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USE OF AERIAL THERMOGRAPHY
IN CANADIAN ENERGY CONSERVATION PROGRAMS

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ABSTRACT

This paper summarizes recent developments in the use of aerial thermography in energy conservation programs within Canada. Following a brief review of studies conducted during the last three years, methodologies of data acquisition, processing, analysis and interpretation are discussed. Examples of results from an industrial-oriented project are presented and recommendations for future basic work are outlined.

1. INTRODUCTION

With growing complexity of the industrial economy and the modern trends towards compulsive consumption, the demand for energy in Canada has been accelerating. For example, during the 1961-1971 period, energy consumed by the average Canadian increased by about 50% (1). Until recently, energy policy in Canada was limited to measures directed at locating, acquiring and delivering enough energy to meet the expanding demands. It has become evident, however, that this high energy consumption rate cannot be sustained indefinitely and energy conservation programs must be implemented.

During the past three years numerous energy conservation programs have been initiated by various federal and provincial government departments, universities, school boards, businesses and institutions. In the same period attempts have been made to evaluate the usefulness of aerial thermography for detecting excessive heat loss from buildings and heating lines, and to determine its role in identifying the causes of excessive heat loss and in developing plans for remedial measures.

2. OVERVIEW OF CANADIAN PROJECTS

The Canada Centre for Remote Sensing (CCRS) has been collecting airborne thermal infrared and supporting photographic data for heat loss detection during the last three years (see Table 1). Initial studies were of an exploratory and qualitative nature, with emphasis on detection of major problem areas. The technique proved successful for locating damaged flat roofs, defective heating lines, water

leaks around exhaust vents, and unnecessary energy consumption in locations such as heated ramps or sidewalks which were left operating after snow had melted from the surface (2, 3).

Exploratory work aimed at quantitative assessment of heat loss from residential structures revealed the importance of considering in detail the parameters affecting the heat transfer from the interior of the house to the roof surface. Since the attic space forms a buffer between the ceiling insulation and roof surface of a house, it is necessary to analyse the heat transfer and heat loss mechanisms by taking into account all means of heat dissipation including attic ventilation, conduction-convection from the roof surface, and radiation from this surface (4). CCRS is presently conducting a joint experiment with an electric utility company to evaluate the use of aerial thermography for a quantitative estimation of heat losses from a wide spectrum of residential structures. A test area covering approximately two square kilometers was chosen in Ottawa. This area contains homes built between the end of World War II and the present and includes single family, semi-detached, and condominium structures with various types of heating systems. Aerial thermograms have been collected over this area on several dates and times of day during the 1976/77 heating season, and questionnaires have been sent to approximately 2000 homes in the area to obtain information on house insulation, attic ventilation and roof characteristics. In addition, a mathematical model relating roof surface temperature to ceiling insulation has been developed (4). Attic temperatures and humidity were measured in three test homes in order to assess the validity of some of the model assumptions and aid in developing the model. The aerial thermograms are presently being analyzed and results should be available in the near future.

To take full advantage of the aerial thermography technique, the Ontario Centre for Remote Sensing (OCRS), Ontario Ministry of Natural Resources has been conducting, since early 1975, a progressive aerial thermography program with the aim of developing an operational methodology for employing this technique on a large scale. Initially, selected test sites with single family dwellings, commercial, public and apartment buildings were chosen for study. Using the Daedalus thermal scanning system and criteria specified by OCRS, thermal imagery was obtained and processed by the Airborne Operations Section of CCRS. Data were acquired from altitudes of 360 m, 480 m and 600 m above ground level and under various atmospheric conditions. From this initial test series, 480 m was chosen as the optimum altitude on the basis of the spatial and thermal resolution elements of acquired data and the quality and size of photographic enlargement that can be produced from such imagery.

The findings of the OCRS initial test flights, presented in several in-house reports to the Ontario Ministry of Energy, have lead to a much expanded program in the residential communities of Ontario. The first large scale community-oriented thermography presentation in Canada will take place during May 1977. Thermal imagery of the town of Lindsay, Ontario (population 12, 872) will be made available to the citizens as part of a major energy conservation awareness program. An interpretation centre will be established where each house owner will be able to view the thermograph of his house and be provided with its interpretation. This project has been a joint venture by OCRS and the Ontario Ministry of Energy.

Another energy conservation program initiated and funded by the Office of Energy Conservation (OEC) of the federal Department of Energy, Mines and Resources covers two Maritime provinces and makes extensive use of aerial thermography. The program, which is presently coordinated by a joint federal-provincial committee, consists of several related elements aimed at encouraging greater energy conservation. These elements are: energy use statistics, mobile energy audit buses, design of corrective measures, technical education workshops, in-plant promotion, grants for capital projects, and aerial thermography. These elements are intended to contribute to the effectiveness of the various decision making and action steps involved in improving energy efficiency of an industrial establishment. Aerial thermograms will be used for general presentation in workshops, seminars, displays, etc. They will also be used in the bus program, where an aerial thermogram of an industrial site will be presented to industry management during a visit by a mobile energy audit bus. Thermogram anomalies attributed to excessive heat loss will be discussed, and used to both increase the manager's awareness of and participa-

tion in the program and as an aid in the design of corrective measures. During March 1977 aerial thermograms over most of the industrial and institutional sites in Nova Scotia and Prince Edward Island were collected. Several establishments have been analyzed in a pilot project (5) and some of the results are presented in Section 4.

3. METHODOLOGY

3.1 Data Acquisition and Processing

Remote sensing data have been collected by CCRS aircraft and sensors for Canadian aerial thermography experiments. The sensors may be carried by either of two DC-3's, a Falcon Fan Jet, or (in the future) a Convair 580. In a typical mission, two flights are undertaken within a 24 hour period. Normal colour or colour infrared aerial photographs (or both) with a 60% overlap and 30% sidelap and thermal infrared scanner data are acquired during the near-noon, daytime flight, and thermal scanner data only are acquired at night. Single channel (8-14 μ m) or dual channel (3-5 μ m, 8-14 μ m) data may be collected. The night flights are usually at least 4 hours after sunset at an altitude of 360 to 490 m above ground level under the following meteorological conditions: night temperature below 0°C, clear skies or minimal cloud cover and light winds. These specifications are considered only tentative, however, and further work aimed at determining the optimum data acquisition conditions is underway.

Aerial photographs are developed and reproduced at the National Air Photo Library in Ottawa. Thermal scanner data are reproduced as a 12.5 cm wide black and white (B&W) transparent image in two modes: analogue and level-sliced. Two level-sliced sets are commonly used. The first, usually referred to as the "master set", is obtained by dividing the temperature range between two reference levels into six equal intervals and displaying data within each interval as a single gray tone. The reference levels are obtained within the infrared line scanner by repeated viewing of two internal constant temperature plates. The second set, or "subset", repeats the above quantization procedure but the reference levels are now chosen as any two of the levels within the master set. Typically, a range encompassing two to three slices of the master set contains most of the information and hence is subdivided into six equal intervals. The analogue data may also be digitized to 256 levels (8-bits) for recording on computer compatible tapes for quantitative analysis or for display as a 12 interval, level sliced, colour coded image on a 23 cm wide paper print strip.

3.2 Interpretation

3.2.1 Visual Analysis

The primary source of remote sensing data for heat loss analysis is the nighttime thermogram. Typically, all three image forms (analogue, level sliced master set, level sliced subset) are utilized. For a given site, the thermograms are magnified as required and reproduced as positive B & W prints, which have been found preferable to transparencies (5). Prints are easy to handle in the office and on site, and are convenient for interpretation (marking, referring back and forth between various sources of information, roof delineation, etc.) Stereoscopic aerial photographs provide valuable reference data. In most projects, both colour and colour infrared positive transparencies have been produced at a scale of approximately 1:2,800 to allow detailed examination of the roofs. In a recent project, 70 mm colour and colour infrared stereoscopic photographs (scale 1:12,000) were produced instead, thus decreasing the total data acquisition costs by almost 50%. These proved satisfactory for an analysis of industrial buildings (5). Meteorological data, on-site observations, and other auxiliary data may be used to aid in the interpretation of anomalies observed on the various thermograms. Examination of aerial photographs indicates which of the anomalous warm areas are related to smoke stacks, skylights, sides of buildings, roof vents or penthouses. The roof features can create 'natural' warm points, although care must be taken to analyze their thermal shape and size. Damaged flashings around vents and penthouses are well known water entry points; if the thermal expression around such feature is excessively large or oddly shaped, then the site should be classed as a potential problem area. The remaining apparent heat anomalies are analyzed to determine whether they could

be accounted for by differences in surface materials, presence of water, reflection from the surroundings, roof geometry, etc. Areas where excessive or unexpected heat loss is suspected are marked on the thermogram prints and assessed during an on-site visit where appropriate. These areas often experienced insulation damage through moisture, compaction or other means, thus resulting in reduced thermal resistance and higher heat loss.

A non-destructive method for measuring moisture in roof insulation involves bombardment of a test area with neutrons and measurement of the thermal recoil of the neutrons caused by the presence of water. This radioisotopic method of moisture detection has demonstrated excellent correlation between high moisture content in the roof insulation and areas of high thermal radiance in the thermograms (3).

3. 2. 2 Digital Analysis

Digital processing of airborne thermal infrared imagery is a powerful technique for quantitative image analysis. CCRS has two image processing systems. The CCRS Image Analysis System (CIAS) is based upon a PDP-11/70 computer and an IMAGE 100 and is capable of performing various overlay, transformation, classification, display, and output operations. The Modular Interactive Classification Analyzer (MICA) uses a Bendix Multispectral Analyzer Display connected on-line to a large time-sharing computer. Its capabilities are similar to CIAS but all algorithms are implemented by software. Consequently, MICA is an ideal system for methodology development and will be used extensively in the CCRS project on residential heat loss. Specialized software is available to display a digitized thermogram as an image on the TV display. A cursor-selected area of the imagery may be transferred to a disk file and converted to apparent blackbody temperatures. These temperatures can be related to roof surface temperature and then to heat loss. Changes in models, data calibrations and specific house parameters such as house style, roof pitch, and type of roof material may be accommodated relatively easily.

4. ILLUSTRATIVE RESULTS

Selected examples of aerial thermograms presented in this section were analyzed under contract by Philip A. Lapp Ltd. with OCRS involvement in a pilot project conducted by CCRS and OEC in the province of Prince Edward Island. Data were acquired on March 2, 1977 between 2100 and 2200 hrs. Atlantic Standard Time. Air temperatures were below 0°C all day and -5°C at night. The wind was 8 to 16 km/hr and skies were clear with few scattered clouds. Although the majority of the roof were clear and dry, some snow and standing water were evident on the aerial photographs taken at approximately noon on March 4. Ground information was obtained during visits to the sites on March 17 and 18 after the thermograms had been examined. The site visits helped to validate the initial interpretation of many observed anomalies on the thermograms.

Figure 1 shows a visual photograph and a nighttime thermogram of a shopping centre. In the thermogram light tones correspond to high radiation levels, and thus indicate "warm" sites. The shopping centre building was conspicuously light on the thermogram relative to other similar structures. Aerial photographs, daytime thermograms, and site inspection indicated that the roof was ice-covered to various degrees with (A, Figure 1b) or without (C) liquid water under the ice. In the high radiance areas the roof surface was soft, suggesting breakdown of the waterproof membrane. The "cold" areas (B, Figure 1b) were found during the inspection to be ice-free with a firm dry membrane. Thus the presence of ice appeared to correspond to areas of weak membrane and consequently of water-damaged insulation leading to a higher heat loss. Intermediate radiance levels on both daytime and nighttime thermograms exhibited at C (Figure 1b) could be explained by thinner ice cover and properly functioning thermal insulation (relative to A). The poor thermal performance of this roof was indicated during the discussion with building managers.

Thermal image of a building with different roofing materials is shown in Figure 2. Part A (Figure 2b) is covered with 1.8 cm thick rigid insulation under a tar/pitch membrane without gravel. The remainder of the building has 1.8 cm rigid insulation covered with tar and gravel. In general, the tar-only area appears "colder" than the tar and gravel section. This difference could be caused by different radiative physical properties (emissivity) of the surface materials. However, other explanations are possible. Part A is 3m higher than the remainder of the roof and could thus experience higher sensible heat loss. Furthermore, a small portion of the tar and gravel roof (B, Figure 2b) exhibited radiation levels similar to those of part A. The tar and gravel roof also contains eight skylights (C, Figure 2b), smokestacks (D) and a penthouse (E). These features and the surface discontinuities can be expected to affect the thermogram. The above examples show that a careful thermogram analysis is necessary to avoid interpreting emissivity and geometry effects as heat loss anomalies. The thermogram does, however, contain a significant thermal anomaly (F, Figure 2b). Aerial photography and on-site examination established this to be water collected at a low spot on the roof. Continued presence of water for extended periods of time is known to eventually cause roof deterioration.

Figure 3 is a thermogram of a hospital whose roof consists of three sections. In the upper section (A, Figure 3b), no heat anomalies unrelated to vents or similar structures could be identified. This roof is of the inverted type, i. e. a waterproof membrane is covered with slabs of waterproof insulation and these are in turn overlaid with 5 to 10 cm of crushed rock. This design presents problems in detecting a damaged membrane even when the roof is thermally sound. The central portion (B, Figure 3b) was uninsulated, and this is evident from a higher radiation level of this section. In the lower section (C), the roof was of conventional construction. The "warm" anomaly in this section was identified as a low spot near a drain located in the vicinity of a penthouse and interpreted as an incipient roof failure around the drain; otherwise, the roof had a uniform appearance on both air photographs and thermograms.

5. SUMMARY AND CONCLUSIONS

Results of Canadian studies employing aerial thermography for heat loss detection have demonstrated the usefulness of this technique in locating anomalies associated with excessive heat loss. The value of aerial thermograms for increasing the interest, participation, and motivation of building operators has also been indicated (5), and should become of major significance in future energy conservation programs.

The quantitative aspects of heat loss from roofs are not well understood at the present time. Some of the on-going work should yield a better understanding of the extent to which roof surface temperature is a measure of ceiling insulation and of total heat loss. Additional studies are required to determine the effect of snow, ice, water, temporal changes during the night such as cooling rates, and emissivity on the relationship between roof surface temperature and heat loss. Understanding these parameters is important because optimum conditions are rarely present in large scale projects.

The future of aerial thermography in energy conservation appears very promising. However, it is very important to maintain credibility of the technique by not extending it beyond its limits. These limits depend upon the general understanding of the methodology as well as on specific conditions at individual sites.

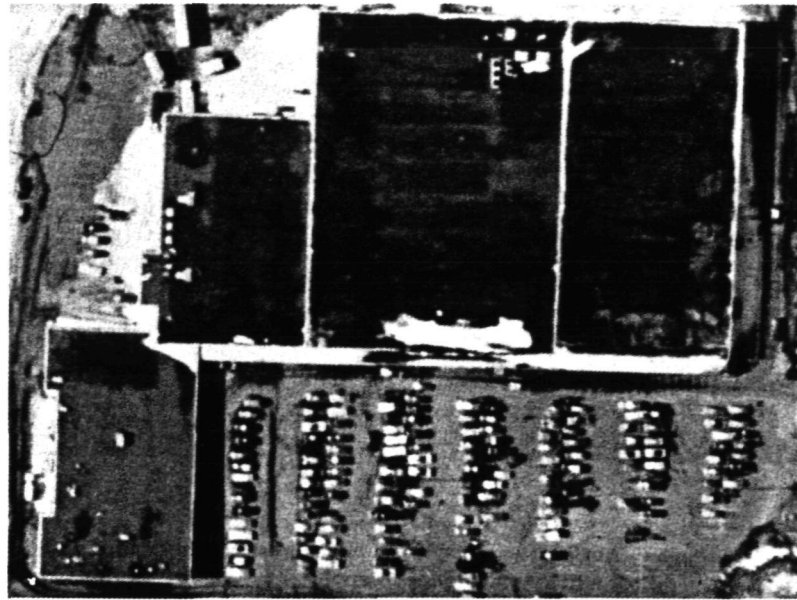
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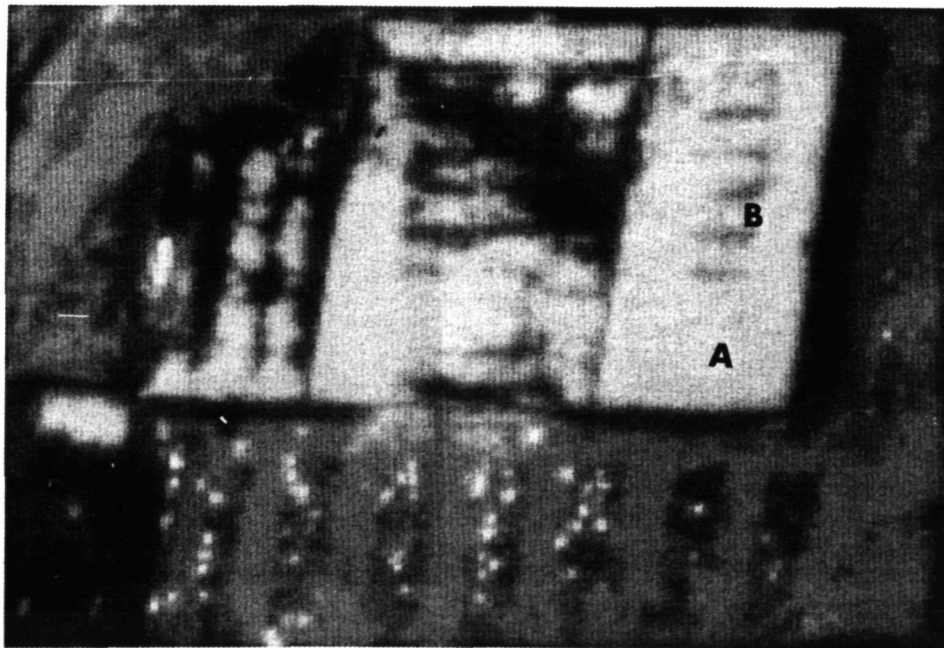
TABLE 1 Summary of Aerial Thermography Projects
for Heat Loss Detection in Canada

AGENCY	YEAR	LOCATION	STATED OBJECTIVE
Canadian Penitentiary Service	1975	Cowansville, Quebec	To locate underground leaks in heat distribution lines.
	1975	Drumheller, Alberta	
Philips Cable Ltd.	1974	Brockville, Ontario	To determine the extent of heat loss from buildings and heat distribution lines.
Ontario Centre for Remote Sensing	1975	Toronto, Ontario	To detect energy loss in buildings
	1976	Toronto, King City, Ontario	
	1977	Toronto International Airport, Cobourg, Centralia, Ontario.	To determine locations of excess heat loss from industrial sites.
Ontario Centre for Remote Sensing (Ontario Ministry of Energy)	1976	Stratford, Brockville, Sudbury, Lindsay, Ontario	A preliminary study on heat loss from residential buildings and presentation to community in an energy conservation program.
	1977	Perth, Prescott, Arnprior, Guelph, Sault St. Marie, Ontario	
Canadian Department of Transport	1976	Ottawa, Ontario	To evaluate the use of aerial thermography to detect roof deterioration at Canadian airports.
Canada Centre for Remote Sensing Canada Dept. of Energy, Mines and Resources	1977	Ottawa, Ontario	To evaluate the use of aerial thermography to quantitatively estimate heat losses from residential structures.
Ottawa Hydro	1977	Ottawa, Ontario	To evaluate the use of aerial thermography to quantitatively estimate heat losses from residential structures.
Office of Energy Conservation, Canadian Dept. of Energy Mines and Resources	1977	All industrial, commercial and institutional sites, in P. E. I. and N. S.	To provide heat loss information for Maritime industrial sites, schools, hospitals etc. in conjunction with the comprehensive national energy conservation program.
Canadian Dept. of Public Works	1977	Selected federal buildings in Ottawa, Ontario	To detect heat losses and damaged roofs from federal

AGENCY	YEAR	LOCATION	STATED OBJECTIVE
McMaster University	1975	Hamilton, Ontario	To detect heat losses
York University	1975	Toronto, Ontario	from buildings and heat
University of Guelph	1975	Guelph, Ontario	distribution lines.
University of Waterloo	1974	Waterloo, Ontario	
University of Calgary	1976	Calgary, Alberta	

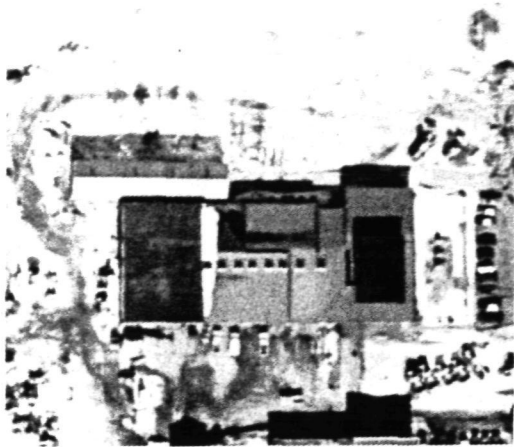


(a)

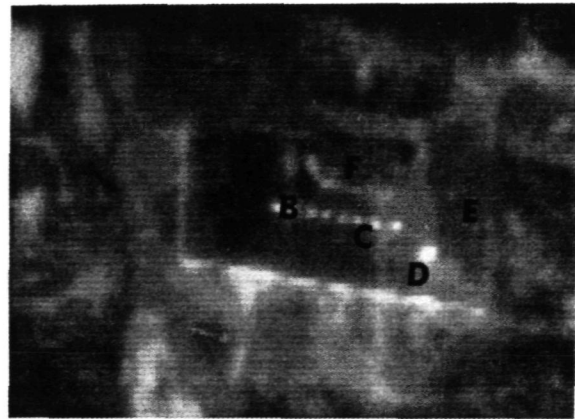


(b)

Figure 1 Aerial photograph (a) and nighttime thermogram (b) of a shopping mall. See text for explanation

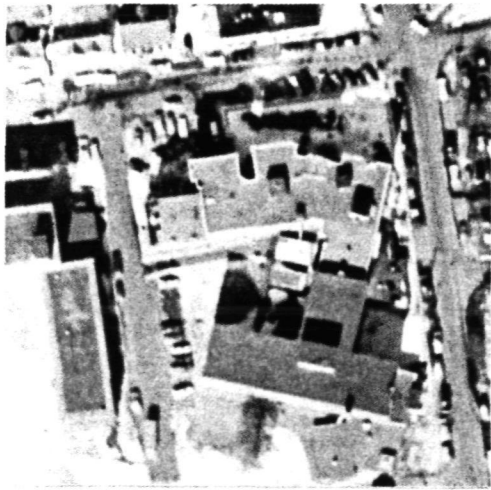


(a)



(b)

Figure 2 Aerial photograph (a) and nighttime thermogram (b) of a heavy machinery depot . See text for explanation



(a)



(b)

Figure 3 Aerial photograph (a) and nighttime thermogram (b) of a hospital. See text for explanation