Impact on Implementation of Retrofit Measures By Including Infrared Thermography in Energy Auditing

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ABSTRACT

Energy auditing of existing buildings, e.g., the EnerGuide for Houses in Canada, especially under the impetus of utility companies and government agencies, is becoming widespread. It has been noticed, however, that recommendations from such audits regarding the building envelope are either nonexistent or not implemented by building owners. A pilot project including various types of buildings, i.e., 22 single-family houses, 8 multi-unit residential buildings, and 15 commercial and institutional buildings, was developed to evaluate the impact of including an infrared thermographic analysis to the traditional energy efficiency auditing in terms of implementation of recommended measures and identification of additional energy savings.

The two main technical aspects of the project aimed at evaluating:

- *the additional potential energy savings resulting from an increased motivation of the building owners or managers to reduce building envelope heat losses following the infrared analysis compared to their motivation following a traditional energy efficiency audit and*
- *the efficiency of infrared thermography to target energy efficiency measures compared to the targeted measures resulting from traditional energy efficiency audits.*

This paper presents the criteria used for building selection, the protocol developed for the infrared thermography analysis, the interviews, and analysis of the energy impact of recommended measures. The results of the study present the added value brought by the use of thermographic analysis in terms of added energy savings vs. cost of measures. The latest results indicate that the extra cost of adding thermography is counterbalanced by the efficiency of thermography to detect weak points in the envelope and to convince owners of the energy savings potential. This program was developed and supported by the Energy Efficiency Fund, whose mandate is to promote energy efficiency among buildings heated by natural gas.

INTRODUCTION

Energy auditing of existing buildings, e.g., the EnerGuide for Houses program of Natural Resources Canada, especially under the impetus of utility companies and governmental agencies, is becoming widespread. It has been noticed, however, that recommendations from such analysis regarding the building envelope are either nonexistent or not implemented by building owners. A pilot project including various types of buildings, i.e., 22 single-family houses, 8 multi-unit residential (MUR) buildings, and 15 commercial and institutional (C&I) buildings, was developed to evaluate the impact of including an infrared thermographic analysis to the traditional energy efficiency audit in terms of implementation of recommended measures and identification of additional energy savings.

All buildings included in the project had already been the object of a traditional energy audit, through subsidized programs of the Quebec government's Energy Efficiency Agency, the federal government's Energy Efficiency Office, or

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the main provincial gas utility. Interviews on the implementation of the recommendations from this first analysis were conducted with building owners. The thermographic analyses were performed from February to early April 2002 and from late December 2002 to early April 2003. The analysis of the energy impact of the measures recommended based on the thermographic analysis and a second round of interviews were performed in the fall of 2003. Compilation of all data was completed between January and March 2004.

OBJECTIVES

The project objectives were to evaluate:

- the additional potential energy savings resulting from an increased motivation of owners/managers to reduce building envelope heat losses following the infrared analysis, compared to their motivation following a traditional energy efficiency study; and,
- the efficiency of infrared thermography to target energy efficiency measures compared to the targeted measures resulting from traditional energy efficiency audit.

METHODOLOGY

Building Selection

Eligible buildings were selected from various types: single-family, multi-unit residential, commercial, and institutional. To be eligible, buildings had to use gas for space heating and had to have been the object of a traditional energy audit. For participation in this project, priority was given to buildings for which

- the gas consumption for space heating seemed high;
- a history of energy consumption covering an adequate period was available;
- the energy efficiency study had been realized using an energy consumption simulation model (such as HOT2XP or EE4); and
- it was expected that the building envelope provided a minimum degree of airtightness.

The selection of the buildings was done independently of their location on the natural gas provider distribution grid.

Data Sources

Four sources of information were used in the project, namely,

- the results of the traditional energy efficiency analyses of the selected buildings, including the input data of the software simulations;
- the results of interviews with the owners or managers of the selected buildings, before and after the infrared thermographic analysis;
- the results of the infrared thermographic analyses;
- the energy consumption of the selected buildings in the year preceding the traditional energy efficiency audit.

The collected data were input into a database, using the software Access.

Traditional Energy Efficiency Studies. Traditional energy efficiency studies were obtained for every building of the projects. For single-family houses, the studies were obtained from the provincial governmental's Energy Efficiency Agency, more exactly from the *Service d'inspection énergétique résidentielle* of the *Agence de l'Efficacité Énergétique* (AEÉ). The studies included visual inspection, measurements such as a blower door infiltrometry, and calculation of the energy-saving potential. All the studies included a simulation performed with the HOT2XP software, which is used through an interface program developed for the EnerGuide Program for Homes.

The energy efficiency studies for the other buildings, i.e., for the MUR and C&I buildings, were done by engineering and architectural consulting firms in the context of the government's and utility's programs, i.e., AEÉ's *Programme d'interventions en efficacité énergétique dans le secteur institutionnel* and the Société en commandite Gaz Métropolitain (SCGM)'s *Programme d'études de faisabilité*. The section on "Building Selection" has already mentioned that software-run energy simulations were expected to have been done for all buildings to be included in the project. It was unexpected to find out that no energy efficiency study included an energy simulation using any software. Calculations seemed to be based on simple manual methods. As no simulation work had been performed on these buildings and because the research protocol of the project required an evaluation of the energy-savings potential resulting from the thermographic observations, it was necessary to develop electronic files using the EE4 simulation software describing the geometry, building envelope, HVAC zoning, and equipment of each building. This new step in the project necessitated an additional source of information: the construction plans for the architecture, envelope, and mechanical systems of the buildings.

Interviews. Two interviews were conducted to evaluate the intentions of the building owners or managers of implementing the recommendations suggested by the traditional energy efficiency study and then, in the second interview, by the infrared thermography report. Questionnaires were prepared to guide the interviews, and interviewers were trained in order to ensure optimal data gathering and consistency among interviews.

The first interview was conducted just before the infrared analysis, using Questionnaire 1. Its objective was to establish the base-line energy consumption before the implementation of energy efficiency measures recommended in the traditional energy efficiency study. It also allowed the identification of the following:

- Changes to the building and its components or other factors that may have had an impact on energy consumption related to space heating since the traditional audit was done.

- Energy efficiency measures that were recommended in the traditional energy efficiency study, indicating if they had already been implemented or if the owner or manager intended to implement them later. For each measure, interviewees were reminded of the potential energy savings in terms of dollars and the estimated remedial cost in dollars as included in the EnerGuide reports or as presented in the reports for the MUR and C&I studies.
- The level of financial assistance needed, in particular by the low-income clientele, to implement the energy efficiency measures related to the building envelope recommended in the traditional energy efficiency study.

The second interview was conducted after the infrared analysis report was submitted to the clients, using Questionnaire 2. Its objective was to establish the additional energy savings resulting from the infrared analysis and also to identify the following:

- The additional energy efficiency measures that were considered following the infrared analysis compared to those that were considered following the traditional energy efficiency studies. For each measure, interviewees were reminded of the potential energy savings in terms of dollars calculated with HOT2XP or EE4, respectively, for houses and MUR and C&I buildings and the estimated remedial cost in dollars.
- The level of financial assistance needed, in particular by the low-income clientele, to implement the energy efficiency measures related to the building envelope recommended in the traditional energy efficiency study.

Infrared Thermography Analysis. The aim of infrared thermographic analysis was to identify the deficiencies of the building envelope in order to quantify the associated energy losses and evaluate the energy-savings potential of correcting these deficiencies. Also, the building owner/manager was invited to follow the thermography analyst and watch the walk-through in a second video output.

Carrying out the infrared thermography analyses. The thermography analyses were performed according to a protocol developed specially for the project, based on the Standard Procedures ASTM C1060, ISO 6781-1983, and ONGC (F) 149-GP-2MP. A standardized thermogram data sheet, described below, was proposed (see Figure 5). Furthermore, for quantification of the identified deficiencies, standard measurements and descriptions were proposed.

Thermographic analyses were done from inside the buildings. In certain cases, a verification of the building envelope was performed from the outside. The thermographic analyses were to be done at least one hour after sunset, with a minimum temperature differential of 15°C between the exterior and interior and with moderate winds of less than 6.7 m/s.

All accessible rooms in single-family houses were visited, including unfinished basements. In multi-tenant buildings, at least two units per floor were visited. In institutional and commercial buildings, only accessible and relevant spaces were visited. For each building, a minimum of four thermograms of deficiency-free typical envelope areas were recorded for a portion of wall, of ceiling, and of a window and a door. In addition, any deficiency was to be annotated, whether it was an isolated case or a typical situation that could be extrapolated to the whole building.

For single-family houses, there were two walk-throughs, with and without a negative air pressure differential of 30 Pa induced to accentuate deficiencies related to air leakage. So the sequence of measurements in houses was as follows:

- sketching of a schematic plan of the house;
- recording of measurements of the conditions required in the thermogram data sheet (see Figure 4);
- recording of the four typical thermograms;
- identification and recording of thermal conduction problems, e.g., probable thermal bridges and insulation defects;
- generation of air pressure differential (approximately –30 Pa) with a blower door;
- identification and recording of probable air leakage locations;
- noting location of all thermograms on the schematic plan;
- taking a digital photo for all these locations.

Standardization of infrared thermography findings. In order to ensure uniformity in the quantification of deficiencies, a typical Deficiency Data Sheet and a summary table of recommendations were developed. The data sheet and deficiency summary table were elaborated so that similar reports were presented to clients, regardless of which analyst had performed the infrared thermography and prepared the report. This standardization of the procedure and presentation of results also made possible the input in a consistent manner of the deficiencies into the simulation software. In addition to the Deficiency Data Sheet and recommendation summary table, a summary table of deficiencies (not presented to the clients) was developed to further facilitate the integration of deficiencies in the simulation software.

For each deficiency deemed significant or representative, a Deficiency Data Sheet was prepared. In addition to information used to identify and put in context the deficiency, surface temperatures for the typical wall and for the location with the deficiency were recorded. These measurements were used to calculate apparent RSI values for the wall, as well as for the deficiency, using the following equation:

$$RSI_{w,\,d} = \frac{1}{h_{film}} \times \frac{(T_i - T_e)}{(T_i - T_{w,\,d})} \tag{1}$$

where

$RSI_{w,d}$ = apparent thermal resistance of assembly (RSI_w) or deficiency (RSI_d) ($m^2 * °C / W$)

h_{film} = $8\ W / m^2 * °C$

Table 1. Accepted Terminology for Deficiencies and Their Corrective Measures to Be Used By the Thermographs in Their Report

Probable Deficiencies	Recommendations to Correct Deficiencies
Thermal Conduction/ Thermal Bridges	
• Space between framing elements with no or little insulation • Settling of the thermal insulation between the framing elements • Non-uniform/insufficient insulation • Apparent thermal bridge (if possible, specify what)	• Open wall and insulate • Add insulation from the inside • Add insulation from the outside
Air Leakage	
• Exterior wall / floor junction • Exterior wall / foundation wall junction • Exterior wall / interior wall junction • Exterior wall / opening junction • Exterior wall / roof junction • Window components • Electrical outlet or fixture • Interior wall • Top of interior partition not airtight at attic space • Mechanical room not airtight at attic space	Seal: • Around windows • At junctions between assemblies (specify which) • Top of interior partitions from attic space • At junction of pipes or conduits with the ceiling assembly • Replace electrical outlet or fixture boxes with airtight electrical boxes

T_i = interior ambient temperature (°C)

T_o = outdoor ambient temperature (°C)

$T_{w,d}$ = interior surface temperature of assembly (T_w) or deficiency (T_d) (°C)

To ensure consistency in the description of deficiencies and recommendations presented in the Deficiency Data Sheets, a list of probable insulation deficiencies and a list of probable air leakage deficiencies were provided to the infrared analysts, as shown in Table 1. A list of recommendations was also prepared and submitted to the infrared analysts for each type of deficiency. In addition, to identify the deficiency and recommend a correction measure, the thermographs had to estimate either the area or the length of the deficiency. A table summarizing the deficiencies and recommendations was included in the reports. Examples are shown in Figure 1.

In summary, the standardized infrared thermography report contained the following information:

- basic information on the building, e.g., building identification, location
- schematic plans with location of thermograms
- outdoor climatic conditions
- thermogram data sheets of the four typical locations
- thermogram data sheets for the deficiencies
- summary sheet with a list of deficiencies and their magnitude

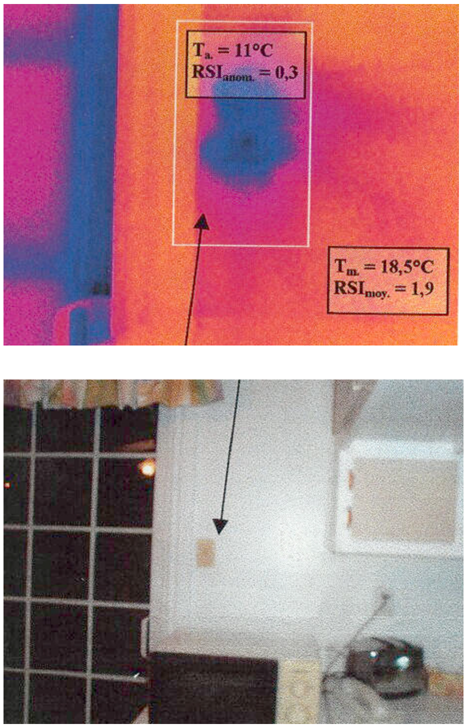
Energy Consumption of the Selected Buildings in the Year Preceding the Traditional Energy Efficiency Audit. The data for past energy consumption were available from the traditional energy audit report.

PROJECT HISTORY

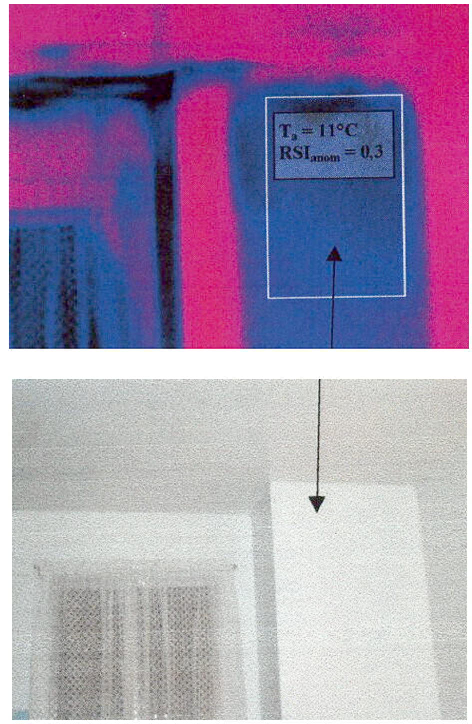
This project was proposed by the manager of the Fund for Energy Efficiency, Mr. Jean-Pierre Finet, and, following a request for proposal of services, the final team included Dominique Derome, as scientific advisor; Hubert St-Pierre and Guylaine Desmarais to manage the implementation of the project with the aid of Marie-Hélène Paquin for conducting interviews and Marianne Bérubé-Dufour in data processing; and, upon a call for qualification, Pierre Brisson and Pierre Gendron, thermographs.

In January and February 2002, Jean-Pierre Finet and Dominique Derome developed the documents that would describe the objectives, methodology, and analytical methods of the projects, i.e., the protocols for the management of the project, its implementation, the infrared thermographic analysis, and the data analysis and evaluation. Also, in the same period, a call for qualified infrared thermography analysts was launched in order to identify a certain number of firms specialized in the field that would be interested to perform infrared analyses in the buildings selected for the project. Requirements were set regarding experience and qualifications as well as infrared equipment. A preparatory meeting was held with representatives of the selected firms in order to validate the proposed protocol for the infrared thermographic analysis and to coordinate the carrying out of the infrared analyses of the selected buildings. Five thermography firms started in the project. After Phase 1, three of the firms withdrew from the project because they were unable or unwilling to comply with the protocol.

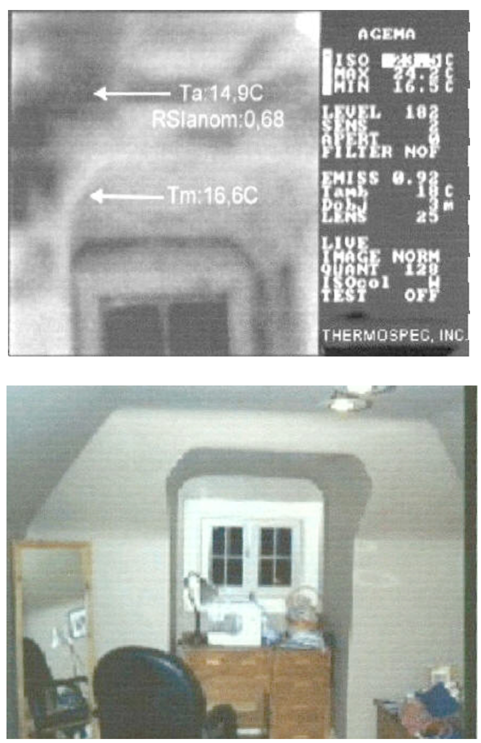
During the same time, eligible buildings were identified and owners or managers were contacted on their interest to participate in the project. Since the project started in February



Air leakage through electrical outlet or fixture.



Air leakage through mechanical shaft not airtight at attic space.



Non-uniform/insufficient insulation.

Figure 1 *Examples of the deficiencies found during the course of the project; top view is thermogram, bottom view is photograph of same location.*

Table 2. Number of Buildings Accepted and Analyzed in Phase 1 and Phase 2

	Buildings Supplied before Jan-01-2003	Buildings Supplied after Jan-01-2003	Thermographic Visits in Phase 1	Thermographic Visit in Phase 2
Single houses	9	12 + 3**	2	19 + 1**
Low-income single houses	1 + 1**	0	0	1
Multi-tenant	5 + 1*+ 2**	3	0	8
Commercial	4 + 3* + 2**	3	2 +2**	5
Institutional	3 + 1* + 2**	5	3 + 2**	5
Total	22 + 5* + 7**	23 + 3**	7 + 4**	38 + 1**

* Incomplete information—building eliminated at beginning of the project.

** Incomplete information or change of mind of the owner or manager—building eliminated during project for different reasons (e.g., simulation file lost by EnerGuide supplier, sickness of owner, building function, i.e., heating plant, did not meet project objectives, or building too complex to be modeled).

2002, the project had to be conducted in two phases: 11 infrared thermographic analyses were realized during Phase 1 (2001-2002 winter season) and the rest during Phase 2 (2002-2003 winter season). However, some of the buildings initially included in the project had to be eliminated for various reasons. Table 2 summarizes the number of infrared analyses that were done for the project.

By January 2004, the evaluation of potential energy savings resulting from the infrared thermographic analyses was completed for all 45 buildings of the project. The second interviews with the owners of the 22 single-family houses and the 23 MUR and C&I buildings were completed during winter 2004.

RESULT ANALYSIS IN TERMS OF ENERGY SAVING POTENTIAL

Calculation Methods for Estimating the Energy Impact of Deficiencies

For each building, the potential of energy savings of the proposed measures was calculated using energy simulation software.

For houses, the software used was HOT2XP

> which serves as a quick and easy tool for analyzing energy use in residential buildings. While its graphical interface is simple enough to be used by homeowners, the underlying analysis engine is that of HOT2000^{TM}, which is based on over 10 years of building simulation experience and has been validated against DOE-2 and other hourly simulation models. HOT2XP is designed to speed up the task of characterizing a house by requiring only a small amount of critical information. However, the user may edit many of the program's underlying rules and assumptions, which allows for a far greater control of the analysis than is suggested by the main interface (<*http://buildingsgroup.nrcan.gc.ca/software/hot2xp_e.html*>).

For the EnerGuide program, an Access–based program was developed as a user interface and to integrate a database of recommendations.

All houses had already been simulated for the EnerGuide audit. The input file of the traditional EnerGuide audit was used as the base of a second analysis that took into account the findings of the infrared inspection. The findings were grouped in two categories and implemented in two steps: problems related to thermal resistance and thermal bridging and problems related to air leakage.

The thermography reports proposed solutions for the problems of missing insulation, low level of thermal resistance, and thermal bridges when such measures were assessed to be feasible. Some defects were evaluated as being either too onerous or difficult to correct. The proposed solutions for the detected defects were implemented in the HOT2XP files by changing the thermal resistance for the recorded area of each defect, and the calculation of energy consumption before and after the changes provided a ratio of expected energy reduction that was applied to the actual energy use.

For air leakage defects, such a straightforward application of the inspection findings was obviously not possible. The available information was of two different sorts: on one hand, the blowerdoor results in ACH at 50 Pa and, on the other hand, the defects found with thermography while the house was depressurized. There is not yet a method to quantify on site the air leakage defects detected by thermography. However, the thermography findings provided an assessment of the distribution and types of air leakage defects that was used to evaluate the potential of improvement of the ACH that would result from the repair of the defects, as shown in Table 3. As HOT2XP uses the equivalent leakage area (ELA) at 4 Pa, the changes in ACH were transposed into ELA. Thermographic images were also used to evaluate qualitatively the size of the leak in order to estimate the costs of the repair.

For larger buildings, i.e., multi-unit residential, commercial, and institutional buildings, the software used was EE4, which was developed by Canmet of Natural Resources Canada as an interface for DOE2.1e, the comprehensive building energy analysis program developed by Lawrence Berkeley National Laboratory. The interface was designed to verify compliancy of alternative building designs to the Model Energy Code of Canada. EE4 is composed of an interface,

Table 3. Values of Air Change Per Hour Used to Estimate Energy-Saving Potential of Increasing Airtightness

Measured ACH50	Estimated Possible Improvement with Few Defects	Estimated Possible Improvement with Some Defects	Estimated Possible Improvement with A Lot of Defects
7-8	6.5-7.5	6-7	5-6
4-6	none	3.5-5.5	3-5
3-4	none	none	2.5-3.5

which includes a building editor and a series of libraries as well as the DOE-2.1E calculation engine.

The EE4 simulations were performed by CANMET Building Group of Natural Resources Canada, one of the partners of the project. As mentioned above, it was a surprise to the project team to find out that, although all buildings had gone through an energy efficiency audit that incorporated proposed solutions and their expected impact in terms of energy savings, none of the 23 buildings had been simulated with any energy simulation software. Therefore, an "as is" input file first had to be developed for each building. It was decided to perform state-of-the-art EE4 simulations even though such tasks were not planned as part of the project and would be very labor intensive. In any event, the 23 buildings were simulated using actual architectural and mechanical plans for the inputs in most of the cases. In other cases, measurements were taken on site. Zoning respected the mechanical system layouts and orientation of the buildings. These developed files were used as the basis of the second analysis that took into account the findings of the infrared inspection. Once again, the findings were grouped in two categories and implemented in two steps: problems related to thermal resistance and thermal bridging and problems related to air leakage.

The proposed and feasible solutions for the problems of thermal conductance of the envelope were implemented in the EE4 files by changing the thermal resistance for the recorded area of each defect, and the calculations of energy consumption before and after the changes provided a ratio of expected energy reduction that was applied to the actual energy use.

For air leakage defects, as was the case with residences, such a straightforward application of the inspection findings was obviously not possible and even less information was available, as no evaluation of the actual airtightness of the envelope was available. The available information was the defects found with thermography under normal operating mode of the building. It should be mentioned that areas of C&I buildings that were under a positive air pressure differential were avoided as they made the identification of air leakage problems more difficult. Airtightness of the building envelope for energy simulation using DOE2.1e is taken into account with the air permeance value, the default value in the software being 0.25 L/s·m^2. To evaluate the impact of improving the airtightness of the envelope of the multi-unit residential, commercial, and institutional buildings, runs using the files incorporating the thermal conductance improvements were performed directly in DOE2.1e as EE4 did not allow the modification of the air permeance. Four simulations were performed, i.e., for base case air permeance, base case plus 10%, base case minus 10%, and base case minus 20%. The results led to almost linear relationships.

Table 4. Values Used to Estimate Energy-Saving Potential of Increasing Airtightness

Estimated Possible Improvement with Few Defects	Estimated Possible Improvement with Some Defects	Estimated Possible Improvement with A Lot of Defects
0-5%	5-15%	10-20%

Then, using the thermography results, estimation of the potential for improving the airtightness of buildings were made, and the brackets of improvement shown in Table 4 were used to estimate the energy savings resulting from improving the airtightness with the measures identified by thermography.

To accompany the infrared analysis report, a summary table of the recommendations, listing estimated costs and potential energy savings, was submitted to the clients. The costs of the recommended measures were split into costs of material and of labor, using unit costs appropriate for the Montreal area.

Energy Savings from the Retained Measures in the Houses

The calculations of the energy savings for the houses were done with HOT 2XP. Table 5 presents the energy profile of the 22 houses and the average energy use, 3,400 m^3 of gas per year for heating.

Using the answers of the two interviews, a database documented each retrofit measure that was recommended either by the EnerGuide or the thermographic analysis report. Each measure was described in terms of type of intervention (insulation or air leakage), description of actual measure, and costs and status of its implementation (refused, considered, or implemented by the owner). Tables 6 and 7 present results of the analysis using this database. Table 6 shows that implementing the whole of the measures recommended by the EnerGuide reports for the envelope (airtightness and insulation measures) of houses would have a potential of reducing the average heating energy use by 22%, or 723 m^3 per house. Similarly, implementing all the measures recommended by the thermographic analysis would lead to a reduction of 8%, or 264 m^3 of energy used for heating. It should be kept in mind

Table 5. Energy Profile of the 22 Houses of the Project

	Total Area (m^2)	Total Area (ft^2)	Electricity (kWh)	Electricity (CAN$)	Gas (m^3)	Gas (ft^3)	Gas Heating and Hot Water Cost (CAN$)	Gas Heating Cost (CAN$)	Heating Gas (m^3)	Heating Gas (ft^3)	Others/ e.g., Wood (CAN$)	Total Year Cost (CAN$)
1	159	1,711	7,300	504	3,012	106,354	1,958	1,610	2,477	87451		2,462
2	215	2,318	5,036	438	3,506	123,797	2,103	1,882	3,138	110787		2,541
3	225	2,421	10,387	741	4,687	165,498	3,037	2,533	3,909	138033		3,778
4	169	1,818	5,800	480	3,087	109,002	1,775	1,398	2,431	85851		2,255
5	312	3,351	26,505	1,822	3,911	131,805	1,864	1,050	2,203	70,726		3,686
6	143	1,539	4,655	418	2,519	88,946	2,621	2,112	2,030	71673		3,039
7	174	1,872	7,290	538	2,222	78,459	1,559	1,184	1,688	59586	376	2,473
8	294	3,163	12,661	1,345	5,438	192,016	3,263	2,901	4,835	170713		4,608
9	362	3,895	5,521	464	7,815	275,948	4,825	4,550	7,370	260220		5,293
10	178	1,915	6,330	506	3,510	123,938	1,755	1,571	3,142	110944		2,261
11	369	3,970	30,970	2,136	5,206	183,824	3,312	2,532	3,980	140532		5,448
12	333	3,583	8,069	557	7,247	255,892	3,623	3,397	6,795	239929		4,180
13	154	1,657	10,869	777	2,602	91,877	1,763	1,400	2,066	72959		2,540
14	232	2,496	7,034	545	4,765	168,252	2,750	2,537	4,396	155220		3,295
15	230	2,475	5,800	400	2,889	102,011	1,948	1,699	2,520	88971		2,348
17	181	1,948	6,868	563	5,310	187,496	2,792	2,383	4,532	160030		3,355
19	277	2,981	8,977	654	3,593	126,869	2,393	1,958	2,940	103807		3,047
20	207	2,227	6,763	532	4,373	154,411	2,851	2,345	3,597	127006		3,383
21	198	2,130	9,424	697	2,879	101,657	1,807	1,319	2,101	74204		2,504
22	314	3,372	21,559	1,486	5,663	190,843	3,600	3,125	4,916	157,825		5,086
23	161	1,732	6,868	515	4,831	170,583	4,603	2,432	2,552	90128		5,118
29	98	1,054	2,584	305	1,707	60,274	1,237	936	1,292	45608		1,542
average	**227**	**2,438**	**9,876**	**747**	**4,126**	**139,052**	**2,611**	**2,130**	**3,405**	**109,316**		**3,375**

Table 6. Savings in m^3 of Gas That Would Result from the Complete Implementation of All Recommendations of the Energuide and of the Thermographic Reports

File Number	Heating Savings Resulting from All Energuide Measures (CAN$)	Heating Savings Resulting From All Energuide Measures (m^3)	Heating Savings Resulting from Envelope Energuide Measures (m^3)	% (Saved Energy Source/Total)	Heating Savings Resulting from All Thermographic Measures (CAN$)	Heating Savings Resulting from All Thermographic Measures (m^3)	% (Saved Energy Source/Total)
1	0	0	0	0	154	237	10
2	691	1,152	1,125	36	206	343	11
3	250	386	299	8	216	333	9
4	331	576	56	2	118	204	8
5	661	1,387	986	45	30	63	3
6	745	664	664	33	112	99	5
7	603	611	611	36	128	130	8
8	609	1,015	627	13	154	256	5
9	995	1,612	1,612	22	123	198	3
10	564	1,025	562	18	103	186	6
11	1,448	1,564	628	16	236	255	6
12	1,813	3,627	1,950	29	448	896	13
13	482	711	487	24	29	43	2
14	1,625	2,643	1,055	24	125	202	5
15	531	788	359	14	301	446	18
17	354	673	0	0	295	561	12
19	887	1,289	904	31	53	76	3
20	483	741	51	1	343	526	15
21	602	781	764	36	89	115	5
22	1,255	1,974	1,509	31	220	346	7
23	2,775	2,912	1,365	53	213	223	9
29	718	921	291	23	58	74	6
average	**837**	**1,230**	**723**	**22**	**170**	**264**	**8**

Table 7. Estimation of Number of Cubic Meters of Gas Saved According to Considered Energy-Saving Measures

	Saved m^3 (ft^3) if All Recommendations Were Implemented	% of Recommendations Retained	Average Cost of Retained Measures (CAN$)	Saved m^3 (ft^3)*
According to Energuide analysis	723 m^3 (25,530 ft^3) 22% of heating	32%	$913	231 (8,150)
Insulation measures retained		31%	$698	
Air sealing measures retained		33%	$215	
According to thermographic analysis	264 m^3 (9,320 ft^3) 8% of heating			
Measures non-targeted or retained with Energuide	200 m^3 (7,060 ft^3) 6% of heating	69%	$1,163	182 (6,426)
Insulation measures retained		69%	$564	
Air sealing measures retained		69%	$599	

* Based on the hypothesis that measures costs are proportional to savings.

Table 8. Calculated Potential Energy Savings Using Recommended Measures as Retained in the Eight Multi-Unit Residential Buildings

	Saved m^3 Econ-mises if All Mea-sures Were Retained	% of Suggested Mea-sures that Were Retained	Average Cost of Retained Measures (CAN$)	Saved m^3 (ft^3)*
	average consumption 19,350 m^3 (683,250)			
According to traditional audit	3,970 m^3 (140,180 ft^3, $1,891) (20% of heating)	75%	$8,614	2,978 (105,155)
According to thermographic analysis	3,283 m^3 (115,920 ft^3) (5% of heating)			929 (32,800)
Insulation measures retained		100%	$2,871	
Air sealing measures retained		85%	$1,574	

* Based on assumption that measures cost is proportional to savings.

that the thermographic deficiencies were very circumscribed in space; hence, recommendations touched only the exact area of the deficiencies.

Table 7 presents an estimation of the number of cubic meters of gas saved that would result from the measures considered and implemented. The assumption for these calculations, that the ratio of cost of measures is equivalent to the ratio of the energy savings, is proposed as valid as the measures considered, air sealing and insulation, are all of the same type and considered separately.

It is interesting to observe that the recommendations retained from the thermographic reports would lead to an averaged 182 cubic meters of gas saved, which would be in addition to the 231 cubic meters of gas saved from the recommendations implemented and considered from the EnerGuide reports.

Energy Savings of Measures Proposed for the Multi-Unit Residential, Commercial, and Institutional Buildings

The calculations of the energy savings for the multi-unit residential, commercial, and institutional buildings were done with EE4. A second interview with building managers investigated their intentions of implementing the recommended measures as presented in the thermographic analysis report. The data of intention of implementation and the resulting potential in terms of energy savings are represented in Tables 8, 9, and 10 for each type of large buildings.

ANALYSIS OF COST/BENEFITS RATIO

The cost/benefits ratio for the integration of the thermographic analysis takes into account the energy savings that

Table 9. Calculated Potential Energy Savings Using Recommended Measures as Retained in the Commercial Buildings

	Saved m^3 Economises if All Measures Were Retained	% of Suggested Measured that Were Retained	Average Cost of Retained Measures (CAN$)	Saved m^3 (ft^3)*
	average consumption 428,025 m^3 (15,113,562 ft^3)			
According to traditional audit	92,500 m^3 (3,266,175 ft^3, $44,052) (22% of heating)	95%	$206,574	87,875 (3,102,870)
According to thermographic analysis	3,283 m^3 (115,922 ft^3) (0.7% of heating)			2,429 (85,770)
Insulation measures retained		0%		
Air sealing measures retained		78%	$4,574	

* Based on assumption that measures cost is proportional to savings.

Table 10. Calculated Potential Energy Savings Using Recommended Measures as Retained in the Insitutional Buildings

	Saved m^3 Economises if All Measures Were Retained	% of Suggested Measured that Were Retained	Average Cost of Retained Measures (CAN$)	Saved m^3 (ft^3)*
	Average consumption 414,535 m^3 (14,637,230 ft^3)			
According to traditional audit	77,044 m^3 (2,720,425 ft^3, $36,688) (19% of heating)	60%	$165	46,226 (1,632,240)
According to thermographic analysis	9,756 m^3 (344,485 ft^3) (2.4% of heating			8,585 (303,136)
Insulation measures retained		98%	$5,287	
Air sealing measures retained		86%	$76,200	

* Based on assumption that measures cost is proportional to savings.

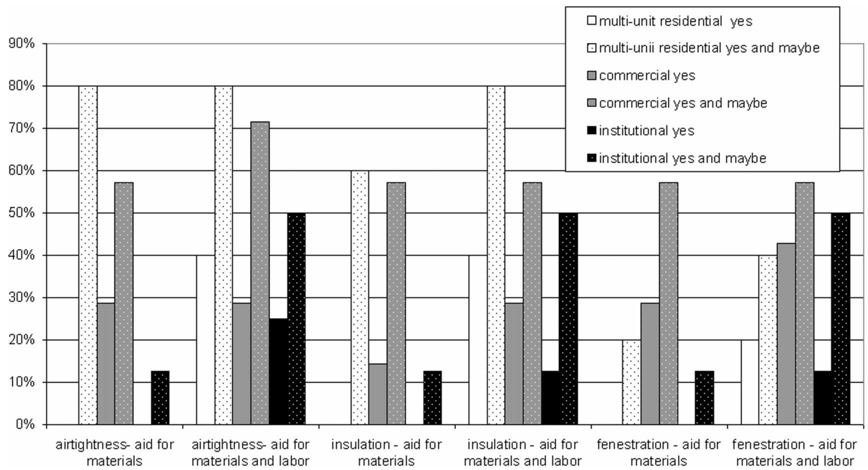


Figure 2 *Percentage of respondents that would proceed if financial aid were available.*

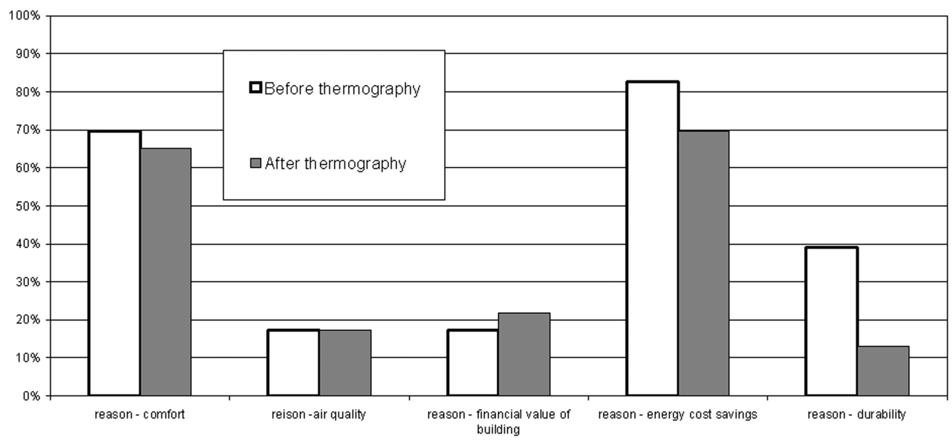


Figure 3 *Main reasons of implementation of recommended measures in single-family houses.*

resulted from the implementation of measures identified by thermography, for measures not implemented, or not identified by the traditional analysis. The costs of thermography versus the added benefits in terms of gas saving in dollars can lead to the determination of the cost of the additional cubic meters of gas saved resulting from thermography. Table 11 gives a summary of the energy savings that resulted from the implementation of or intention to implement the energy retrofit measures suggested either by the traditional energy audit or by the thermographic analysis.

ANALYSIS OF COMMENTS AND NEED FOR FINANCIAL SUPPORT

A study of the financial aid needs based on the interviews was part of the study. Figure 2 demonstrates that, overall, residential building managers would more often mention that they would require financial aid to implement the measures than institutional building managers. Also, the interviews contain questions on the motivations behind the decision for implementation. Results are presented in Figures 3 and 4 show energy cost savings and comfort to be the main motivators.

CONCLUSIONS

The project aimed at verifying the impact of adding an infrared thermographic analysis to the traditional energy audit in terms of additional energy savings. A protocol for integrating thermography was presented and has been implemented in 45 building analyses, including houses, multi-unit residential buildings, and commercial and institutional buildings.

The results presented in this paper show that, when it comes to evaluation of the building envelope, the use of infrared thermography allows more specific deficiencies to be located and identified and a better definition of the scope of work for the recommended measures. The fact is that in most traditional energy analysis reports on the commercial and institutional buildings included in this study, no or close to no

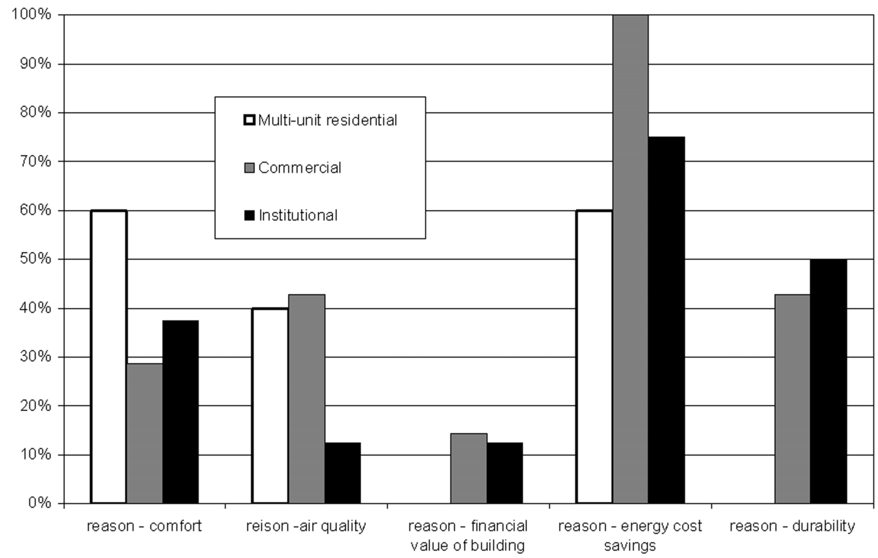


Figure 4 *Main reasons of implementation of recommended measures from first interview with the large building managers.*

Table 11. Summary of Savings Resulting from Measures Retained from Both Energy Efficiency Analyses

	Savings Resulting from Energuide Analysis, m^3 (ft^3)	Savings Resulting from Thermographic Savings, m^3 (ft^3)	Average Cost of Thermographic Analysis (CAN$)
Single family houses	231 (8,156)	182 (6,426)	880
Multi-unit residential buildings	(HVAC) 2,978 (105,153)	929 (32,800)	2,300
Commercial buildings	(HVAC) 87,875 (3,102,865)	2,429 (85,780)	2,331
Institutional buildings	(HVAC) 4,6226 (1,632,240)	8,585 (303,135)	2,501

recommendation considered the building envelope. The bulk of recommendations in these studies was directed at the mechanical systems and therefore all potential energy efficiency measures related to the building envelope were overlooked.

Furthermore, as owners/managers were present during the thermographic visit, and with the support of the report, it seems that the thermograms allowed them to better understand what was going on in their buildings and increased their motivation to implement the recommended measures.The integration of thermography in an energy audit seems advantageous for the houses.

There is still a lot of work to be done to optimize the use of infrared thermography in energy analysis/audits of building. First, there is a need for uniformity among the practice and reporting of thermographs. Second, the measures that are the most implemented and most profitable in terms of energy savings are the ones addressing airtightness. When well targeted, it is relatively simple for owners/managers to seal the required location. Motivations are not only about energy savings but also about thermal comfort of occupants. Therefore, it would seem natural to integrate the thermographic inspection with the blower door infiltrometry for a small building energy audit. Third, an eventual quantification method of the volume of air coming through the detected deficiencies would transform the traditional qualitative thermographic analysis in the quantitative domain. Such quantification of volume of air could then lead to a more precise evaluation of the energy savings resulting from the correction of the detected deficiency.

ACKNOWLEDGMENTS

We would like to acknowledge the work of Pierrre Brisson and Pierre Gendron, the thermography analysts involved in this study, for their resilience, their comments, and the quality of their work. Also, our appreciation goes to Michel Tardif, eng., who performed the 23 EE4 simulations.

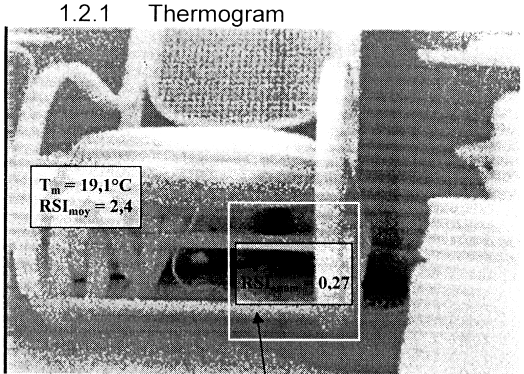
LOCATION :
Address : 1234 rue de l'Efficacité Énergétique
Room : Living room, facing west

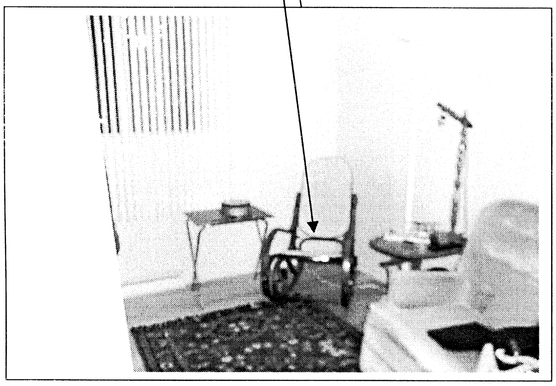
Date : Dec. 11 2002
Ext temp. (T_e) : 2 °C
Wind : 5 km/h

Thermogram with air pressure differential : -30 Pa

Measurements below without delta P

1.2.1 Thermogram





Natural pressure differential :
ΔP = -2 Pa

Indoor temperature:
T_i = 20,0°C

Average wall surface temperature:
T_w = 19,1°C

$RSI_{ave.}$: 2,4 (Apparent)

Average temperature of deficiency area:
T_a = 12,0°C

$RSI_{deficiency}$: 0,27 (Apparent)

Estimated surface emissivity:
0,93

1.3 Comments

The base of the wall corner is not airtight.

Probable airtightness deficiency
- Air infiltration at the exterior wall/floor junction

Recommendation
- Seal at the junction

Probable insulation deficiency
- None here

Recommendation
- Does not apply

Figure 5 *Sample thermogram data form, here describing a deficiency.*

REFERENCES

ASTM C1060-90, Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings. American Society for Testing and Materials.

*ISO 6781-1983 (E), Thermal Insulation—Qualitative Detection of Thermal Irregularities in Building Envelopes—Infrared Method.*International Organization of Standards.

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<http://buildingsgroup.nrcan.gc.ca/ee4/english/index_e.shtml>.