrigeration systems in order to improve their performance, whenever a thermal source is available to activate the ejector. This heat source can for instance be waste heat from compressor superheat production if cycle optimization is being dealt with, or free rejected heat from an industrial process if we are in an industrial plant. In this respect 1-D ejector and cycle modeling for design and accurate operation analysis has been performed. The results were encouraging as for the potential of this technology. This has prompted further activity in this area, namely:

- CFD modeling for a fundamental investigation of the flow structure, an essential element in the optimization of geometry and mixing for performance maximization (Bartosiewicz et al. 2003; Ouzzane and Aidoun 2003; Aidoun and Ouzzane 2004)
- Building of a test bench for ejector testing and operation. The test bench should be ready by the end of 2005.

4.2 Synthetic Refrigerant Charge Reduction

The use of secondary loops on the hot (condenser) and on the cold (evaporator) sides of the refrigeration system allows for up to 90% reduction of the total synthetic refrigerant charge and leaks in supermarkets. With increased concerns about the impact of refrigerant leakage on global warming, new supermarket refrigeration system configurations requiring significantly less refrigerant charge are being considered. Most of the cold secondary loops currently found in supermarkets use brines or propylene glycol as a fluid. The drawback of the use of these fluids is the high energy consumed by the circulation pumps as well as the cost and space taken by the piping. The adoption of phase changing fluids like CO₂ and ice slurries in secondary loops can help overcome these weaknesses due to their high energy density.

CTEC-Varennnes has designed and built a secondary refrigeration loop that uses CO₂ as a changing phase, moderate pressure transport fluid. This will permit data collection and expertise development on the use and behavior of this fluid as a natural, environment friendly alternative to the currently encountered fluids and brines in the refrigeration industry. At this stage of development:

- The test bench is completed and running. The test bench has been designed in such a way that sufficiently large operation intervals can be experimented in order to broaden the amount and quality of data necessary for future developments.
- The design and simulation models for evaporators, condensers and heat exchanger operating with CO₂ have been developed (Aidoun and Ouzzane 2004) and simulations for supermarket operation have been performed.

4.3 Adaptation to Canadian Climatic Conditions

Most of the refrigeration systems used in commercial buildings in Canada are not optimized for the Canadian climate. These systems work at an almost constant condensing temperature all over the year and do not take advantage of the available (and free) cold.

CTEC-Varennnes has designed and built a refrigeration test bench to evaluate new refrigeration technologies (Ouzzane et al. 2003) and to adapt them to Canadian climatic conditions. A detailed simulation model of the test bench has also been developed and validated.

Currently the research team is working in the development of new control strategies aimed at the reduction of the energy consumption, as well as the improvement of the capacity and reliability of the refrigeration systems. Among these strategies we can mention the development of a control algorithm for electronic expansion valves. The algorithm has been validated experimentally under a wide range of condensing temperatures and its performance compared against thermostatic expansion devices.

5 ALTERNATIVE REFRIGERANTS

Under the terms of the Montreal Protocol all CFCs were phased out in the industrially developed countries at the end of 1995. HCFC refrigerants have a lower Ozone Depletion Potential (ODP) and were proposed as interim substitutes for CFCs in some applications. However, a freeze in consumption of HCFCs occurred in 1996, and a complete phase-out was set for 2020 in Canada. Also affecting the refrigeration and air-conditioning industry at that time the Canadian Energy Efficiency Act of 1992 regulated the minimum energy efficiency of products. Equipment operating with alternative refrigerants

needed to be energy efficient and provide satisfactory thermodynamic performance, as well as meeting stringent restrictions on ozone depletion, global warming, toxicity, and flammability.

To address these issues a coordinated R&D program was established at the national level, with NRC taking the lead technical role in collaboration with various industrial partners. Additional funding support was provided by Environment Canada and the Program on Energy Research and Development (PERD), and through a joint funding agreement with refrigerant manufacturer ICI Klea.

5.1 Joint Research Program

The specific objective of the Program was the evaluation of alternatives to CFC and HCFC refrigerants for systems and equipment required to operate with acceptable energy efficiencies. For selected fluids this included establishing thermodynamic performance capabilities, heat transfer characteristics, thermophysical properties, fluid stability, lubricants compatibility, etc. NRC had test facilities that were well suited to experimental measurements and evaluation of the above properties for alternative refrigerants.

Early testing work in the program investigated the performances of HFC-152a and HFC-134a as potential substitutes for CFC-12. A typical set of results showed very similar refrigerating capacities for all three refrigerants over the temperature range covered, but higher Coefficients of Performance (COPs) for HFC-152a (Snelson et al. 1991). However, despite its advantageous thermodynamic properties, HFC-152a carried a small risk of flammability, which ultimately ruled it out, and HFC-134a was adopted as the long-term replacement for CFC-12 in these applications.

The majority of the work carried out under the program involved the performance testing of various refrigerant blends being proposed by different refrigerant manufacturers as potential long-term replacements for R-502 and HCFC-22. Most of the blends were mixtures of three components combined in specific concentrations to form a zeotropic refrigerant. Two sets of alternatives were investigated in detailed sub-programs:

In the case of R-502 a systematic series of tests was conducted on three alternative refrigerant blends: R-404A, R-407A, and R-507. An existing commercial scale low temperature R-502 refrigeration plant was extensively instrumented and adapted as a special purpose test facility. Performance tests were carried out under controlled conditions at different condensing temperatures and over a range of evaporating temperatures. Polyol ester oil was used with each of the test refrigerants. Typical test results indicated that the overall system capacities and COPs for each of the three blends were somewhat lower than those for R-502 (Hearty et al. 1996). In a follow-up series of tests the effects of temperature glide in counter-flow heat exchangers were investigated for the two zeotropic blends (Triebe et al. 1996). Overall it was concluded that all three of the refrigerant blends were acceptable alternatives to R-502.

Two zeotropic blends R-407C and R-410A were the primary alternatives proposed as replacements for R-22 in air-conditioning and heat pump applications. Performance comparison testing was carried out using a 10.5 kW residential central heat pump and a 10.5 kW air-conditioner. The test units were set up within controlled-environment and performance evaluations were conducted using the relevant Canadian Standards Association (CSA)/Air-Conditioning and Refrigeration Institute (ARI) rating conditions. Polyol ester oil was used in all tests with R-22 and both refrigerant blends. Typical test results in the case of the heat pump showed that the capacities, energy efficiency ratios (EERs) and COPs for R-407C were all lower compared to R-22, but the corresponding performances of R-410A were all higher (Linton et al. 1997). Results from these and other tests clearly indicated that R-410A would have the best performance. However the operating pressures for systems using R-410A are approximately 50% higher than for R-22, implying major redesign of an R-22 system is required for optimal utilization. Thus it was concluded that R-410A would be the most likely choice for a new system properly designed to take advantage of its

characteristics, whereas R-407C would be preferred for utilization of existing R-22 equipment with minimal changes.

5.2 Expert Panel

In May 1995, the Canadian Council of Ministers of the Environment endorsed a series of recommendations to strengthen Canada's ozone layer protection program. This resulted in Environment Canada setting up the first Expert Panel to review alternatives to the use of CFCs and HCFC-22, and to provide guidance on how to facilitate the development or introduction of such alternatives to the Canadian market. The panel was composed of two NRC staff members and two private sector consultants with special expertise in that area of technology.

Input and suggestions were obtained from a broad cross-section of stakeholders in Canada regarding possible replacements for CFC and HCFC-22 refrigeration, air-conditioning and heat pump equipment in the residential, commercial/automotive and industrial/transportation sectors. For each sector a matrix of base cases and corresponding possible alternatives was established. Base cases considered equipment operating with CFCs or HCFCs. The alternatives included zero ODP refrigerants such as HFCs and natural refrigerants (e.g. hydrocarbons) operating in conventional electric-driven vapour compression systems, as well as not-in-kind technologies such as absorption, engine-driven systems, etc.

The performances of base cases and possible alternatives were compared using the Total Equivalent Warming Impact (TEWI) analysis technique, which determines the overall contribution to global warming for the particular equipment over its operating lifetime. The analysis was conducted for five cities representing different climatic regions across Canada. Promising alternatives emerging from the TEWI analysis were reviewed for technical and economic feasibility and for potential barriers to implementation, such as health and safety issues. The results were found to vary with location in Canada, as the indirect component of TEWI depends strongly on the specific electricity generation mix. Complete results from this analytical study are contained in three separate reports (Expert Panel 1999, 2000).

6 RETSCREEN INTERNATIONAL CLEAN ENERGY PROJECT ANALYSIS SOFTWARE

The *RETScreen International Clean Energy Project Analysis Software* (<http://www.etscreen.net>) is an innovative and unique energy awareness, decision support and capacity building tool developed by CETC- Varennes, with the contribution of over 150 experts from industry, government and academia. The use of RETScreen significantly reduces the cost and increases the precision of pre-feasibility studies and contributes to the formulation of more fully informed decisions prior to project implementation. In addition to the software, the tool includes product, cost and international weather databases; an online manual; a case study based college/university-level training course and electronic textbook; and an Internet-based Marketplace. All of these are available free, in both English and French, at the RETScreen Website (see bibliography). For those with limited or no Internet access, all the materials are also available on CD-ROM.

RETScreen now has more than 53,000 users in 200 countries around the world and is growing at 250 new users every week.

6.1 RETScreen Ground-Source Heat Pump Project Model

The *RETScreen Ground-Source Heat Pump Project Model* can be used world-wide to easily evaluate the energy savings, life-cycle costs and greenhouse gas emissions reduction for the heating and/or cooling of residential, commercial, institutional and industrial buildings. The model can be used to evaluate both retrofit and new construction projects using either ground-coupled (horizontal and vertical closed-loop) or groundwater heat pumps.

6.2 RETScreen Combined Heat and Power (CHP) Project Model

The *RETScreen Combined Heat and Power (CHP) Project Model*, which includes various heat pump technologies, can be used to evaluate any one or combination of the following applications: power; heating; cooling; single buildings or multiple buildings; industrial processes; communities; district heating and district cooling.

Further, it permits analysis with a wide range of renewable and non-renewable fuels (which can be used in parallel), including landfill gas; biomass; bagasse; biodiesel; hydrogen; natural gas; oil/diesel; coal; municipal waste, etc.

Finally, these fuels can be evaluated using multiple types of power, heating and/or cooling equipment, including reciprocating engines; gas turbines; gas turbine combined cycle; steam turbines; geothermal; fuel cells; micro turbines; boilers, compressors, absorption chillers, heat pumps, etc., all working under various operating conditions (base load, intermediate load and/or peak load).

6.3 RETScreen Refrigeration Project Model

The *RETScreen Refrigeration Project Model*, currently under development, can be used to evaluate energy efficient refrigeration systems for commercial and institutional buildings, such as grocery stores, skating ice rinks, curling rinks and food storage facilities. For example, it is possible to provide all of the heating needs of these types of buildings, including heat for occupied spaces, ventilation air and feed water, by recovering heat rejected from refrigeration systems. The new *Refrigeration Project Model* will be released in mid-2005.

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