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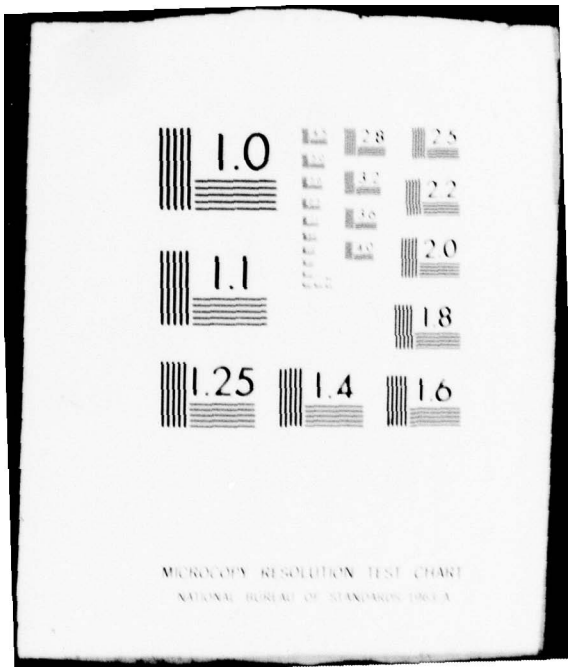
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Special Report 79-1

February 1979

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INFRARED THERMOGRAPHY OF BUILDINGS

A BIBLIOGRAPHY WITH ABSTRACTS

Stephen J. Marshall

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This report contains annotated abstracts of over 100 reports (66 more than the 1977 edition) on the new, but rapidly expanding subject on infrared thermography of buildings. Infrared thermography of buildings (IRTB) is a rapid, noncontact, real-time technique that uses an infrared thermal imaging system to detect heat loss or gain, structural defects, moisture, and other anomalies in building envelopes. Photographs (thermograms) or video recordings of the imagery provide hard-copy documentation of faults detected. The references cover remote sensing airborne surveys of large numbers of buildings, close-up ground surveys

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of individual buildings, and qualitative (speculative) and semi-quantitative (ground-truth) field surveys. The report presents examples of thermographic energy audits, roof moisture surveys, building retrofit surveys, solar panel analysis, window assessments, and other practical applications by government agencies and private sector survey teams. It lists research and development efforts to provide fundamental information to improve quantification accuracy, evaluate equipment, and develop interpretation standards, along with examples of daily usage in contract specifications, public awareness programs, and product testing.

PREFACE

This report was prepared by Stephen J. Marshall, Physical Science Technician, of the Physical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

Primary funding was provided under DA Project 4A161101A91D, In-House Laboratory Independent Research; Work Unit 267, Field Heat Loss Quantification Using a Thermal Imaging System. Secondary funding was provided under DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions; Task A3, Cold Regions Operation and Maintenance of Fixed Facilities; Work Unit 002, Effects of Cold Environment Upon the Infrared Characteristics of Buildings.

The technical content of this report was reviewed by C.J. Korhonen and S.N. Flanders of CRREL.

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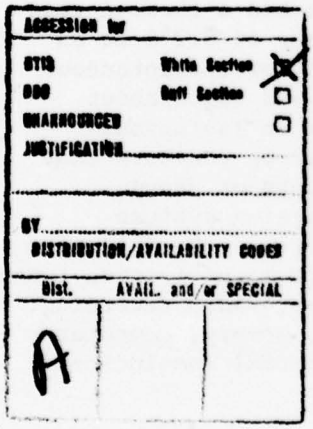

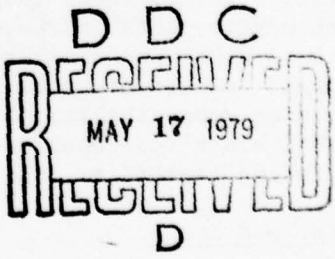

INTRODUCTION

This report contains annotated abstracts of over 100 reports, (66 more than the 1977 edition) on the new but rapidly expanding subject of infrared thermography of buildings. Infrared thermography of buildings (IRTB) is a rapid, noncontact, real-time technique that uses an infrared thermal imaging system to detect heat loss or gain, structural defects, moisture, and other anomalies in building envelopes. As the system scans a building or series of buildings, the varying infrared intensities from the target are proportionately converted to varying visual intensities (i.e., white is hot and black is cold) and displayed on a monitor. Photographs (thermograms) or video recordings of thermal imagery provide documentation of the anomalies detected. An experienced thermographer interprets the documentation usually by reference to measured temperatures or other factors, or by visual comparison with the actual building or sample buildings, and attempts to arrive at some useful end product. This end product can range from energy conservation public awareness programs to detailed energy audits or inspections of specific building problems to prove compliance or noncompliance with contract specifications.

The infrared thermal imaging systems operate in either the midwave infrared (2 to 5.6-μ wavelength) or longwave infrared (8 to 14-μ wavelength) portions of the infrared spectrum because these two bands are "windows" through which infrared radiation can pass without being absorbed by the atmosphere. A typical field system has a thermal resolution or a minimum detectable temperature difference of 0.2°C at an object temperature of +30°C and a spatial resolution or instantaneous field of view of 2.5 milliradians at 50% contrast, and costs about $45,000 with accessories. Some of the systems have an isothermal function that superimposes on the picture brightened-up contours that identify areas of equal temperature (i.e., equal tones of gray). Recent developments indicate that future thermal imaging systems will be lighter and smaller and will have one or more of the following features: electronic zoom infrared lens, or picture magnification feature, television compatibility, broadcast-quality pictures, video recording, internal black-body absolute temperature standards, memory, computer interfacing capability, and improved spatial and thermal resolutions.

Purpose and Scope

Infrared thermography of buildings is too new to be described in a textbook or journal, but articles on the subject are emerging from a wide variety of sources. The objective of this report is to present an overview of the subject as well as detailed information on scientific research from the sources covered. Topics include remote sensing

airborne surveys of a large number of buildings and closeup ground surveys of specific buildings. Most of the survey reports are qualitative or semi-quantitative.

The research and development reports basically attempt to verify survey results or to address difficulties in obtaining quantitative numbers (e.g., British thermal unit or thermal resistance values).

Report Organization

The Bibliography is organized alphabetically by author and has a synopsis of the essential, pertinent and unique points contained in each work. Reports are available from the authors. Reports containing proprietary information are considered generally unobtainable and are therefore not included.

ABSTRACTS

1. *AGA INFRARED SYSTEMS (1976) Spotting heat loss from buildings - Thermovision. AGA Corporation, 550 County Ave., Secaucus, New Jersey.*

This manual is an introduction to an important new aspect of technology that is the most significant development in the science of heat detection in the last 25 years: the use of an infrared camera system to inspect structures for heat loss and heat gain. This technology, infrared thermography, can reveal where and how much energy is being wasted in both residential and business establishments. The energy efficiency of buildings can be increased selectively, at minimum expense and with maximum effect, through the use of thermographic inspection to select sites for improvement. Without thermographic inspections, efforts to improve the thermal integrity of buildings are little more than guesswork.

2. *BATTLES, M.K. The dissemination of infrared imagery to 27 Minnesota communities. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September 1978, The American Society of Photogrammetry, 105 Virginia Ave., Falls Church, Virginia 22046.*

As part of a multi-faceted residential energy conservation program, the Minnesota Energy Agency conducted aerial infrared surveys of 27 communities during the 1976-77 heating season. The purpose of this demonstration project was to determine the potential of infrared technology as a diagnostic and implementation tool for energy conservation programs.

This paper examines the objectives, mechanics and preliminary results of disseminating infrared imagery and energy conservation technology on a broad scale with particular emphasis on how the information was relayed to the general public.

The Minnesota program, established as a cooperative effort with local communities, was carried out at the local level using volunteers, part-time employees and/or city personnel unfamiliar with infrared and energy conservation technology. As a result, the agency worked closely with individual communities to assist in selection of staff for dissemination centers, to aid in film organization and display, to provide adequate training and conservation materials, and to suggest procedures for effective operation of dissemination centers. These aspects of the program are described and program examples are cited to illustrate the effects of various dissemination strategies on the program.

Preliminary results of a survey conducted to analyze the impacts of the program are also included.

3a. *BJORKLUND, J., F.A. Sohmer and R.E. Isakson (1975) A report on the use of thermal scanner data in an operational program for monitoring apparent rooftop temperatures. Proceedings of the Tenth International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, Ann Arbor, Michigan (1975), p. 1437-1446.*

3b. *BJORKLUND, J., F.A. Sohmer and R.E. Isakson (1975) Aerial thermal scanner data for monitoring rooftop temperatures. Remote Sensing Institute, S.D. State Univ., Brookings, South Dakota, and Central Telephone and Utilities Corp. CENGAS Div., Lincoln, Nebraska, SDSU-RSI-75-11, 5 thermograms, 20 p. Same Abstract - expanded text.*

CENGAS, A division of Central Telephone and Utilities Corporation, in cooperation with the Remote Sensing Institute, South Dakota State University, is using airborne thermal scanner data to monitor relative rooftop temperatures. Four Nebraska communities and one South Dakota community were surveyed by the Remote Sensing Institute for CENGAS. Thermal scanner data were converted to a film format and the resultant imagery has been successfully employed by CENGAS. The program places emphasis on heat losses resulting from inadequate home insulation, offers CENGAS customers the opportunity to observe a thermogram of their rooftops, and assists home-owners in evaluating insulation needs.

4. *BOWMAN, R.L. and J.R. Jack (1977) Application of remote thermal scanning to the NASA Energy Conservation Program. Lewis Research Center, NASA, Cleveland, Ohio, Report No. E-9017. National Aeronautics and Space Administration Report No. NASA TM X-73570, 24 p.*

Airborne thermal scans of all NASA centers were made during 1975 and 1976. The remotely sensed data were used to identify a variety of heat losses, including those from building roofs and central heating system distribution lines. Thermal imagery from several NASA centers is presented to demonstrate the capability of detecting these heat losses remotely. Many heat loss areas located by the scan data have been verified by ground surveys. For such energy-intensive areas, thermal scanning has proven to be an excellent means of detecting many possible energy losses.

This report presents a brief introduction to infrared thermal scanning primarily for the nontechnical user, discusses its application to the detection of energy losses in energy-intensive installations, and presents some typical experimental results. Results of ground surveys based on the remotely sensed data are also presented.

5. *BRAND, T. (1978) Infrared thermography programs by Northern Illinois Gas Company. Fourth Biennial Infrared Information Exchange, St. Louis, Missouri.*

Northern Illinois Gas (NI-Gas) serves approximately 5 million people in an area of about 17,000 square miles. The company's service area covers 35 counties which compose most of the northern third of Illinois, mainly outside the city of Chicago. NI-Gas distributes about 48% of gas utility energy in Illinois, or considering the total amount of utility energy distributed, about 37%. The company supplied over 535 billion cubic feet of gas to its 1,400,000 residential, commercial and industrial customers in 1976.

NI-Gas has actively promoted the conservation of energy among all classes of customers for several years. The programs suggest ways to conserve energy and emphasize the reasons conservation of energy is so important for the future. Through these education and assistance programs, the company has succeeded in establishing a high level of awareness of the need to conserve energy among its customers and has helped them to conserve a substantial amount of gas.

In the spring of 1977, a Thermography Survey Program was initiated. The equipment is basically an infrared camera system which is used to detect and visibly display areas of heat loss. Before-and-after pictures can be taken to show the effect of corrective action and to identify areas where further conservation activity is needed. The equipment and its operator have been made available, free of charge, to the 3,150 gas-consuming schools in the NI-Gas area.

The public relations benefits received from press, T.V., and radio have been significant.

In November 1977, based on the response of the school program, a service for commercial and industrial customers was developed as a contracted service for a fee. "Thermmaster," as it is known, is implemented by utilizing independent contractors under an agreement with NI-Gas to provide the most comprehensive service available anywhere in the continental USA.

6. *BROWN, N.B. (1971) Heat leakage detection in a building using an infrared radiometer camera system. Geophysical Institute, University of Alaska, College, Alaska, 3 thermograms, 10 p.*

The surface temperature distributions on the exterior walls of a University of Alaska building were measured by mapping the intensity of thermally emitted radiation with an infrared radiometer camera system. Heat leakage and thermal bridging in the structure were readily observed and detailed examples are given. The use of this technology is suggested for future thermal evaluation studies in building research and construction.

7. *BROWN, R.J. (1978) Canadian experiences with the use of aerial thermography in energy conservation programs. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September 1978, The American Society of Photogrammetry, 105 Virginia Ave., Falls Church, Virginia 22046.*

Rapid increases in the cost of energy have, within the last couple of years, made most Canadians and Canadian government departments at all levels aware of the need for energy conservation. The Canada Centre for Remote Sensing, a branch of the federal Department of Energy, Mines and Resources, has taken an active role in developing the methodology for the application of aerial thermography for the detection of building heat loss.

The advantages and limitations of the technique are described. The in-house research program has been directed towards producing a quantitative estimate of the amount of attic insulation in residential structures. It is extremely difficult to arrive at an unambiguous estimate of attic insulation levels because of the complicating effects of attic ventilation, roof pitch, and roof emissivity. The effects of these parameters upon roof temperature are discussed but the application of the technique to flat roof structures is more straightforward. An operational industrial energy conservation program using aerial thermography is described to illustrate how well the technique works for such structures. In spite of the problems of applying aerial thermography to the detection of heat loss from residential structures, it has been used successfully in several residential conservation programs in Canada.

8. *BROWN, R.J. (1978) Infrared scanner technology applied to building heat loss determination. Canadian Journal of Remote Sensing, Vol. 4, No. 1, April 1978.*

During the last few years, decreasing supplies of fossil fuels and attendant increases in costs have emphasized the need to make more efficient use of energy. Consequently, many government departments and power utility companies have been investigating means of identifying areas where savings might be made. Qualitative studies on the use of aerial thermography for such a purpose have demonstrated the utility of this technique to locate thermal anomalies. This paper examines the possibility of using line scanning equipment operating within the 8 to 14-μm atmospheric window to obtain a quantitative estimate of the amount of heat loss from a residential or commercial structure. It also considers the effects of meteorological factors, construction materials, and construction practices upon the imagery.

9. *Brown, R.J. and J. Cihlar (1978) Introduction to aerial thermography applications in energy conservation programs. Canada Centre for Remote Sensing, Energy, Mines and Resources, Ottawa, Canada, Research Report 78-2, 26 p., 7 thermograms*

Aerial thermography is becoming widely used in many energy conservation programs as an aid in detecting heat losses. In order to realize the full potential of the technique, it is necessary that its advantages and limitations be appreciated. This report attempts to do this in a manner which is understandable to a person who does not have a technical background. A brief introduction to infrared theory is followed by a discussion of the detecting instrumentation and typical residential and industrial construction practices. Finally, examples of imagery are presented which attempt to illustrate the thermal appearance of features commonly encountered in thermograms of residential and industrial structures.

10. *BROWN, R.J., P.M. Teillet and J. Cihlar (1978) The effects of attic ventilation on residential heat loss analysis. Canada Centre for Remote Sensing, Energy, Mines and Resources, Ottawa, Ontario, Canada.*

Infrared imagery has been used in several residential energy conservation public awareness programs in Canada and the United States in the last few years. In most cases the imagery analysis has been very cursory with little attention to factors such as attic ventilation, roof pitch variations and roof emissivity. CCRS has undertaken a project to examine what effect these factors have upon the measured roof temperature.

Nighttime aerial infrared data and daytime photographs were obtained in the spring of 1977. Questionnaires were sent to approximately 1800 households within the test area and 800 responses were received. Image analysis was carried out on the digital analysis equipment at CCRS. This approach facilitated computer calculations of the heat loss mechanisms from the interior of the house to the roof exterior.

From the analysis it was found that attic ventilation efficiency is important in the determination of apparent roof temperature. It was found that attic ventilation efficiency could be determined from the aerial photographs from a consideration of house style and age, and the presence of roof vents. Results of model calculations of attic insulation levels incorporating attic ventilation rates assessed from the aerial photographs are presented. The model calculations including the effects of attic ventilation, compared to the results obtained from a regression analysis of apparent roof temperature versus thermal resistance (R) value, showed a two-to fourfold improvement in the explained variation of attic thermal resistance.

11. *BROWN, G. and B. Pettersson (1976) Detecting and analyzing building insulation defects by the thermography method. Swedish National Authority for Testing, Inspection and Metrology, P.O. 5608, S-11486, Stockholm, Sweden, 35 thermograms, 38 p.*

Thermography uses an infrared camera. Cold portions of a depicted surface are seen as dark on an oscilloscope screen or on photographic paper. When this method is used in Sweden for building inspection, cameras sensitive to radiation in the wavelength range of 2-5.6 μm indicate the temperature distribution over wall and floor surfaces. By taking thermal pictures (thermograms) in a building which has to be inspected, and by comparing them with thermograms from a correctly constructed building of the same design, it is possible to assess insulation defects (poor insulation work, air leakage, moisture damage).

Rules for interpretation of thermograms are drawn up at the Swedish National Academy for Testing, Inspection and Metrology. The climatic and other conditions necessary for getting reliable results are investigated. This method is now used as a routine instrument for building inspection. A proposal for an international standard in the field of thermography has been submitted to the International Standards Association.

12. *BURCH, D.M., T. Kusuda and D.G. Blum (1977) An infrared technique for heat loss measurement. National Bureau of Standards, Report NBS TN-933, 44 p.*

This paper describes a newly developed technique for measuring heat-loss rate utilizing an infrared television system. A device called a heat-flow reference pad was developed that makes it possible to measure quantitatively the heat-loss rate through the surface of a building without a conventional heat-flow meter mounted on the surface. Technical considerations for the design of a heat-flow reference pad are presented. The infrared measurement technique predicted heat-loss rates in the laboratory and field within approximately 12%.

13a. *BURKHART, C.H. (1976) Infrared thermography of buildings. Civil Engineering Technical Report. U.S. Coast Guard Headquarters, Washington, DC, CETR-1, 9 thermograms, 27 p.*

13b. *BURKHART, C.H. (1976) Infrared thermography of buildings. Coast Guard Engineer's Digest, CG-133, No. 192, 4 thermograms, p. 9-29.*

Recent international concern over energy management and utilization has led to the accelerated development of practical applications of certain techniques which had previously been of concern only to researchers. One of these techniques is the ability to detect infrared radiation using

super-cooled semiconductors. Through pioneering efforts in Sweden, the concept of infrared thermography of buildings has developed into a powerful tool for energy management.

The key word is "tool." Thermography provides valuable information with a depth, speed, and quality never before possible, but it does not solve energy management problems by itself. It is a "qualitative" tool. It indicates exactly where heat losses are occurring, and gives a very good idea of the relative magnitude of the loss .... but it does not enable the user to accurately quantify the absolute loss.

This report discusses the theory of thermography and infrared radiation, explains how detection is accomplished and why it is indicative of temperature, tells how to survey a facility and outlines the nature of the information such a survey will provide, and generally describes the tool to the extent required by the Coast Guard facility manager.

14. *CARNEY, J.C., T.C. Vogel, E.R. Love and G.E. Howard (1977) Interagency energy and environmental survey. Geographic Information Systems Division, U.S. Army Engineer Topographic Laboratory, Technical Report, 15 thermograms, 58 p.*

The results of this survey demonstrate the feasibility of using multispectral remote sensing techniques, whereby a U.S. Army Facility Engineer can reduce the number of man-hours currently required for energy and environmental assessments. These include detecting building heat losses and deteriorated insulation invisible to the human eye, performing electrical inspections under full operating loads, and monitoring environmental conditions on a successive annual basis. This survey method, developed during the winter and summer of 1976, employs a hand-held infrared camera and color conventional and infrared aerial photography.

The thermal imagery is used in conjunction with color aerial photography to detect energy losses and defective roof insulation. This imagery should be obtained during the winter season on a 2-year cycle, 2 to 3 hours after sundown at a scale of 1:4,000 and 1:20,000.

The color and color infrared photography aids the Facility Engineer in the analysis of the thermal infrared imagery, provides a source of information for establishing a baseline of environmental conditions for future comparison, and monitors potential environmental problem areas. This photography should be obtained simultaneously on a 4-year cycle, between the hours of 1000 and 1500, at scales of 1:10,000 and 1:20,000. During the first cycle, the photography should be obtained in conjunction with the winter thermal infrared flights and repeated during the

summer season. The photography and infrared imagery should always be acquired in clear weather.

The hand-held infrared camera can detect the exact locations of energy losses and roof areas underlain with wet insulation after they appear in the aerial infrared imagery. It can also be used to survey electrical distribution systems, detect heat losses through building walls, and monitor steam lines.

15. *CASSELIA, J.N. and J.J. Cavalier (1974) Method of detecting and repairing a structural roof damaged by subsurface moisture. Tremco Manufacturing, Cleveland, Ohio, U.S. Patent, 12 February 1974.*

Airborne infrared imagery of a roof should be in the spectral band from about 2 to about 14 μ, preferably from about 8 to 14 μ. Roof portions corresponding to areas of anomalous radiation which are potentially moisture laden areas of the roof are located. These roof portions where the presence of subsurface moisture is confirmed by coring or other inspection procedures are then repaired.

16. *CHOWN, G.A., J. KITTSON, F. MICELI, and P.A.D. MILL (1978) Thermographic investigation - Fathers of Confederation, Centre for the Arts, Charlottetown, Prince Edward Island.*

In response to requests by the Atlantic Region, two thermographic investigations were carried out to assess problems of heat loss through the exterior walls of the Confederation Centre in Charlottetown. The first investigation, 78-01-25 to 27, confirmed the severity of the problems caused by lack of insulation, air leakage, and thermal bridging. A decision was made to construct a second enclosure system on the inside of the existing wall. The new wall was intended to increase the thermal resistance of the enclosure and to provide an effective air seal. The second investigation, 78-03-02 to 03, was designed to assess the performance of one wall with the secondary system in place. The investigation showed that the effective thermal resistance of the wall had been increased fivefold and that air leakage through the wall had been reduced to a level where it could not be discerned thermographically.

17. *CHRISTENSEN, D., B. BRAINERD and J. GODDARD (1978) Preliminary evaluation of a thermographic scanning device for energy conservation studies. Johnson Environmental and Energy Center, Alabama University, Huntsville, Alabama.*

A thermal imaging system, the Magnavox AN/PAS-7 Point Detector/ Scanning Mirror hand-held viewer, was used for a series of tests to measure hot spots (or heat losses) in a solar energy heating system, on the exterior of a nursing home, on a courthouse and a residence, and on

power line transformers and substations. It was concluded that the AN/PAS-7 provides valuable information to aid in the evaluation of thermal systems because of its portability, ruggedness, wide field of view and adaptability. It can also be an important tool for use in the evaluation of solar energy conversion systems and could be especially useful for the evaluation of solar heating and cooling demonstration sites.

18. *CLAWSON, K.H. (1978) Infrared thermography in a physical plant setting. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September 1978, The American Society of Photogrammetry, 105 Virginia Av., Falls Church, Virginia 22046.*

The campus of Cornell University is possibly the most thoroughly thermographed large physical plant in the country. Two complete aerial scans, January 1975 and November 1976, have been conducted, each covering more than 700 acres of campus with 25 miles of directly buried steam line. In addition, each of the 400 major buildings has had the sidewalls scanned at least once. Several buildings have been scanned a second time after attempts were made to decrease the heat flow through the sidewalls.

This paper tells the whole story with before-and-after thermograms. It discusses the value of using aerial thermography for surveying buried steam-line conditions, for determining insulation effectiveness in rooftops, and for other not so obvious uses such as determining sources of thermal drainage outflow. Also discussed is the value of building-sidewall thermograms. What is done after seeing the pictures? What methods are effective in controlling sidewall heat loss? Is urea formaldyhyde foam insulation effective? Are reflective panels behind radiators effective? How is quantitative measure of heat loss obtained?

Thermogram interpretation is discussed - What are the pitfalls? Who should do the interpretation? Can thermograms be accurately interpreted? Is it critical to make a "ground-truth" survey?

These questions and others are answered based upon the Cornell experience. Anyone involved in the physical facilities area who has a desire for knowledge of this survey technique will benefit from the discussion.

19. *COLCORD, J.E. (1977) Urban energy surveys using thermal imagery. The American Society of Civil Engineers Preprint 2955.*

This report describes the problems and results of an airborne IR survey whose purpose was to obtain parameters relevant to 1) the current status of energy use, or 2) the detection of change in building heating.

A military surplus IR scanning system and manpower in the form of a graduate class were used to study sites at the University of Washington and the City of Seattle.

The HRB Singer AN/AAS14 operated in both the 3-5 and 8-14 μ bands and had an angular resolution (IFOV) of 4 milliradians. The surveys were flown at night and included homes of all ages and types but with predominately cedar shake roofs. Several practical considerations for this type of survey are that: 1) the scan angle should be less than 25 to 30 degrees; 2) the ground resolution should be from 0.5 to 1 m; 3) the flying height above ground level should be 1000 ft; 4) the ground condition calibration requires the knowledge of insulation R values and inner building temperatures for a minimum of two buildings for every 2 to 3 miles of line flown.

Problems discussed were 1) fog; 2) wind shadow effects; 3) varying slope distances which change scale and the surface look area; 4) heavy plantings of shrubs and trees which obliterate buildings and make calibration contrast settings difficult. Results of the survey were presented as a five-level estimate (VG, G, F, P, VP) of effective insulation (thermal resistance) for each building. Survey comments describe additional observations such as: 1) loss from exhaust vents; 2) sideshine; 3) outlines of firewalls; 4) skylights; 5) and open smoke louvers.

Recommendations for aerial surveillance for heat loss studies are presented along with a suggested format for specifications for aerial detection of thermal infrared radiation.

20a. *DAEDALUS ENTERPRISES (1976) VANSCAN continuous mobile thermography: Daedalus Enterprises, Inc., P.O. Box 1869, Ann Arbor, Michigan.*

Heat losses are expensive and energy can be conserved and money saved if the losses can be located. VANSCAN detects energy loss problems and gives a permanent picture of where they occur, plus a comparative scale of their thermal severity. The savings are both immediate and long-range through the use of thermograms to resolve major problems and plan future maintenance programs. This is illustrated by a university complex that experienced annual energy losses from wall-mounted radiators. The two white areas on the thermogram indicated temperatures in excess of 43°F where two of the radiators were mounted on the inside wall. The two high heat loss areas on the outside brick wall registered 52°F with an air temperature at 30°F! This is typical of many normally undetected heat losses that occur around campuses which, although small on an individual basis, amount to a large energy dollar waste collectively over each heating season.

The VANSCAN thermograms are continuous strip prints, not frames, created as the vehicle containing the IR scanner moves around the facility to be surveyed. The scanner has a resolution of 1 $in.^2$ at a range of 100 ft and is equipped with a gyro stabilization system to correct distortions caused by instability. The measurements are recorded on magnetic tape; and through the use of patented data processing methods, precisely temperature calibrated, color-coded positive strip prints are extracted. A series of thermogram image strips is produced for detailed inspection.

20b. DAEDALUS ENTERPRISES (1976) Airscan continuous airborne thermography. Daedalus Enterprises, Inc., P.O. Box 1869, Ann Arbor, Michigan.

An airscan survey is normally performed from a twin-engine aircraft carrying both a standard mapping camera for photography and a Daedalus DS-1210 quantitative thermal infrared scanner for heat loss measurements. Coverage of a facility is accomplished by flying a set of overlapping parallel flight lines at a nominal altitude of 1000 ft above the ground. The thermal infrared measurements are made at night to eliminate the effects of solar heating. The measurements are normally made when the ambient air temperature is below 40°F and when the roofs are essentially free of snow and water. The precise internal calibration sources of the DS-1210 scanner are adjusted by the operator in-flight to bracket the total temperature range of the facility being surveyed. All of the thermal infrared measurements are recorded on magnetic tape for subsequent processing to thermograms. The data are produced in both black and white and digicolor quantitative color-coded thermograms. Each of the types of data is processed as a continuous strip thermogram for each flight line.

A reference aerial photo with overlay provides locational information on building layout and heat distribution lines covered on each flight line. It is used for determination of the visual condition of building roofs and correlation with the infrared thermograms. A black and white thermogram provides total range of radiation temperature in a black and white image format. It is used as the primary tool in detecting high losses from all heated surfaces.

A Digicolor Thermogram Range 1 provides quantitative data in the "cooler" temperature range. It is used to determine heat losses from roof surfaces in the "cooler" temperature range. A Digicolor Thermogram Range 2 provides quantitative data in the "warmer" temperature range. It is used for determining heat losses associated with heat distribution lines and analysis of "warmer" features.

21. *DICK, J.M. and F.A. Schmer (1978) Aerial infrared user's manual. Final Draft. U.S. Department of Energy, Division of Buildings and Community Systems, Washington, D.C. 20545, 102 p.*

The Remote Sensing Institute and the Minnesota Energy Agency worked together to produce this manual in an effort to make easy-to-understand information about an aerial infrared flyover program available to those considering such a program. The Remote Sensing Institute contributed experience and technical expertise, while the Minnesota Energy Agency provided information based on experience in conducting aerial infrared programs in 27 Minnesota cities.

The manual was written to gather available information about existing aerial infrared technology and practical experience gained by those who have conducted aerial infrared programs. It does not purport to present new research, but rather is a synthesis of existing information. The manual is divided into the following sections that describe the basic steps needed to prepare for and implement an aerial infrared program:

1. Survey and dissemination program planning including site selection, costs and determination of scope
2. Data collection considerations
3. Data collection equipment options
4. Output products
5. Data dissemination
6. Program evaluation

Also included are four program examples.

22. *EDEN, A. and J.T. Tinsley Second Interim Technical Report on USAFA Solar Test House. Civil and Environmental Engineering Development Office, Tyndall Air Force Base, Florida 32403, Technical Report TR-77-34.*

An AGA Model 750 system and color monitor were used to survey solar panels at the U.S. Air Force single-story Solar Test House at the Air Force Academy in Colorado. Both a ground array and a roof array consisting of 14 liquid flow flat plate collectors with glass covers were analyzed. The following conclusions were made about using thermography to analyze solar panels.

Wind can affect the readings on the thermograms; therefore thermography should be used at wind velocities less than 15 mph. Glare from the glass surface of the collector can cause inaccurate readings. The

thermographic readings were of the glass itself and may not exactly indicate the temperature of the absorber surface below.

The following results were obtained from the thermographic analysis of the panels. Colored thermograms showed more clearly the various areas of changing temperatures than black and white thermograms, and proved very valuable in correlating the thermograms to the actual measured temperatures. Accurate correlation between thermogram apparent temperatures and temperature sensors could be made. A large air blockage in one of the groups of four panels in series was detected by thermography. Reversed flow in the last group of four panels was detected by thermography even though the temperature sensors indicated no reversed temperature readings.

Thermographic analysis led to a decision to cut the flow rate in half, and subsequent thermography studies showed a normal flow pattern and temperature distribution resulting from this change. A balancing technique to reach higher efficiencies was performed using thermography. Thermograms showed that the plumbing raceways were very large sources of energy losses. After the raceways were insulated, thermographic analysis indicated decreased temperatures and lower edge heat losses from the collector arrays. Thermograms also indicated that the flexible tubing feeding the ground array also needed to be insulated.

Thermography was also used successfully to monitor the injection of urea foam into the building walls. Only one small area under a window had to be redone due to poor fill. Thermography also detected the fact that two moveable panels under some of the windows were poorly insulated and resulted in these panels being replaced with insulated sandwich panels.

23. *EUSKIRCHEN, J. (1977) Determination of heat losses by means of infrared techniques. National Technical Information Service, Springfield, Virginia 22161, PC A02/MFA01*

The infrared method is an important tool in finding heat losses in houses. In countries in which it is used more, the studies are carried out more carefully. A qualitative building test should be carried out by a building specialist, but this requires better knowledge of building physics than has been the case until now. This report also explains the fundamentals of the infrared technique and the mode of operation of a heat picture camera.

24. *EVANS, J. (1978) Airborne thermography - Flight plan for tomorrow. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September 1978, The American Society of Photogrammetry, 105 Virginia Ave., Falls Church, Virginia 22046.*

Surveys conducted during the last few winter seasons have demonstrated that airborne thermography is a viable technology in interesting home owners in energy conservation. These surveys are essentially an extension of techniques developed for the military but adapted to large area surveying for heat loss detection. Improvements are being made to provide better technology and/or lower cost per unit surveyed, and to make it easier to transfer information from the thermograms to the individual building owner. The main advantages are that airborne thermography can provide a nearly synoptic overview of large areas (e.g., entire cities) thereby giving a uniform level of information to each building owner within a short time. The overhead technique allows perceiving building components with the highest radiant energy loss potential.

The primary problems encountered include the relatively high costs of equipment, its maintenance and calibration, and operational and interpretation problems which include weather, roof obscuration by trees, roof pitch angle, variable roof materials, attic airflow and other building non-uniformities. Of extreme significance is that thermography records radiant energy, not temperatures and not insulation values. Research is required, and will be forthcoming, to develop improved methods of involving building owners in thermogram interpretation, acceptable empirical methods for determining roof heat loss (backed by theory proven by use), improved specification education to prevent inadequate surveys from being conducted, and development of quality control methods.

Properly applied, airborne thermography will eventually be used as part of building code enforcement and as a specific component of energy auditing. In the interim, however, contract preparation and quality control parameters will continue in confusion. Additional studies will be conducted for heat gain (as associated with air conditioning); but such studies will be criticized for the poor equipment used, inadequate number of variable conditions studied, and limited geographic applicability, and they will not be authenticated by ASHRAE.

25. *FISHBURN, D.C. (1978) Roof thermography - Detection of subsurface moisture. Fourth Biennial Infrared Information Exchange, St. Louis, Missouri.*

The prevalent method of using visual means to detect moisture within the insulation of conventional built-up roofing systems and subsequently cutting into the membrane for verification has provided a largely useful but localized view of moisture damage in roofs. Experience has indicated that utilizing this procedure destroys the integrity of the membrane, invalidates warranties, and often leads to misinterpretation of roofing problems. The development of roof thermography has provided a means to detect, and accurately map, subsurface roof moisture, and promises to play a significant role in nondestructive testing of roof assemblies. Steady-state conditions, complexity of roof assemblies, and sensitivity of roofs to moisture and environmental conditions pose interesting problems.

26. *FISHBURN, D.C. (1978) Roof thermography. The Specification Associate, January/February 1978, Ontario, Canada.*

Roof thermography is being chiefly promoted in three areas of building problems:

1. Quality control for new roof construction
2. Preventive maintenance for existing roofs
3. Assessment of thermal performance of roofs.

Roofing failure represents approximately 25% of all civil actions against architects, and the cost to building owners amounts to millions of dollars each year. Roof thermography test procedures are proving to be a cost effective method for the protection of designers and building owners. Thermography provides a quick, reliable method for qualifying roofs prior to acceptance and ensures that the roofs are left without deficiencies. Thermography also maximizes roof guaranties by providing a precise up-to-date check of the roof prior to termination of guaranties. Early detection and correction of leaks usually eliminate latent defects associated with moisture migration, which are normally excluded by warranties.

Infrared findings permit repair or replacement of localized roof defects at a considerable cost savings over the common practice of removing all or large areas of roofing. Since the amount of damaged insulation can be predetermined, it is possible to establish repair priorities so that realistic budget levels can be established and best design approach arrived at to resolve roof problems.

The thermal upgrading of roofs is an important method for reducing energy requirements. Thermography can assess the heat loss of existing roofs and has proven effective in evaluating new roof designs and construction techniques.

A typical roof thermography specification format is:

"Upon completion and closure of building, and prior to final inspection, conduct a roof thermography survey to determine quality of roof construction and to detect excessive heat loss.

"Operate heating or air-conditioning system as required at time of survey to create a minimum temperature difference of 14°C between interior and exterior of building.

"Engage an independent roof thermography consultant company employing trained infrared camera technicians using a Model 750 infrared camera manufactured by Agatronics Limited of Sweden, or equal; conduct survey from exterior of building during environmental conditions as determined by the thermography consultant.

"Within eight working days of the survey, submit a written and photographic report of roof condition to architect: Conventional photos, 3 x 5 Polaroid or equal, shall accompany infrared photos.

"Repair or replace any roof component found defective by the roof thermography survey. Upon completion of remedial work, provide additional follow-up thermography as required to verify correct installation."

27. *FISHBURN, D.C. (1978) Wall thermography. The Specification Associate, March/April 1978, Ontario, Canada.*

Wall thermography is being chiefly promoted in two areas of building:

1. For quality control of new wall construction
2. For the thermal upgrading of walls.

Physical damage, poor workmanship, and high humidity levels during construction can impair wall performance from the beginning. Thermography provides a quick, reliable method for qualifying walls prior to acceptance and ensures that trades are doing their jobs properly and that walls are left without defects. Wall materials and workmanship guaranties are maximized by providing a precise up-to-date check of walls prior to termination of those guaranties. Thermal scanning reveals the effects of moisture control, jointing, and sealing methods.

Thermography is ideal for thermal upgrading and maintaining a high standard of quality control in the re-insulation of existing buildings. Infrared pinpoints poor or uninsulated wall areas, wet insulation, leaks through windows, and breaks in vapor barriers. Thermography locates cavities and blind wall spaces for injection of insulation.

A typical wall thermography specification format is:

""Upon closure of building and prior to final inspection by architect, _____ shall be appointed to conduct a thermography survey to ensure that thermal integrity of exterior walls has been achieved. Survey shall be conducted while heating or air conditioning system is in operation and when dictated by atmospheric conditions and as determined by thermography consultant. Within eight working days of the survey, submit a written and photographic report of wall condition to the architect. Conventional photos, 3 x 5 Polaroid or equal, shall accompany thermogram photos.

"The general contractor, to the satisfaction of the architect, shall repair, replace or make good any wall component found defective by the wall thermography survey, and upon completion of remedial work, provide additional follow-up thermography to verify correct installation."

28. *GOLDSTEIN, R.J. (1978) Application of aerial infrared thermography to the measurement of building heat loss. ASHRAE Transactions 1978, Vol. 84, Part 1.*

The possibility of using airborne infrared scanners to measure the heat loss through the rooftops of buildings has been examined. Even considering one-dimensional quasi-steady heat flow through the roof, a perfect scanner and no absorption or emission in the atmosphere between the aircraft and the ground, a number of variables could cloud the results and lead to ambiguous interpretation. This is true even on a relative basis assuming fixed sky temperature and fixed ambient air temperature.

One of the important variables that determine the surface temperature of a roof is the local wind speed. Other variables are the sky temperature and (if present) ventilation beneath the roof. These could overshadow the influence of the roof-structure thermal resistance on the surface temperature.

Uncertainties are also present in the roof temperature measurement. Slight changes in roof emissivity do not have a major effect on the actual roof surface temperature. They do, however, have a significant effect on the apparent roof temperature as measured by an infrared scanner.

The results of the present study do not indicate that there are no applications of aerial infrared scanner measurements for determining building heat loss. They do, however, point out the care that must be taken because of the large number of parameters that can have a significant influence on the measurements. They also point out what the application of such measuring systems for roof heat loss will work best with roof surfaces which are homogeneous and horizontal, so that the variations in the surroundings do not affect the results.

On a uniform surface, infrared scanner results are valuable in finding discontinuities in roof surface temperature. This includes effects due to open air vents, heating lines close to the roof, local heat spots within the structure near the roof surface, and local regions within the ceiling where there is not significant insulation or where the insulation is damaged.

Application of the technique to measuring differences in heat losses from individual residences would not appear at present to yield good quantitative results. If the emissivity of a roof surface as well as the micro-climate near a building were known, it might be possible to get qualitative information on the relative heat losses from individual buildings; at least a comparison of roof structures with very low thermal resistances to those with moderate or high resistances should be possible when the wind speed is small.

29. *GROT, R.A., R.H. MUNIS, S.J. MARSHALL and A. GREATOREX (1978) A comparative testing of the applicability of various thermal scanning systems for detecting heat losses in buildings. Fourth Biennial Infrared Information Exchange, St. Louis, Missouri.*

A two-stage program for determining the applicability of various remote thermal scanning systems for detecting heat losses in buildings is described. The types of instruments which were tested were high resolution thermal imaging systems, low resolution thermal imaging systems, thermal line scanners and point radiometers. The first phase of this project consisted of inserting known building defects into a specially designed room at the U.S. Army Cold Regions Research and Engineering Laboratory and having a representative of the manufacturer of each type of equipment inspect the room at three temperature differences across the room envelope. The second phase of this project consisted of a field evaluation of these same instruments in approximately 10 cities in cooperation with a weatherization program for low-income housing sponsored by the Community Services Administration and directed by the National Bureau of Standards. The goal of the second phase will be to determine the cost effectiveness of various remote thermal scanning services.

30. *GROT, R., D.T. Harrje and L.C. Johnson (1976) Application of thermography for evaluating effectiveness of retrofit measures. National Bureau of Standards, Washington, D.C.*

Retrofit measures in single-family dwellings are considered an important part of the overall U.S. energy conservation program. Thermography was used to evaluate the effectiveness of a number of different retrofit measures normally available to the resident-owner. In this study, a group of town houses were selected which, it was suspected, would benefit by commonly available retrofit measures. These houses were thermographically inspected before and after various retrofit measures were taken to increase the tightness of the dwellings. These included caulking of windows, doors, and exterior cracks as well as increasing attic insulations from thermal resistances R-11 to R-30. Thermography was found to be an effective tool for evaluating these retrofit measures which decreased the energy consumption by about 25%.

31. *HARDING, J. (1976) Thermography: Visual proof of an insulation job well done. Roofing, Siding, Insulation Magazine, 2 thermograms, p. 64-66, November.*

Harding Insulation of Minneapolis, Minnesota, utilizes an infrared inspection service (Energy Conservation Consultants, Inc., Bloomington, Minnesota) to stimulate its sales and convince homeowners that they are getting sufficient and proper insulation. Minnesota was the first state to pass a bill for "Design and Evaluation Criteria for Energy

Conservation in New Buildings," which calls for all new homes to be insulated to prescribed performance standards. A suggestion for the use of thermographic inspection of all foamed-in-place urea formaldehyde insulation installations has been issued by the Building Code Division of Minnesota Department of Administration. The city of Rochester will not approve similar installations unless and until they are thermographically inspected.

32. *HARRJE, D.T. and R.A. Grot (1976) Energy conservation in housing, retrofitting and documentation. Thermography and Energy Conservation, First Canadian Symposium, Toronto/Montreal, 2-3 December, 1976, W.D. Stainton, Editor.*

Retrofit measures in single-family dwellings are considered an important part of the overall U.S. Energy Conservation Program. Thermography was used to evaluate the effectiveness of a number of different retrofit measures normally available to the resident-owner. In this study, a group of town houses was selected which, it was suspected, could benefit by commonly available retrofit measures. These houses were thermographically inspected before and after various retrofit measures were performed. Thermography was found to be an effective tool for evaluating these retrofit measures which decreased the energy consumption by about 25%.

33. *HAZARD, W.R. (1978) Alternative methods of measuring heat exchange from building enclosures: A critical comparison. Fourth Biennial Infrared Information Exchange, St. Louis, Missouri.*

A comparison of structural heat loss estimates of 15 test houses, based on (1) standard engineering audits, (2) airborne infrared and (3) ground truth measurements (utilizing digital contact thermometers) shows a remarkable degree of correspondence between infrared and ground-level estimates of loss from roofs, walls and windows.

Factors which were taken into account in the calculations of the airborne audits were as follows:

1. Thermal resistance of the surface air film along roofs, walls and windows.

2. Wind velocities and directions across the building surfaces at the moment the thermal image is obtained.

3. Emissivity (absorptivity) and reflectance of the building surfaces and surrounding ground environment.

4. Radiation effects of the sky, ground and nearby buildings on the measured surface temperatures.

5. Wet and dry temperatures (dew point) of the air envelope surrounding a structure.

6. Viewing angle of the infrared camera and the scanned surface plane.

7. Residual thermal storage from previous daytime sun exposure.

These elaborations will be substantiated and documented in more detail in an interim report to the Department of Energy. The ramifications of this finding should be important for expending the use of airborne audits in comparison to alternative methods of calculating energy consumption from buildings.

34. *HAZARD, W. (1976) A multi-staged thermal survey of housing. Hazard and Associates, Austin, Texas.*

Three broad areas of concern must be examined for a definitive analysis of energy conservation in buildings - those factors which define the nature of the enclosure, those related to thermostat setting and occupant life style, and those related to equipment efficiency and heat recovery devices.

In general, energy transfer through a residential enclosure is a function of the type and quantity of materials used, the quality of construction and certain design features. The factors of importance are: 1) insulation, 2) infiltration, 3) glass, 4) orientation and external shading, and 5) building shape and thermal mass.

This preliminary study of heat gain/loss in Garland, Texas, focused on loss through convection, radiation and conduction from glass and from an infiltration through small openings in joints, around doors and windows, under baseboards, etc. Glass and infiltration aspects of a structure are shown to be the major determinants of the energy performance of building enclosures.

Particularly, the analysis concerned insulation and infiltration factors which have in the past proved to be difficult to determine and elusive to document.

The principal means of estimating loss from 22,577 structures was to observe thermal "flaring" from photographic records of an airborne radiometer.

In the Texas Instruments B-310 radiometer, energy is received by the scanner from the ground, is focused on cryogenic-cooled detectors, converted to light through the use of a light-emitting diode, and by means of a mechanically-coupled recorder exposes the photographic film in the film magazine. The film is moved at a rate proportional to the velocity and height of the aircraft, producing a continuous photographic record of the radiant energy detected.

By utilizing the AGA Thermovision system on the ground, relative surface temperature variations of $\pm 2^{\circ}C$ were calculated, thereby revealing the presence of even the slightest cold air infiltration around casings and jambs, under baseboards, or through joints in the walls and ceilings. Insulation problems due to hot air leakage and cold air infiltration were thus identified.

Energy loss from each of 24 test houses is classified as "severe," "high," "moderate," and "low" by scoring the energy performance of a structure along several dimensions. Conclusions about overall heat loss in Garland, Texas (a suburb of Dallas), were that approximately 2% of the single-family structures in the city exhibit noticeable loss. Eight percent of the multi-family units and nearly 90% of the commercial and industrial buildings show a similar significant degree of heat loss/gain due to infiltration problems.

35. *HEADLEY, R.B., R.J. Larsen, G.M. Goldberg and R.L. Boyd (1977) Infrared thermography requirements study for energy conservation. Final Report no. ARI-ADD-77-1, Prepared for U.S. Energy Research and Development Administration, 20 Massachusetts Avenue, Washington, D.C., 4 thermograms, 138 p. PC A08/MFA01.*

Aerodyne Research, Inc.'s contract with the U.S. Energy Research and Development Administration requires that a study be made to identify users (and their needs) of IR instrumentation that may be applicable in the measurement of heat gain and/or losses from buildings and to identify research and development and demonstration opportunities. The work flow diagram for this study is shown and is intended to provide the following information:

Identify present and potential uses and users of infrared thermographic technology.

Identify presently available IR thermographic instrumentation, techniques, and services, and determine how well they can serve the users and uses identified above.

Identify technical opportunities for research, development, and demonstration (RD&D) on new IR thermographic technology that will better serve the users and uses identified above.

Under a subcontract to Aerodyne, the NAHB Research Foundation, Inc. has analyzed the building sector requirements, identified the user measurement requirements, and provided cost guidelines for instrumentation. This work is described in Section 2.

Section 3 contains an analysis of the constraints, requirements, and limitations of measurable parameters. This analysis provides the basis against which the IR instrument survey was conducted and reported in Section 4.

The building sector requirements study indicates the general satisfaction of the user community with the use of IR thermography for qualitative evaluation of heat loss from buildings. It is pointed out that qualitative evaluation requires resolvable temperature differences of 1 to 3.5°C. Cryogenic thermographic scanning systems as they exist today have this capability but have been used, for the most part, for qualitative heat loss evaluation. If 1°C resolution systems can be used to provide the same qualitative information, then the reduced resolution may allow for instrumentation with a 5:1 or better cost saving. The community use should increase significantly.

Wider use of IR thermography will require education and training. Demonstration programs are needed to develop the art of thermographic interpretation for wider community use. As a part of this effort, it will be necessary to demonstrate that thermography using 1°C instruments provides essentially the same qualitative information as do 0.1°C instruments.

Absolute temperature measurements for quantitative code enforcement and for laboratory use require 0.1° to 0.35°C accuracy. This can be done in IR measurements from the inside of buildings. Outside measurements are limited to 1°C uncertainty, however. Accuracies better than this require a temperature computation and instrument calibration that will account for spectral wavelength properties of the atmosphere, background, and building materials. Spectral emissivities of building materials must be known to the order of 0.5%. A measurement program is required to determine the limitation in emissivity measurement and to evaluate the effect of the nonuniform IR background that is reflected off the structure into the IR thermographic camera. Recommended R&D includes the need to:

1. Measure spectral radiation parameters such as emissivity that now limit the usefulness of quantitative temperature measurements.

2. Develop very low cost electro-optical thermal imaging devices for qualitative heat loss evaluation.

3. Accomplish spectral optimization of electro-optical thermal imaging cameras for precise quantitative measurements of heat loss.

4. Develop infrared liquid crystal and semiconductor photographic sensor material and cameras with very low cost thermographic picture potential.

36. *HESS, R.A. (1975) Aerial heat sensing detects hidden energy waste. Airconditioning and Refrigeration Business, October, 1 thermogram, 2 p.*

Thermal scanning from a helicopter offers the energy manager an opportunity to study energy use and waste over his entire facility at one time. It gives him a profile of the interaction of the various buildings and operations in his plants and offers an opportunity to set priorities for energy savings.

For instance, one survey showed a tremendous heat loss from a warehouse. The owners asked themselves if the warehouse really needed to be heated since its only occupant was an occasional fork-lift operator. Another survey found electrically heated steps that ran continually, rather than only during periods of ice and snow. The 16.5-kW-steps were wasting 56,336 Btu/hr. In another case, it was found that a small steam leak of 1/2-in diameter under 90-lb pressure over a 12-month period, at a cost of $4 per 1000 lb of steam, would cost about $14,000.

A typical college campus survey costs between $7,000 to $12,000; but steam leaks detected waste more than that in energy costs in less than a year.

37. *Holmsten, D. (1977) Energy conservaton: Thermography of buildings for quality inspection. Engineering Digest, Vol. 23, No. 1, January 1977, p. 21-26. (Toronto, Ontario, Canada).*

For more than ten years "Thermography" has been applied in Europe to reduce to a minimum energy wastage in residential and commercial buildings, and also in industrial plants. More recently, infrared sensing has become an important tool in heat loss detection in North America. The technique comprises an infrared scanner linked to a CRT screen displaying dynamic thermal patterns and permitting the immediate identification of defects in insulation, air leaks, air infiltration, wet insulation, and other major sources of heat loss in buildings. Temperature gradients are measured instantly to establish the seriousness of the problem, and a permanent record is made by taking photographs of the display screen. Thermographic building inspection has now found its way to North America and is available in Canada.

38. *HUMPHRIES, G. (1978) Infrared, a municipal tool. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September 1978, The American Society of Photogrammetry, 105 Virginia Ave., Falls Church, Virginia 22046.*

In 1975 the decision was made to conduct an infrared flyover for the City of Garland, Texas. The decision was prompted, in principle, because of high electric bill complaints. The City of Garland has its own Electric Generating, Transmission, and Distribution System.

Garland has a population of 145,000. There are about 43,000 single-family residences in the city with over 10,000 all-electric heated by electric resistance heat. The area has a high air-conditioning requirement, yet the winter peak, with the added all-electric load, is running in excess of 85% of the summer peak. With average consumption in January 1977 over 3200 kWh per all-electric home and maximum at over 10,000 kWh, the need for assistance to the all-electric home owner is monumental. The city conducted its first infrared flyover in February 1976 in weather that was too warm for acceptable results. A second flyover was made in January 1977 during a period that was more than sufficiently cold. The 1977 study is being used at present. A third flyover is planned for the coming winter.

How We Use Infrared

Customer Service: Answering high electric bill complaints. Finding overlooked problems in large industrial complexes. Cataloging high heat loss customers for future energy audits.

Building Inspection: Locating swimming pools, carports, and other construction that may not have been permitted.

Planning: Evaluating off-street parking and value of rear-entry garages. Future land use planning.

Infrared is an ongoing program in the city of Garland, and additional uses are continually being found.

39. *HUPPMANN, G. (1977) Quantitative evaluation of infrared pictures of house facades. The Measuring System 'Thermobil'. Messerschmitt G.m.b.H. Offobrunn, Germany.*

The mode of operation of the Thermobil measuring system used for the detection of heat losses in buildings is described. First, heat images supplied by an infrared camera are digitized, displayed and stored on-line. These data are evaluated by means of a suitable calculating program. They present a temperature image of the surface with the temperature given in absolute values. Under favorable conditions, an image of the heat flow which, by means of a computerized program can be calculated from this temperature image, is presented as computer printout.

40. *HURLEY, C.W. and K.G. Kreider (1976) Applications of thermography for energy conservation in industry. National Bureau of Standards, Dept. of Commerce, Washington, DC, Report no. NBS TN-923, 11 thermograms, 31 p.*

Infrared thermography has been developed as a tool to measure the temperature of various types of surfaces. Notable applications include thermal detection of diseases such as cancer and circulatory problems in human beings, aerial land mapping of hot surfaces to detect thermal pollution and geological formations, and remote scanning of buildings to detect heat losses. More recently, infrared scanning has been used to detect defects in high amperage electrical connections, transformers, and steel processing furnaces in industrial environments.

It was the intent of the NBS IR program to build on these technologies to assist energy conservation engineers to assess heat losses in industrial plants. IR teams from the NBS Center for Building Technology had previously used the equipment to survey heat losses in buildings where the IR camera was found to be particularly useful in detecting infiltration problems, missing insulation, and construction defects. The intent of this project was to survey furnaces and heating systems in addition to electrical and mechanical systems to find areas suggesting energy conserving actions. This qualitative survey has been found to be an excellent method to detect heat losses in unit process equipment and auxiliary systems. The survey method described in this paper was carried out in 15 industrial plants to develop a methodology and examine the feasibility of the approach.

In addition to the qualitative survey, quantitative data were gathered by calibrating the temperature of the "hot spots" uncovered in the survey. This information was very useful in developing priorities and estimating the magnitude of the heat loss due to a given defect.

41. *Inframetrics, Inc. (1976) Thermographic heat loss survey of the Given/Rowell Medical Building Complex at the University of Vermont. Inframetrics, Inc., 225 Crescent St., Waltham, Massachusetts, 7 thermograms, 4 p.*

The survey was conducted at night on 5 and 6 April 1976 with normal inside temperatures and an outside temperature of 3°C. Some observations were as follows:

1. As much as 50% of the energy consumed was expended through the exhaust louvers.

2. Areas on the roof of the heat exchanger penthouse indicated heat loss and need of repair.

3. Hot spots on some windows indicated that the air deflectors on the heat exchangers below the windows were directing the air blast against the windows and should be reoriented to direct the heat back into the rooms.

4. Heat was being lost through a window behind the elevator.

The survey suggested that $1213/year could be saved by correcting these deficiencies. Energy loss calculations from a thermograph in terms of cost savings per year are described in an appendix.

42. *JONES, A.M., I.E. SMITH and S.D. PROBERT (1977) External thermography of buildings and structures as a means of determining their heat losses. Society of Photo-Optical Instrumentation Engineers, Bellingham, Washington. Vol. 110, Industrial and Civil Applications of Infrared Technology (SIRA June 1977 London).*

Infrared imaging techniques offer the possibility of mass monitoring of the external temperatures of buildings such as factories and dwellings on a non-intrusive basis to determine those losing an excessive amount of heat. It is shown that typically external surface temperatures are only a few degrees above ambient, and to relate thermal images to the surface temperature the emissivity of the material must be accurately known. Emissivities of common building materials in the range 2 - 5.6 μ have been determined and are tabulated.

43. *KISATSKY, P., M. Barbarisi and G. Tirellis (1977) A preliminary thermographic heat survey of U.S. Army Armament Research and Development Command Facilities (Dover, NJ). Technical Report: ARLCD-TR-77014, ARRADCOM, LCWSL, Applied Sciences Division (DRDAR-LCA) Dover, New Jersey 07802, 48 p.*

An infrared thermographic survey was made of buildings and facilities in Picatinny Arsenal to demonstrate the usefulness of IR thermography as a diagnostic technique for discovering and identifying sources of heat loss. Several examples are shown in which thermography yields valuable information on insulation deficiencies, poorly insulated steam lines, running vent fans, open windows, etc. Thermographic data need careful interpretation and are vulnerable to emissivity variations. Parameters for developing a quantitative thermographic methodology are identified as a basis for future work.

44. *KORHONEN, C. and W. TOBIASSON (1978) Detecting wet roof insulation with a hand-held infrared camera. First Biennial Infrared Information Exchange, St. Louis, Missouri.*

Since 1975, CRREL has used hand-held infrared scanners for detecting wet insulation under built-up roof membranes. Thermocouples installed on roofs have shown that temperature differences between areas of wet

and dry insulation may exist during both day and night. The optimum time to detect these differences with an infrared camera is at night when solar interference is eliminated. Surveys have been conducted successfully in locations from Alabama to Alaska during both warm and cold weather. Three-inch diameter core samples of the roof membrane and insulation have been obtained to verify infrared findings.

45a. *KORHONEN, C., W. Tobiasson and T. Dudley (1977) CRREL roof moisture survey: Pease Air Force Base, Buildings 33, 116, 122 and 205. U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) Hanover, New Hampshire, 4 thermograms, 14 p. (Also published as 45b).*

During the night of 14-15 October 1976, the roofs of Buildings 33, 116, 112 and 205 at Pease AFB were surveyed with an infrared camera. Infrared photographs (thermograms) were obtained on light-colored (hot) anomalies on each roof. Suspected moisture-caused anomalies were outlined with white spray paint. The following day, samples were taken to verify infrared findings, conventional photographs were obtained, problem areas were examined for visual signs of distress, and dimensions were taken to locate the anomalies on plans of each roof. Water contents of all samples were subsequently determined by oven drying at 110°F. This report covers the above work and also includes information on Building 116 obtained on 10 September 1975 as part of the roof research program that CRREL is conducting for the Facility Engineering Directorate of the Corps of Engineers.

45b. *KORHONEN, C., W. Tobiasson and T. Dudley. The infrared detective: thermograms and roof moisture. September 1977, ASHRAE Journal, p. 41-44, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (Also published as 45a).*

Four building roofs at Pease AFB were surveyed with a hand-held infrared camera to detect wet insulation. Areas of wet insulation on these roofs were marked with spray paint, and 3-in.-diam core samples of the built-up membrane and insulation were taken to verify wet and dry conditions. Flashing defects are considered responsible for most of the wet insulation uncovered in this survey. Recommendations for maintenance, repair, and replacement were developed from the infrared surveys, core samples and visual examinations.

46. *LAWRENCE, G.R. (1976) Ontario Centre for Remote Sensing Airborne Thermal Sensing Program for the Detection of Building Heat Loss. Thermography and Energy Conservation. First Canadian Symposium, Toronto/Montreal, 2-3 December 1976, W.D. Stainton, Editor.*

Energy conservation is first and foremost the elimination of existing waste energy. One area of significant waste energy is the heat

lost in winter through the inadequate or damaged roof insulation of homes, commercial buildings and other structures. To make the residents and owners of buildings aware of heat leakage, or the amount of money being wasted in heating costs, an efficient method of obtaining a heat loss assessment on a large scale is needed.

To meet this need, the Ontario Ministry of Energy, through its Energy Conservation Program, requested the Ontario Centre for Remote Sensing to assess the applicability of thermal remote sensing to this problem.

The initial stage of this assessment program was to examine the technical aspects of thermal sensing as they related to the detection of building heat losses. This also included a complete literature review of the subject. These findings were presented to the Ministry of Energy. The report showed that terrestrial thermal sensing could be considered an operational technique, as a close-up method for determining structural heat loss of a local nature.

Airborne applications for coverage over large areas, however, were found to be in an early stage of development. Only one large-scale airborne operation had been reported on.

The report supported the hypothesis that thermal remote sensing could play a substantial role in an energy conservation program. The existing studies offered answers to many questions regarding applicability of this technique and provided a body of information on which to base further research.

47. *LEWIS, J. (1978) Infrared survey: Iowa utility experience. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September 1978, The American Society of Photogrammetry, 105 Virginia Ave., Falls Church, Virginia 22046.*

In October of 1977, the Iowa Utility Association announced it was embarking on a project called Operation Sky Scan, which involves the most comprehensive thermogramming effort ever attempted for conservation purposes. The Association, representing 11 investor-owned utilities, contracted with Texas Instruments, Inc., to overfly virtually every incorporated community within Iowa, over 800 of them, and to develop prints which could be reviewed by utility personnel and the homeowners or occupants of the overflown buildings. In addition to the 11 investor-owned companies, several municipal utilities have participated in the survey program. The survey flights are conducted during the nighttime when temperatures are below 35°F and rooftops free of snow. The completion of the program has been impeded by the fact that Iowa suffered one

of its most severe winters in history with snow cover remaining on houses in much of the state for the vast majority of the winter months. Even so, over 200 communities were surveyed, and those results have been made available to the individuals involved.

The remainder of the cities are expected to be surveyed this coming winter.

This project was selected for a number of reasons, including the following:

1. Its breadth and massiveness are such as to create a significant amount of important news and public information activities with a resultant impact on conservation education.

2. The cost/benefit ratio is such that very excellent returns on the investment by the participating utilities can be achieved through pursuant conservation actions by the building owner or occupant.

The survey aircraft include a Queen Air and a DC3, both of which were used in Iowa during the periods in which weather allowed the program to be conducted.

48. *LINK, L.E., Jr. (1976) Procedures for the systematic evaluation of remote sensor performance and quantitative mission planning. Mobility and Environmental Systems Laboratory, U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, Mississippi 39180, Technical Report M-76-8.*

An effective application of remote sensing techniques to civil engineering and environmental problems requires the selection of the sensor systems that will best provide the information desired. Because of the many phenomena involved and the lack of a simple means to consider them collectively, planning remote sensing missions has been done subjectively, quantitatively on a piecemeal basis, or solely on the experience of the investigator. None of these offers a systematic means to optimize the mission for acquisition of specific information types as a function of the many variables involved. The purpose of this study was (1) to quantitatively examine the natural phenomena that influence the information content of remote sensing imagery obtained in the visible and infrared (IR) portions of the electromagnetic spectrum, and (2) from the knowledge gained through these examinations, to develop analytical tools for planning remote sensing missions and provide guidance for application of photographic and thermal IR sensor systems to civil engineering and environmental problems.

This study consisted of (1) development of analytical models that allow systematic control of the major variables that influence the character of imagery produced by photographic and thermal IR scanning sensor systems, and (2) formulation from the models of simple, but comprehensive, tools for planning photographic and thermal IR remote sensing missions. The basic concept of the models and the mission planning tools is an organized and quantitative means for evaluating photographic and thermal IR sensor systems for particular data acquisition jobs by contrasting the magnitude and spectral content of energy received by the sensors with performance characteristics of the sensor systems. The ability to quantitatively predict performance provides the capability necessary to quantitatively plan missions for specified types of data. Variables considered include the source of electromagnetic radiation, interactions with terrain materials, interactions with the atmosphere, sensor altitude, time of day, time of year, source-sensor position, and sensor spectral and spatial characteristics.

The Photographic Systems Simulation Model and the Thermal IR Systems Simulation Models provide a new dimension for systematic evaluation of remote sensor performance and quantitative mission design previously unavailable to personnel applying remote sensors to civil engineering and environmental problems. The systems models and the graphical products derived from the models allow selection of the best (of those available) sensor system for a specific data acquisition problem by providing a means of quantitatively comparing the expected performances of a variety of sensors for the specific data needs. In addition, the models and derived products provide a means of quantitatively planning the remote sensing mission to optimize the information content of the resulting imagery for the specific data needs.

The systems models consider the major phenomena that influence the informational content of photographic and thermal IR sensors imagery. As is usually the case, a variety of analytical methods could have been used to model these phenomena. The methods used were chosen to provide a comprehensive description of the phenomena and yet minimize the number of hard-to-get inputs required to execute the models. As such, the models were oriented toward the people who apply remote sensors rather than those who design them.

49. *LINK, L.E. (1976) Demonstration of a new technique for rapidly surveying roof moisture. Miscellaneous Paper M-76-14, MESL, U.S. Army Engineer Waterways Experiment Station (WES), P.O. Box 631, Vicksburg, Mississippi. Final Report prepared for U.S. Air Force, SAC Hdqrs., Offutt AFB, Omaha, Nebraska, 49 p.*

The results of this study demonstrate the potential of the combined thermal IR-nuclear moisture meter roof survey technique. Application of the technique at Dyess AFB, Texas, resulted in the detection of roof

areas with entrapped moisture on 5 of the 128 buildings surveyed. Airborne thermal IR imagery proved to be a very effective means of identifying roof areas with potential entrapped moisture. Some false alarms were created by air vents on smaller buildings; however, prior knowledge of the position of the vents (i.e., during the examination of the imagery) would probably reduce this problem considerably. Not all the questions were answered. Information is needed to define the usefulness of the technique as a function of climatic conditions and roof types. In addition, more data are needed to help define the optimum time for acquiring thermal IR imagery for roof moisture surveys.

50. *LINK, L.E. (1977) Airborne thermal infrared and nuclear meter systems for detecting roof moisture. Proceedings of the Symposium on Roofing Technology, National Bureau of Standards and National Roofing Contractors Association, p. 258-260.*

Roof maintenance and repair is a multimillion dollar item for both government and industry. Leaks are often associated with moisture entrapped within the roof system. Entrapped moisture in built-up roofs can cause deterioration of roof materials and destroy the effectiveness of insulation, resulting in excessive energy loss through the roof. Early detection of entrapped moisture may prevent costly replacement of deteriorated materials and at times allow localized repair or replacement, instead of replacement of an entire roof system. The ability to nondestructively detect and delineate roof areas with entrapped moisture would be valuable for monitoring roof conditions and planning roof maintenance and repair, and for quality assurance on new roof construction.

The U.S. Army Corps of Engineers has been evaluating a number of techniques for rapidly surveying roof moisture conditions. The techniques of primary interest have been (1) hand-held thermal infrared (IR), (2) airborne thermal IR, and (3) nuclear moisture meter systems. Hand-held thermal IR sensor systems have been investigated by the U.S. Army Engineer Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, and the Facilities Engineering Support Agency, Fort Belvoir, Virginia.

This paper describes a companion effort, conducted at the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, to evaluate airborne thermal IR and nuclear moisture meter systems for use as roof moisture survey tools. The WES effort deals not only with evaluating the potential of these systems for operational use, but also with formulating methodologies for their efficient application. The following sections present and discuss (1) the basic principles of the airborne IR and nuclear meter systems and (2) recommended methodologies for their application and examples of results.

51. *LLOYD, J.M. (1975) Thermal imaging systems. New York: Plenum Press, 11 thermograms, 445 p.*

In the early days of thermal imaging technology, strong competition kept design practices closely guarded secrets. Now that the field has expanded, many of these procedures have become standard, and an integrative, cohesive assessment is required. That is the aim of this book.

This volume, a dynamic introduction, as well as a ready reference for experienced practitioners, sets forth the essential design conventions which form the basis for forward-looking infrared (FLIR) practice. The work not only provides a useful compendium of previously unpublished or obscurely published literature, but also offers a systematic treatment of fundamental methods for thermal imaging system engineering. It includes more than 250 references and extensively details every major thermal imaging process - from thermal energy generation to visual psycho-physics.

This book is intended to serve as an introduction to the technology of thermal imaging and as a compendium of the conventions which form the basis of current FLIR practice. Those topics on thermal imaging which are covered adequately elsewhere are not treated here, so there is no discussion of detectors, cryogenic coolers, circuit design, or video displays. Useful information not readily available is referenced as originating from personal communications.

52. *LOWE, D.S. (1978) Improved airborne thermal mapping with an active/passive scanner. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September 1978, The American Society of Photogrammetry, 105 Virginia Ave., Falls Church, Virginia 22046.*

The concept of measuring thermal heat loss from buildings with thermal imaging sensors flown at 150 mph is appealing. Airborne thermography has been shown to be useful for detecting the worst energy conservation offenders in residential areas, but the technique is limited in its ability to precisely quantify heat loss because of variations in unknown parameters such as roof emissivity, roof view factor, and meteorological conditions. Variations in roof emissivity are particularly critical in estimating heat loss from commercial buildings.

This paper describes and illustrates the effects of emissivity on estimating surface temperature and recommends a program to automatically correct for variations in emissivity. The system would use an active 10.6-μm laser scanner to measure roof reflectance, while a passive thermal scanner measures the apparent temperature. With the aid of calibration panels, the data are processed automatically to derive surface temperature.

53. *LUKENS, J.E. and T.L. Flynn (1977) Thermography and energy conservation. New England Innovation Group, 39 Pike Street, Providence, Rhode Island, September 1977, 1 thermogram, 12 p.*

This report describes the results of an intergovernmental science and public technology demonstration project using thermography as a tool to identify excess heat loss and initiate major activities in the correction of building and heating system deficiencies in New England's publicly owned structures.

Some of the objectives discussed are how to: 1) close the information gap among the IR suppliers and potential public sector users of this technology; 2) demonstrate the utility of thermography in meeting the needs of New England local and state governments; 3) identify operating problems encountered in adopting this type of technology to civilian needs; 4) ultimately commercialize thermography, resulting in job and business opportunities in the energy conservation and management industry.

Fundamentals of thermography are discussed and general conclusions about using thermography effectively are presented. The results of energy conservation programs involving thermography reported over the past four years are summarized.

Costs and benefits ranging from $600 to $900 for a ground survey for a half-day to $2000 to $3000 for an airborne survey for a half-day are discussed. The return (benefits) to a building owner are presented. Some examples are: 1) $10 fuel savings over a 2 to 3 year period for every dollar spent on the survey, but not including the cost of repairs; 2) estimated annual fuel savings of 8% to 10% of the total cost of the survey and repairs; 3) fuel savings of about $1000 per year per building if 30 or more buildings are surveyed.

The report points out that IR surveys can provide data otherwise difficult to obtain to use in energy balance (or budget) calculations. IR surveys were found to be a very effective public service device by public agencies and utility companies. A list of equipment manufacturers, survey contractors, books, papers, and reports is provided for the convenience of the reader.

54. *LUKENS, John E. (1978) Vermont heat loss survey interpretation manual: Analysis of heat loss from buildings using aerial thermography. Reconnaissance Corporation, Box 374, Wickford, R.I. 02852.*

Within the past 10 years, thermography has been developed from its origin as a military intelligence tool into a tool that can be used by

public administrators and private building owners alike to make their energy conservation programs more effective. Thermography is the only technique that allows a rapid, synoptic, and nondestructive appraisal of the thermal characteristics of building surfaces and components. These thermographs (or "heat pictures") are primarily used to show where excessive energy losses are occurring, but they also can give a rough approximation of the amounts of energy loss.

This report describes interpretation techniques to be applied to aerial thermographs taken of selected cities and institutions in the State of Vermont in the spring of 1978.

55. *LYNCH, J. (1976) Practical application of infrared inspection of residential dwellings. Energy Conservation Consultants, Inc., Hopkins, Minnesota.*

Energy Conservation Consultants, Inc., have been offering infrared inspection services to residential home owners and insulation contractors for nearly a year. Using this technique, the user of this service can be provided with an on-site qualitative analysis of his energy losses. The basic inspection, interior or exterior, usually takes one hour or less. Interior inspections are becoming increasingly the trend, although exterior inspection is still important for identifying gross defects. Most high energy losses produce significant temperature variations, allowing for easily identifiable detection. Variations in building materials and weather conditions must always be taken into account but these do not prohibit practical inspection from being cost-effective.

56. *MARSHALL, S.J. Infrared thermography of buildings: 1977 Coast Guard Survey. USACRREL Special Report (in prep.)*

An IRTB (infrared thermography of buildings) field survey, producing 631 thermograms, 127 photographs, and weather data, was conducted during a 14-day study of 10 Coast Guard stations in Maine, New Hampshire , and Massachusetts. This report discusses how the survey was initiated and performed with emphasis on details for the benefit of the reader wishing to plan a survey. One-hundred and twenty selected thermograms and photographs in this report illustrate many types of heat loss and compare thermally ineffective doors and windows with units designated as standards for thermal effectiveness. Radiator heat leakage through walls, mottled moisture patterns on brick walls, infiltration patterns on glass, and poorly covered openings are illustrated. Thermograms of severe heat losses through glass doors, glass transoms, and glass wall panels are also included, and several solutions for individual heat loss problems, such as fiberglass garage doors and porcelain insulated panels, are suggested. Unanticipated survey problems, such as difficulties in obtaining photographs to compare with thermographically discovered artifacts and adjustments to survey techniques for inclement weather, are also discussed.

57a. *MARSHALL, S.J. and R.H. Munis (1974) An infrared thermographic analysis of Dartmouth College, Winter 1974. Part I: Thermogram inventory. CRREL Technical Note (unpublished), 114 thermograms, 30 p.*

During March-April 1974, 32 buildings on the Dartmouth College campus were surveyed at night with a Barnes Mobile Infrared Camera. One-hundred-fourteen thermograms are reproduced in this report with a listing of the operator's comments and other data.

57b. *MARSHALL, S.J. and R.H. Munis (1976) An infrared thermographic analysis of Dartmouth College, Spring 1976. Part II: Thermogram inventory. CRREL Technical Note (unpublished), 67 thermograms, 18 p.*

During March 1976 selected buildings on the Dartmouth College campus were resurveyed using an AGA Model 750 Thermovision System. Sixteen buildings were resurveyed and 64 thermograms taken.

57c. *MARSHALL, S.J. and R.H. Munis (1976) An infrared thermographic analysis of Dartmouth College. Part III: Building photographs, building energy usage data, weather data, campus map. CRREL Technical Note (unpublished), 50 p.*

Building photographs, building energy usage data and weather data are compiled in support of Parts I and II of the Dartmouth College infrared survey.

58. *MARSHALL, S.J. and R.H. Munis (1976) An infrared thermographic telephoto analysis of the Dartmouth 175-ft smokestack during a steeplejack inspection. CRREL Technical Note (unpublished), 15 thermograms, 19 p.*

During April/May 1976, the Dartmouth 175-ft unlined smokestack was inspected by a steeplejack to determine the extent of deterioration and recommend repairs.

This afforded an excellent opportunity to survey the smokestack at the same time with an infrared thermographic camera fitted with an infrared telephoto lens. The outside stack was also photographed with a telephoto lens to afford the opportunity of a close visual examination.

The thermograms were compared with the photographs and the chimney inspection report. It was concluded that dry mortar and stairstep cracks can be detected but that further research needs to be done in order to refine the technique.

59. *MARSHALL, S.J. and R.H. Morris (1976) Infrared thermographic analysis of a solar energy absorber plate. CRREL Technical Note (unpublished), 14 thermograms, 18 p.*

On 19 May 1976, a AGA 750 Thermovision System was used to observe a stacked panel experiment in operation. The experiment consisted essentially of two Olins Brass 17-in. x 50-in. solar panels which were operated backwards; i.e., hot water was pumped through them and the resulting heat patterns were studied by an infrared camera. This was found to be a unique and successful way to test solar panels. The panels were painted with Rustoleum to increase the surface emissivity.

The panels exhibited different thermal patterns when operated horizontally or vertically. In the horizontal position, the fluid tended to flow in the two lower paths and ignore the four upper paths. In the vertical position, the fluid tended to flow in the two middle paths and ignore the outer four paths.

Varying the flow rate changed the thermal patterns and a uniform thermal pattern was thought to correspond to the minimum flow rate necessary to operate the system at its maximum efficiency.

Trapped air was a problem throughout the test and real-time thermography was found to be a way to tell immediately if efforts were successful in trying to remove the trapped air.

Several path constrictions were easily located with thermography. These constrictions appeared to be the result of trapped impurities and/or constrictions due to irregularities inside the liquid path walls.

It was concluded that, by varying all the parameters while watching the thermal pattern changes with a scanning infrared system, parameters for optimum efficiency of operation of the solar panels could be determined which were not necessarily the manufacturers suggested parameters of operation.

60. *MAVROTHERIS, N.A. and J.L. Passauer (1977) Detection of heat loss through the use of aerial infrared imagery. 544 Intelligence Exploitation Squadron, Offutt Air Force Base, Nebraska 68113.*

On 7 February 1977, the Nebraska Air National Guard was used to fly over five 2500-ft paths which covered Offutt Air Base and surrounding military and civilian housing facilities. The conditions for the infrared survey were 6°F, 1000-ft height, and 0630 hours.

The imagery shows a halo effect around some of the buildings caused by heat which has escaped through windows and side walls and risen straight up as it hit the cold outside air.

Relatively new two-story, four-unit town houses displayed extremely poor insulation characteristics. On the site, investigation revealed as little as 2 in. of insulation in the attic and missing and thinly wrapped insulation around the duct work. A child-care center building, which is an adapted SAC design for other installations, showed excessive heat losses. No insulation whatsoever was found between a false ceiling and the gravel/pitch/felt roof. As a result of the IR survey, the roof design is being modified to include insulation.

Several side-by-side single-story and two-story duplex units revealed different heat loss patterns. The single-story units exhibited well insulated patterns, but the two-story units were almost uniformly bad, and even the white halo around each was brighter. Both types had 4 in. of rock wool in the attic, but the single-story units had all their duct work in the basement while the two-story units had their heating ducts in the attic.

Newly built civilian homes, except for one home, appeared well insulated. The owner of the latter home found that the contractor had neglected to install any insulation; this oversight was shortly corrected.

A comparison between old and new roofs in side-by-side buildings illustrated water seepage into the felt through cracks in the pitch and through capillary action in the deteriorating older roof. The new roof appeared uniformly dark and cool.

61. *MILL, P. (1978) Thermography - A new building science tool. Fourth Biennial Infrared Information Exchange, St. Louis, Missouri.*

Since September 1977, Public Works Canada has been surveying Canadian Federal Government buildings, involving the PWC headquarters, Department of National Defence, National Research Council, and Department of Indian and Northern Affairs. The objective has been to determine the potential for thermography and building science in evaluating building enclosures in diverse Canadian environments, with particular attention to design of arctic buildings. The results indicate that use of hybrid thermographic/video equipment, in ground and aerial building performance surveys, yields significant maintenance and retrofit cost savings through early identification and resolution of enclosure defects. Thermography relies on building science expertise for correct interpretation: without it, thermography currently cannot interpret adequately any building failures. It is important, consequently, that an operator be competent in knowledge of fundamental building science as well as in knowledge of thermography.

62. *MILL, P.A.D. (1978) Development of PWC capability in thermographic diagnosis of building envelope deficiencies. Public Works Canada, Technical Development, Architecture Division, Ottawa, Ontario, Canada, Report Series No. 26, March.*

Public Works Canada's study of the design and performance of building enclosures in Canada has revealed that insulation placement, air tightness and vapor control frequently are defective. These inadequacies result in moisture accumulation on the inside surfaces of wall and roof construction. This reduces thermal effectiveness, and in certain instances, eventually causes material degradation. In the arctic environment the effects of these deficiencies are more apparent because of the low temperatures, and the effects lead to severe and unnecessary stress on building occupants. The immediate effect on the building operation can be inefficient energy use with respect to heating and cooling, resulting in unnecessary discomfort for the occupants.

The Property Administration Branch of PWC indicates that approximately $10 million was spent on building maintenance in 1976-77. At least two-thirds of that sum was spent on repair and general maintenance of building enclosure elements. Use of building science for quality assurance extends from the development of design concepts and contract documents to supervision of the construction, and preventive maintenance. This is particularly critical to the occupants in the Arctic owing to severity of climate and relative isolation of buildings. To date little if any formal building science analysis has been included in any of these processes.

Recently developed methodologies in thermography and building science offer great potential for quickly and economically identifying buildings with enclosure defects and diagnosing their causes. Evaluation of four government buildings during the winter of 1976-77 demonstrated that thermography can be an effective tool for locating thermal inadequacies in a building enclosure. The costs incurred for maintenance and/or retrofit of the four buildings over a period of 5 to 10 years totalled some $650,000. However, much of this cost could have been avoided if thermographic analysis had been applied during the early stages of building occupancy, or in certain instances, if building science principles had been reflected in the design phase.

While other countries, notably Sweden and the United States, are developing thermography to evaluate energy efficiency in buildings, little is being done in Canada. Only Public Works Canada is using building science techniques with thermographic evaluation to provide more precise analytic capabilities and to identify a broader range of enclosure-performance issues for extreme climatic environments.

The need to ensure the competence of an operator to detect thermal inadequacies correctly has been demonstrated throughout the pilot and subsequent building studies. In addition, the interdepartmental approach has proven to be pragmatic, efficient and highly desirable. Following completion of the current field programs, another interdepartmental and regional program should be considered to further develop thermography to:

1) assist in the quality evaluation of new buildings by identifying and understanding thermal inadequacies while the buildings are under guaranty, thus avoiding costly long-term degradation

2) become an effective preventive maintenance tool

3) assess the energy efficiency of building enclosures by interpreting heat-flux distribution through the building walls (for retrofit purposes)

4) improve building science expertise in design and construction in Canada.

63. *MOREWOOD, H.W. (1974) Infrared imaging in snow and fog. Defense Research Board of Canada, DREV, P.O. Box 880, Courcelette, Quebec, G0A 1R0, DREV Technical Note 2091/74.*

A Series of infrared contrast measurements of heated buildings against snow background was carried out at DREV under a variety of winter weather conditions to obtain an indication of the usefulness of this type of equipment during inclement weather in the Arctic. Images were obtained on an 8-13 μm AGA Thermovision which was calibrated using a portable AGA Source and a Barnes PRT-5 radiometer. In ordinary snowfall the infrared was no better than, and sometimes inferior to, visual performance. However, there was some indication of an advantage for the infrared in very fine blowing or falling snow as well as a distinct advantage in some fog conditions.

64. *MUNIS, R.M. and R.A. Grot (1978) Current status of ASHRAE standards for conducting thermographic energy audits of buildings. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September 1978, The American Society of Photogrammetry, 105 Virginia Ave., Falls Church, Virginia 22046.*

During the past five years the use of infrared thermography for conducting energy audits of buildings has increased significantly. As the requirement for an objective analytical technique for documenting

heat losses from buildings has grown steadily, so has the availability of various infrared remote sensing systems.

The evolution of these systems, which vary widely in price and capability, has created a need for clarification of their respective roles in assessing the nature of heat losses from buildings. Therefore, an ASHRAE Standards Committee (SPC 101P) was created to devise acceptable procedures in using these systems, with participation of both the public and private sectors.

This paper gives a short history of the use of infrared thermography in conducting energy audits of buildings. The progress and current status of the ASHRAE Standards Committee are reviewed. The problems in attempting to develop a quantitative standard are contrasted with those problems inherent in the development of a qualitative standard. Possible solutions applicable to both situations are discussed. The results of a comparative evaluation of the major types of infrared remote sensing equipment, sponsored by the Department of Energy and made at the U.S. Army Cold Regions Research and Engineering Laboratory, are presented. The paper ends with a short discussion of the success of the New England Innovation Group, in spite of all the potential standardization problems, in using infrared thermography to help local public officials in New England control rapidly escalating heating costs.

65. *Munis, R.H., A. Grot, S.J. Marshall and A.R. Greatorex (1978) Comparative evaluation of portable infrared devices for determining locations of heat loss from buildings. New England Innovation Group, 39 Pike St., Providence, Rhode Island, 02903, 7 thermograms, 5 p.*

The types of portable infrared sensing devices considered for this test were: high resolution thermal imaging systems, low resolution thermal imaging systems, and thermal line scanners. The test consisted of locating 50 insulation and construction defects, deliberately hidden in the walls of an electrically heated test shelter situated in a large laboratory cold chamber. Each participant performed three 30-minute tests at temperatures of approximately 25°C, 15°C, and 10°C across the envelope of the test room.

Analysis of the results showed that the two high resolution systems performed considerably better than the line scanner and low resolution systems. All systems identified low resistance levels (i.e., voids, defects, air leaks) better than they determined the level of insulation of insulated regions. The high resolution systems located two to three times the number of defects and air leaks located by the other systems. Hard-copy capability, especially video recording, was judged to be beneficial because several defects not reported due to operator error were found on the hard-copy documentation by the evaluators and included in the scoring.

The probability of a high resolution system finding a defect or variation ranged from 79% to 97%; the low resolution system ranged from 29% to 34%; and the line scanner from 38% to 46%. The line scanner seemed particularly susceptible to temperature variations caused by opening and closing the test shelter door.

66. *MUNIS, R.H. (1977) How to reduce heating costs without alternative energy sources. DM Publications, Thetford Center, Vermont, 2 thermograms, 58 pages.*

This book is addressed to do-it-yourself homeowners who are interested in how to correctly and effectively insulate their houses. It outlines the first steps toward learning the facts about house insulation. It introduces the terminology used by building and insulating contractors, and explains why very few of them have been able to insulate houses successfully to cope with today's high cost of energy.

Most important, as a pioneer in the use of infrared thermography to pinpoint insulation deficiencies in buildings, the author explains and demonstrates the entire process of insulating correctly to effect a dramatic reduction in fuel bills. No one showed him; he acquired this information the hard way. He not only demonstrates the techniques of effective insulating, but describes the essentials of various types of insulation.

The author dispels several popular myths about insulating. He shows how to insulate a house to both save money and have a more comfortable, draft-free house.

Most people believe that insulating a house can be done only by an experienced contractor. But the author describes techniques that most contractors are not even aware of. Although many people enjoy doing carpentry work, some may not be interested in becoming involved with insulating. These people are missing the satisfaction of creating a warm and comfortable house while at the same time enjoying the praise of family, friends, and neighbors for being able to lower heating costs. This book offers an alternative to having high heating costs and an uncomfortable home.

67. *MUNIS, R.H. (1975) Thermography: A new way to profit from the energy crisis. Hicksville, New York: Exposition Press, Inc., 2 thermograms, 45 p.*

This book outlines an annovative, existing technology that promises to become, within the next five years, the single most important technology for effecting energy conservation in all buildings across the United States - infrared thermography.

Infrared thermography uses an infrared camera system to detect heat radiated from an object, and can be employed to pinpoint the locations of wasteful and costly heat loss and gain in every conceivable type and size of building. The book emphasizes that a short-term solution to the Energy Crisis can be obtained only by adequately insulating every building in this country - and infrared thermographic inspection is the only method by which the effectiveness of a building's insulation can be monitored.

The author gives a detailed explanation of this technology and its potential as a new and lucrative business (i.e., how a building heat loss inspection service can be established and profitably operated), and illustrates that no new technologies are required to assist homeowners, businessmen, and industrialists.

Photographs of the AGA Thermovision Infrared Camera System are included as well as thermograms ("heat pictures") showing costly heat loss.

68. *MUNIS, R.H., R.H. Berger, S.J. Marshall, and M.A. Bush (1974). Detecting structural heat losses with mobile infrared thermography. Part I: Description of technique. CRREL Research Report 326, AD 001549, 9 thermograms, 12 p.*

A method to assess quickly the insulation effectiveness of buildings using mobile infrared thermography has been developed at CRREL. In contrast to the infrared thermography done in Sweden, this method concentrates on obtaining useful data by measuring the outside surface temperature of structures. This report outlines the basic principles involved in these measurements, and discusses field measurements and the inherent advantages of infrared thermography. Typical thermograms are presented in the appendices.

69. *MUNIS, R.H., R.H. Berger, S.J. Marshall and M.A. Bush (1975) Detecting structural heat losses with mobile infrared thermography. Part II: Survey of Pease Air Force Base, Portsmouth, NH. CRREL Research Report 338, AD A012117, 32 thermograms, 29 p.*

During the winter of 1973-74, a mobile infrared thermography system was used to survey housing units and base facilities at Pease Air Force Base, Portsmouth, New Hampshire. This report provides both qualitative and quantitative evidence regarding heat flow out of the eave vents of these housing units. Calculations indicate that a significant amount of heat is being lost in this manner due to inadequate attic (cap) insulation. Possible evidence of incomplete ventilation could explain the presence of condensation in the housing units. Analyses of thermograms are presented to show the possible existence of low and high pressure areas around a structure and how they relate to heat loss.

70. *MUNIS, R.H., R.H. Berger, S.J. Marshall and M.A. Bush (1975) Detecting structural heat losses with mobile infrared thermography. December 1975. Part III. Survey of USACRREL. CRREL Research Report 348, AD A020375, 8 thermograms, 9 p.*

During the winter of 1973-74, a mobile infrared thermography system was used to survey the CRREL main building at Hanover, New Hampshire. This report provides a description of excessive heat losses at several locations around the building. This report also discusses the need to carefully monitor meteorological conditions before starting a survey of a building exterior to determine if solar radiation decay from the building surface might interfere with thermographic analysis by masking the heat emanating from within the building.

71. *MUNIS, R.H., S.J. Marshall and M.A. Bush (1976) Detecting structural heat losses with mobile infrared thermography. Part IV: Estimating quantitative heat loss at Dartmouth College, Hanover, New Hampshire. CRREL Report 76-33, A031803, 4 thermograms, 9 p.*

During the winter of 1973-74, a mobile infrared thermography system was used to survey campus buildings at Dartmouth College, Hanover, New Hampshire. This report provides both qualitative and quantitative data regarding heat flow through a small area of a wall of one brick dormitory building before and after installation of aluminum reflectors between radiators and the wall. These data were used to estimate annual cost savings for 22 buildings of similar construction having aluminum reflectors installed behind 1100 radiators. The data were then compared with the actual savings which were calculated from condensate meter data. The discrepancy between estimated and actual annual cost savings is explained in detail along with all assumptions required for these calculations.

72. *MUNIS, R.H., C.H. Burkhart and R. Riley (1976) Infrared thermography at the U.S. Coast Guard Academy. CRREL Technical Note (unpublished), 77 thermograms, 40 p.*

On 25 and 26 February 1976, CRREL workers surveyed Coast Guard Academy facilities in New London, Connecticut, using the AGA Thermovision System 750. The main purpose of the survey was a field evaluation of the AGA system. The survey time and scope were limited to those necessary to obtain a reasonably good idea of the capabilities and limitations of the AGA system; however, almost every academy structure was surveyed from two or more sides; this report gives a good general idea of the relative thermal efficiency of each building.

The report contains thermograms of various buildings, paired with normal photos taken some time later from about the same position. Thermograms in this report have been enlarged about two times. "Normal" photos were taken with a Kodak Pocket Instamatic.

Each page facing the thermograms and photos describes the particular building surveyed and makes certain observations deduced from an analysis of the thermographs. Almost all of these thermograms were taken at night, between 2100 and 0200, when the temperature was about 45°F. This was necessary during the survey period because of the unusually warm (mid-60's), sunny days. The difference between outdoor and indoor temperature should be greater than 30°F for effective thermography. Further, the absorption of solar energy by masonry and concrete surfaces completely distorts the true thermal picture; it is also possible that reradiated solar energy affects thermography if many hours have not passed since sunset.

A single number in the upper left-hand corner, or at the top edge of each thermogram (usually "2" or "5"), indicates the normal differential thermal scale shown. This number is in degrees Celsius, and represents the approximate difference in temperature between "very dark" (representing cool) and "very light" (representing warm). The left-hand scale is used in the "isotherm mode," which is explained within the report.

73. *MUNIS, R.H. and S.J. Marshall (1977) Infrared thermography of buildings: Qualitative analysis of window infiltration loss, Federal Office Building, Burlington, Vermont, CRREL Research Report RR77-29, 28 thermograms, 17 p.*

An interior, infrared thermographic survey of single-pane, aluminum-frame, projected windows was performed to pinpoint locations of excessive infiltration. Infrared thermographic inspection accomplishes this more quickly and more accurately than conventional techniques of studying window infiltration. This report presents 32 thermograms and photographs, which in many cases dramatically illustrate infiltrations 1) around the mullions, 2) along the top opening cracks, and 3) under the frame/sill interfaces. Poor glazing seals were easily detected and the exact points of glass/frame leakages were pinpointed. Plumes of warm air on the window glass, rising from the convectors, were dramatically captured by the infrared camera system. In several cases, the plumes were noted 12 ft above the convectors on the top window panels. Heat loss from the convectors was noted through the walls of the building in thermograms taken from the outside. Several recommendations were prepared for the General Services Administration, owner of the Federal Office Building in Burlington, Vermont.

74 *MUNIS, R.H. and S.J. Marshall (1977) Qualitative analysis of five buildings at Rickenbacker Air Force Base, Columbus, Ohio, RR77-26, 40 thermograms, 21 p.*

A heat loss survey was performed on five typical Air Force Base buildings with an infrared camera system: two with wood frames and wood clapboards, one with wood frame and aluminum siding, and two of cinder block construction with brick veneer. A walk-through inspection was also performed on three of these buildings chosen by project monitors

for retrofitting. This report presents thermograms typical of the heat loss problems in each of the five buildings along with a complete explanation of each thermogram. The purpose of the report is to serve as a basis upon which Air Force civil engineers can plan a future retrofit program for the buildings surveyed and write a set of specifications incorporating thermography. Typical thermograms show heat loss from large, single-pane, steel-frame, projected windows, which in one building account for 50% of the total wall area. Infiltration losses through framing spaces for all windows are evident. Heat patterns from precast concrete floor slabs and radiators under the windows show up clearly. Ribs in uninsulated door panels are clearly seen as well as leakage around the doors. Heat loss through the roof of a one-story duplex was easily recorded from the ground using the infrared camera system. Thermographic comparisons between windows with storm sashes and a picture window with insulating glass were made. Heat was found escaping from slab foundation vents and gable vents.

75. *MUNIS, R.H. and S.J. Marshall (1978). An airborne and ground thermographic inspection of the 26-story J.F. Kennedy High Rise Complex. CRREL Technical Note (unpublished), 23 thermograms, 12 p.*

A close-up infrared thermographic analysis of the total envelope of a modern high-rise building consisting of two 26 story towers and a connecting low-rise unit was performed during April 1977. The side walls and interior portions were surveyed with a AGA Model 750 Portable Thermal Imaging System and the flat roofs were surveyed from a helicopter using an Inframetrics Model 510 Portable Thermal Imaging System.

The ground level analysis of the side walls revealed significant infiltration and conduction losses from the single pane windows which constituted approximately 50% of the total wall area. Unevenly distributed plumes of heat rising against the inside glass surfaces indicated uneven heat circulation from the convectors in addition to excessive losses through the glass. Many of the concrete spandrels under the windows showed warm patterns coming from the convectors and risers indicating an uneven application of specified insulation.

Closeup investigation from the inside of selected windows revealed inadequate caulking and poor glazing seals and leakage between units. Excessive leakage was observed from all glass stairwells and connecting corridors.

Entrapped moisture was detected in the second floor overhang above the two-story all glass lobby.

The Infrared roof survey revealed only one wet area on the low rise roof. The two high-rise roofs and several small connecting roofs appeared to be dry. The suspected wet area was marked with aluminum paint which allowed the airborne thermographer to check its exact location and confirm via two-way radio.

76. *MUNIS, R.H. and S.J. Marshall (1978) An airborne and ground thermographic inspection of the Internal Revenue Service Regional Center, Andover, Massachusetts. CRREL Technical Note (unpublished).*

An infrared thermographic survey was made of the total envelope of the one-story IRS building which covers an area of approximately 300,000 square feet. The seven-acre roof was surveyed from a helicopter using an Inframetrics Model 510 Portable Thermal Imaging System and the extensive side wall perimeter was surveyed using a AGA Model 750 Portable Thermal Imaging System.

Thirteen suspect locations were discovered on the roof and marked with aluminum paint under the direction of the airborne thermographer. Core samples of these suspect locations were taken to verify the extent of entrapped moisture in the roof insulation. Most of the core samples were soaking wet when removed. On the basis of this infrared survey, GSA personnel decided to change their plans to replace the entire roof and instead repair the wet locations at considerable cost savings. Correlation of the ground survey thermograms with the roof thermograms led to the discovery that the north, east, and west walls contained moisture approximately below the locations corresponding to the three roof moisture locations that existed along the parapet walls on these three faces. This suggested that the roof moisture got into the walls at these locations. The south face was found to be dry as was the roof along this face.

The side wall survey identified exfiltration from single-pane windows and doors, unusually warm vertical columns, and a warm floor slab. Since most of the large wall area did not contain any openings, it was decided that the wall heat loss was reasonable and no recommendations were necessary at this time.

77. *MUNIS, R.H. and S.J. Marshall (1977) Qualitative assessment of window heat loss using infrared thermography. CRREL Technical Note (unpublished), 6 thermograms, 6 p. Thermography and Energy Conservation, First Canadian Symposium, Toronto/Montreal, W.D. Stainton, Editor.*

An experiment was performed to evaluate four identical side-by-side windows in the same room. They consisted of 1) a single-pane glass, 2) a single-pane glass with storm sash (air space 1 1/2 in.), 3) a single-pane glass with 6-mil clear plastic (air space 1 1/2 in.), and 4) insulating glass (1/4-in. air space).

Conclusions were that either glass or plastic performs equally well as the second glazing, but that the important factor is the size of the enclosed air space. The 1/4-in. insulating glass did not appear to perform much better than the single-pane glass. Infiltration around window casings was also studied. The camera was able to identify locations of deteriorating and/or missing caulking.

78. *MUNIS, R.H., S.J. Marshall and P.E.J. Vogel (1977) Pinpointing locations of excessive heat loss in ten selected office buildings, Concord, New Hampshire. CRREL Report (in preparation).*

Pursuant to a contract negotiated between the State of New Hampshire and the U.S. Army Cold Regions Research and Engineering Laboratory, a heat loss survey to pinpoint excessive heat losses was made of 10 selected buildings in Concord, New Hampshire. Three thermographers, Dr. Richard H. Munis and Stephen J. Marshall of CRREL, and Paul E.J. Vogel of the U.S. Army Materials and Mechanics Research Center (AMMRC), performed the survey using an AGA Thermovision Infrared Camera System. Following the heat loss survey, a walk-through inspection was made of all buildings. The combination of data from both inspections was used to make recommendations for corrective actions.

In order to make a comparison of the 10 buildings, the concept of structural thermal efficiency is introduced in this report. It is strictly arbitrary and somewhat subjective, with the sole purpose of trying to assign a priority to those buildings that were estimated to have the worst heat losses and, therefore, the highest potential for maximum dollar savings to the State of New Hampshire. The ranking of the 10 buildings is as follows (the lowest structural thermal efficiency, or worst heat loss, is #1; the highest structural thermal efficiency, or least heat loss, is #10):

1. Department of Public Health
2. State House Annex
3. State House
4. State Highway Garage
5. Supreme Court
6. State Library
7. John O. Morton Building
8. Department of Fish and Game
9. Health and Welfare Laboratory
10. Legislative Office Building (Old Section)

Detailed reports on each of the 10 selected buildings are presented.

79. *MUNIS, R.H. and P.E. Vogel (1977) Excess heat loss study of the Harold F. Scott School, Warwick, Rhode Island. CRREL Special Report (in preparation), 7 thermograms, 6 p.*

The Harold F. Scott School was surveyed with an infrared camera during November 1976. It is a single-story 14-sided polygonal building built in 1965. The unusual-shaped roof was viewed with a fire department aerial tower. Pockets of subsurface moisture were observed. Conduction through the steel rafters was evident.

The single-pane glass heat loss appeared to be about as large as the roof loss because the source of heat was under the windows. Up to 16°F temperature differences were found between classrooms. Vandalism was a factor in deciding not to incorporate double glazing.

Recommendations are included in this study, based on thermographic analysis and walk-through inspections. This analysis represents the first known attempt by public administrators to recognize the potential of infrared thermography and use it to survey publicly owned buildings through the Federal Technology Transfer Program.

80. *New England Innovation Group (1978) New England Community Energy Management Program: Application of thermographic inspection to the thermal analysis of typical structures in the Berlin, N.H. Region. NEIG, 39 Pike St., Providence, Rhode Island 01903.*

Four reports are included in this series:

1. Energy management study of the Marston School and Berlin Junior High School, Berlin, N.H., 29 thermograms, 33 p.

2. Energy management study of the North Country Community Services Building, Berlin, N.H., 14 thermograms, 15 p.

3. Thermographic inspection of a Berlin, N.H., multifamily residence participating in the CD rehabilitation program, 7 thermograms, 7 p.

4. Thermographic inspection of the Pinkham Notch Camp Trading Post Appalachian Mountain Club, Pinkham Notch, N.H., 10 thermograms, 10 p.

The purpose of this study was to identify cost effective energy conserving opportunities in four buildings included in a comprehensive thermographic inspection and energy audit conducted in and around Berlin, New Hampshire, by the New England Innovation Group (NEIG). The results of this study will assist local public officials and private citizens in developing budgetary priorities in their attempt to reduce operating costs.

The thermographic energy audit is an innovative and unique approach to the study of heat loss from buildings. It is an indispensable analytical technique used in conjunction with a class-A walk-through audit to locate and document heat loss that is not evident visually. This permits the assignment of priority to the various retrofit processes. Prior to any retrofit, a thermographic energy audit is conducted with the aid of an infrared camera system. A thermographic inspection is

also used after a retrofit to confirm the quality of the retrofit process to ensure that dollars are properly spent to reduce operating costs.

Heat loss from the four buildings is documented in thermograms in these reports. The thermograms were analyzed to acquire complete knowledge of the locations of all heat losses from this building complex. This information provides the building operators with extremely accurate data for their energy conservation program.

Each thermogram shows one or more of the types of heat loss considered in this study: infiltration, exfiltration, conduction, convection, and radiation. Each shows a specific section of the building in terms of the four cardinal points of the compass. Photographs are used to familiarize the reader with the building.

Based on the evidence from the thermographic energy audit, the heating system of the building is analyzed and recommendations for reducing heating costs are made.

81. *New England Innovation Group (1976) Structural heat loss detection by infrared techniques. NEIG, 29 Pike St., Providence, Rhode Island, 02903, 48 p.*

Aero-Marine Surveys (AMS) was contracted by the New England Innovation Group (NEIG) to obtain thermal infrared imagery of selected sites within southern New England. A total of five missions, (seven thermal sorties and two photo/recon sorties), were executed for the purpose of evaluating airborne thermal infrared techniques for the detection of structural heat loss. Due to the late season and a general shortage of funds, efforts were concentrated on gathering qualitative data on a variety of publicly owned buildings in the greater Providence, R.I. area. For the same reasons, no attempt was made in the program or in this report to render a final verdict on the infrared techniques. Instead this report discusses only the equipment and techniques used, the targets covered, and the apparent quality of the resultant data. A supplemental report by Dr. John E. Lukens of Rhode Island School of Design is planned (subject to funding), which will offer in-depth interpretation of data on selected targets covered in this report. The data developed in this program suggest a great potential for guiding decision-makers in evaluating management options relating to the energy equation. When the data interpretation is accomplished, a methodology might be derived for management use.

82. *OHRT, U. and W. Tesche (1977) Measuring energy losses. Mobile infrared measuring system Thermobil now being tried, conceived for use in communities. Energy Research Abstracts, No. 15272, 15 April 1978.*

This article deals with the possible application of infrared thermography on the building sector. Due to the progress made in the development of infrared-sensitive semiconductor detectors and the miniaturization of the electronic parts, devices are on the market today which render thermography independent of laboratories and allow outdoor temperature and heat radiation measurements to be made with the aid of batteries. Under the sponsorship of the Federal Minister for Research and Technology, Messrs. Messerschmidt-Boelkow-Blohm (MBB) have developed a device which enables very exact quantitative measurements to be made and will be used as a mobile infrared measuring system, mainly in communities. The system is now in trial operation. The basic novelty of the systems is a digitalization of the image signals into image points which are stored in a fast semiconductor store for some time and then permanently stored on a tape cassette. The data are evaluated by means of a large computer.

83. *PALJAK, I. (1976) Experiences from building thermography in Sweden 1968-76. Thermography and Energy Conservation. First Canadian Symposium, Toronto/Montreal, 2-3 December 1976. W.D. Stainton, Editor.*

Since 1968, thermography has been used in Sweden by the National Institute for Materials Testing to detect heat leaks in external walls of buildings. In 1972, a report was issued by the institution which gives instructions to interpret thermograms and describes methods to avoid disturbing factors at measurements. This report is now the basis of the routine measurements at the institution which now carries out investigations of buildings - mostly dwellings - on commission. This year a Swedish Standard has been prepared on the method. It presents terminology, principles of interpretation of thermograms, measurement techniques, conditions, etc. A draft International Standard was presented at the 1977 ISO/TC 163 meeting in Berlin, Germany.

84. *PALJAK, I. and B. Pettersson (1972) Thermography of buildings. Svensk Byggtjarst, Box 1403, S-11184 Stockholm, Sweden, 700 thermograms, 56 p.*

Thermography of buildings is the first comprehensive manual (in the world) which describes the theory and techniques employed in using an infrared camera to determine insulation defects in buildings. An IR-camera produces a thermal image (thermogram) which immediately reveals points of air leakage and insulation defects in the structure under examination. Thermography is a convenient nondestructive test method which may be expected to assume extensive application and considerable economic significance.

An introductory section describes the method of operation of an IR-camera and the theory underlying the interpretation of thermograms produced by this camera.

The main section describes the technique of thermography and provides practical rules for work on the site. Conditions during measurement and the accuracy of the method are discussed in view of the possible sources of error and the desired results. Proposals are put forward for the interpretation of the thermograms produced.

The document is concluded by a 56-page catalog containing over 700 typical thermograms, many of them in color. The catalog is divided into two sections, one which contains typical thermograms of the most common wall designs built strictly according to specifications, and the other of the same walls with constructional and insulation defects of general occurrence. Four different types of wall are described in this way, two framed cladding panels, one sandwich wall and one lightweight concrete wall.

This manual with its catalog of typical thermograms is expected to become a standard work of reference, and it may also have legal significance in checking building defects. For instance, thermography is eminently suitable for use in a dispute to provide a ruling as to whether a structure satisfies the specified insulation requirements. During the inspection of buildings, the manual is expected to be an essential work of reference for quick and correct interpretation of thermograms obtained with the IR camera.

Developers and building enterprises may expect to save large sums of money by the introduction of thermography as an integral part of the building inspection process.

85a. *PONTELLO, A.P. (1976) Energy and thermography: Partners of tomorrow. Proceedings of the Third Biennial Infrared Information Exchange, St. Louis, Missouri.*

85b. *PONTELLO, A.P. (1978) Thermography: Bringing energy waste to light. Heating, Piping/Air Conditioning, March, p. 55.*

Experimental thermography tests were conducted in Philadelphia to determine the possible extent of heat/cool air losses escaping from rooftops, windows, and doors of buildings and homes within a selected section of the city. The tests were conducted using a combination of both aerial and ground level infrared thermography concepts. The objective of the aerial tests was to capture the maximum area possible of a large metropolitan city showing sources of energy losses. The results obtained from the aerial photographs were later used as an advertising display

to create public awareness of energy conservation. The ground-level thermograms, taken of selected buildings along the route of the flight were used to verify results of the aerial photographs. Additionally, the ground-level thermograms furnished evidence of specific areas of buildings where the extent of energy losses was the greatest. These sources of energy losses were the results of poor, and/or insufficient insulation, improper caulking, and lack of weather-stripping.

An overflight of a section of Philadelphia covering an 11-mile swath was conducted at 0200 hours at 32°F outside temperature using an AGA Model 680 system. Results showed major heat loss from windows, doors, and glass-faced buildings rather than rooftops in both residential and tall buildings. Ground-level thermograms of individual homes and buildings confirmed these results.

Thermograms were taken at ground level of several buildings constructed of different materials and varying in styles. Results showed that excessive heat loss is experienced by modern-type glass-faced buildings rather than by older masonry buildings. A comparison between the renovated portion and the older portion of a large building revealed that there was more heat loss from the renovated area, but the windows in both sections were uniform in emitting heat.

The lower floors of a large building appeared substantially warmer than the upper floors. It was determined that the building windows were being recaulked at the time. Also, it was theorized that thermography could detect an over-pressurized air system that creates a cyclonic atmosphere and certain centrifugal forces which separate the heated air from the inside walls of the upper levels and force warm air downward and against the windows of the lower levels of a tall building. A detailed study of a pane of dark glass permanently bonded in place on a modern glass building showed traces of heated air escaping from the bonded window. Also, the lightly tinted glass above and below the bonded window revealed excessive amounts of heat loss by conduction.

Numerous cases of insufficient or decayed caulking, and/or lack of weather-stripping were detected around many windows on many buildings.

Laboratory tests were designed to study the air flow patterns of fiberglass material having various thicknesses and different densities. The resistance to air flow was determined as a measure of time. Results showed that the average time for the heated air to filter through the various grades of fiberglass ranged from 5 seconds for the 2-in loosely packed fiberglass to 3-minutes for the tightly packed 6-in material. Heat lost, as measured by time, was 35 times less

for the tightly packed 6-in material than for the loosely packed 2-in material. The tightly packed fiberglass fibers, after a period of time, had a tendency to bind themselves together, self-sealing any minute holes.

The evaluation of the quality control of different grades of fiberglass revealed, by thermography, that disruptions in the uniformity of the density of the fiberglass material, regardless of thickness, result in excessive heat loss by conduction.

86. *SAMPSON, R.E. (1976) Applications of infrared technology to buildings. Thermography and Energy Conservation, First Canadian Symposium, Toronto/Montreal, 2-3 December, 1976, W.D. Stainton, Editor (also published as ref 88).*

During the 1975-76 winter heating season, Environmental Research Institute of Michigan conducted studies to test the applications of airborne and ground-based infrared technology to the requirements for energy conservation in buildings. Quantitative airborne data of Ypsilanti, Michigan, were collected and processed to identify roof temperatures and, subsequently, using a thermal model, to interpret ceiling insulation status. Environmental factors found to influence the relation between roof temperature and insulation include the interior and sky temperatures, roofing materials, and pitch and orientation of the roof. A follow-up mail survey established the ability to identify insulated houses from the airborne infrared data.

Ground-based thermovision surveys provided detailed information concerning construction and insulation conditions of small buildings. In particular, interior thermal images showed the location of wall and ceiling structural members, heat ducting, and sources of air infiltration. In application to a large steam heating system of the University of Michigan, the ground based thermal imagery revealed defective steam traps, with a projected energy savings valued at approximately $35,000.

87. *SAMPSON, R.E. (1977) Applicability of infrared imagery to construction code enforcement. Environmental Research Institute of Michigan, 47 pages, 24 thermograms.*

Michigan has adopted ASHRAE 90-75 as its energy construction code to become effective in June 1977. As part of this effort, the State Energy Administration and the Construction Code Commission has investigated the applicability of infrared imagery as a construction code enforcement tool. The program is one aspect of a broader program funded by the Federal Energy Administration to facilitate the implementation of the new construction code. The adoption of this code is one of several positive steps taken by the state to reduce the demand pressures on its energy.

The Environmental Research Institute of Michigan was selected to investigate the applicability of thermal imagery collected with ground-based infrared instrumentation to construction code enforcement. In this recently completed study, 30 homes, representing the spectrum of construction practices, heating requirements, housing locations and styles in the state, were surveyed to evaluate the potential of infrared as a code enforcement tool. The equipment used and the results of this study are described in this report.

It is well known that many residential structures are not well designed or constructed from an energy viewpoint. Thus, the question which this report addresses is whether infrared devices provide a practical and useful tool to identify and facilitate reduction of building energy losses. This study examines infrared instrumentation, its operating characteristics and analysis requirements, and inspects heat transfer characteristics of a variety of structures. Several examples of the value of infrared imagery in identifying heat losses are given. In addition, the specific applicability of this instrumentation and analysis technique to construction code enforcement is demonstrated. This study does not cover every aspect of infrared sensing but does provide sufficient background for the non-infrared specialist to interpret thermal images of buildings.

The first part of this report provides background material on infrared instrumentation, and the methodology of data collection and analysis. The second part presents and discusses some of the qualitative results obtained in the program (i.e., construction abnormalities and energy loss characteristics observable without analysis). The third part describes the quantitative information obtained and demonstrates the use of the technology to determine compliance with codes. The fourth part demonstrates the calculation of a total energy balance to facilitate analysis of the most cost effective means of reducing energy consumption in homes.

88. *SAMPSON, R.E. and T.W. Wagner (1976) Application of infrared technology to buildings. Environmental Research Institute of Michigan, Ann Arbor, Michigan (also published as ref. 86).*

During the 1975-76 winter heating season, ERIM conducted studies to test the applications of airborne and ground-based infrared technology to the requirements for energy conservation in buildings. Quantitative airborne data of Ypsilanti, Michigan, were collected and processed to identify roof temperatures and, subsequently, using a thermal model, to interpret ceiling insulation status. Environmental factors found to influence the relation between roof temperature and

insulation include interior and sky temperatures, roofing materials, and pitch and orientation of the roof. A follow-up mail survey established the ability to identify insulated houses from the airborne infrared data.

Ground-based thermovision surveys provided detailed information concerning construction and insulation conditions of small buildings. In particular, interior thermal images showed the location of wall and ceiling structural members, heat ducting, and sources of air infiltration. In application to a large steam heating system of the University of Michigan, the ground based thermal imagery revealed defective steam traps, with a projected energy savings valued at approximately $35,000.

89. *SCHOTT, J.R. (1978) Principles of thermal infrared remote sensing for heat cost determination. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September, 1978, The American Society of Photogrammetry, 105 Virginia Ave., Falls Church, Virginia 22046.*

Aerial infrared thermographic surveys offer a potential for low-cost roof-top heat loss surveys of commercial and residential structures. The realization of this potential involves development of analysis techniques which account for a number of variables ignored by qualitative surveys. Heat loss from a roof surface is discussed in terms of convective and radiational losses. The variables involved in rooftop heat loss are defined and the unknown parameters identified. Techniques for aerial measurement of rooftop temperature (and/or other required parameters) are discussed in terms of atmospheric, background and material properties. Once again, the variables involved and their relationship to heat loss are defined and the unknown parameters required for calculation of heat loss identified. Existing techniques to account for some of these unknowns are presented. The feasibility of developing techniques to measure the remaining unknowns is addressed. Some potential approaches are suggested which could eventually lead to quantitative heat loss measurements.

90. *SMITH, I.E., M. Flanagan and S.D. Probert (1976) The effect of uncertainties in the emissivity on thermal loss estimates from buildings and structures. School of Mechanical Engineering, Cranfield Institute of Technology, England.*

The use of infrared thermography to quantitatively determine the heat loss from buildings requires that temperature differences of only a few degrees between the surface of the fabric and ambient be measured; therefore accuracies of only tenths of a degree are called for.

This report shows that, to achieve such a degree of precision in the interpretation of thermograms, values of the fabric emissivity must be known to at least 1% if the emissivity is in the range 0.95 - 1, and considerably more accurately if the emissivity is less than this.

An apparatus has been designed and fabricated which enables emissivities to be determined with a high degree of accuracy, and experimental results for a range of building materials are reported.

91. *STAINTON, W.D. (1978) Quantitative interpretation of building thermograms. Fourth Biennial Infrared Information Exchange, St. Louis, Missouri.*

This paper proposes that the essential interpretation of a thermogram should accomplish one or more of the following objectives:

1. Characterize thermal performance in terms of insulation levels and/or annual energy.

2. Identify anomalies in the thermal pattern as to energy implications, condensation potential, and possible cause (insulation or infiltration).

3. Characterize the uniformity of the building surface temperatures for use in the design of thermal breaks, material and method combinations before and after retrofit; and comparisons with established standards of uniformity.

92. *STAINTON, W.D. (1971) Thermal insulation and vapor barriers (unpublished) Toronto, Ryerson Polytechnical Institute, 50 Gould St., Toronto, Ontario, Canada M5B 1E8.*

Mathematics and theory of surface temperature and emissivity of surfaces are discussed. Film coefficient, minimum performance standards, coefficient of surface temperature heterogeneity, temperature index, water detecting materials, condensation temperature, dew point temperature, testing insulation cold box, AGA Thermovision 680 system, inch-degree data, thermal bridges, durability of cladding, comfort, and contact measurements are discussed.

93. *STAINTON, W.D. (1971) Thermography and "U" values (unpublished). Ryerson Polytechnical Institute, 50 Gould St. Toronto, Ontario, Canada M5B 1E8.*

This paper describes the use of Thermovision to calculate region of U-values and gives a basis of calculation for the coefficient of heat transfer.

94. *STAY, B.J. (1977) Radiation transfer and infrared measurement in the context of energy conservation. Society of Photo-Optical Instrumentation Engineers, Bellingham, Washington, Vol. 110, Industrial and Civil Applications of Infrared Technology (SIRA June 1977 London), 6 p.*

In attempting to reduce the heat losses from buildings and other structures greater attention should be paid to radiation losses. These are less well understood and less easily controlled than conduction and convection losses. The sources of radiation range from the sun (6000 K) to room temperature objects (293 K) and the range of wavelengths being radiated is very large. Materials which are transparent at some wavelengths can be opaque or highly reflecting at others. Use can be made of such wavelength selective properties and new selectively reflecting materials are being developed. The requirements for windows, for example, are very different than for walls or for industrial insulation. Assessment of the properties of these materials requires new techniques both in the laboratory and in the field.

95. *TANIS, F.J. and R.E. Sampson (1977) Application of airborne infrared technology to monitor building heat loss. Proceedings of the Eleventh International Symposium on Remote Sensing of Environment, 25-29 April 1977. Environmental Research Institute of Michigan, Ann Arbor, Michigan.*

During the 1975-76 winter heating season ERIM conducted studies to test the application of airborne infrared technology to the requirements for energy conservation in buildings. Quantitative airborne data of the City of Ypsilanti, Michigan were collected and processed to identify roof temperatures. A thermal scanner was flown at an altitude of 1,200 ft with two thermal bands 8.2-9.3 μm and 10.4-12.5 μm recorded by an analog system. Calibration was achieved by standard hot and cold plates. Using a thermal model to interpret ceiling insulation status, environmental factors were found to influence the relation between roof temperature and insulation. These include interior and sky temperatures, roofing materials, and the pitch and orientation of the roof. A follow-up mail survey established the ability to identify insulated and uninsulated houses from the airborne infrared data.

96. *TANIS, F.J., R.E. SAMPSON AND T.W. WAGNER (1976) Thermal imagery for evaluation of construction and insulation conditions of small buildings. FEA/D-77/119. Office of Energy Conservation and Environment, FEA, Washington, DC 20461. Contract no. CO-04-50233-00. Environmental Research Institute of Michigan, Ann Arbor, Michigan, 78 thermograms, 56 p.*

Final technical results are presented on the use of airborne and ground infrared imaging techniques to gain information on heat loss from buildings. A portable infrared device has been used to examine the

interiors and exteriors of residences. Example thermograms presented show the kind of construction defects and insulation problems that can be analyzed from ground surveys. Aerial survey imagery is shown and analyzed with residential questionnaire results. The applicability of new and commercially available infrared (IR) technologies to construction and insulation practices of small buildings has been studied. Since many residential and commercial structures are not well constructed from an energy standpoint, the central question is whether infrared devices provide useful information in identifying building energy losses. Within the constraints imposed by the technology and the complexity of actual heat transfer mechanisms, this study attempts to illustrate the applications and limitations of infrared technology.

This report examines the heat transfer characteristics of a variety of structures and illustrates with specific examples the value of infrared imagery in identifying heat losses. While this study does not cover every aspect of infrared sensing, it does provide sufficient background for the non-specialist to interpret thermal images of buildings.

The first part of this report provides background material on heat transfer analysis, building construction, applications of instrumentation, and methodology on data collection and analysis. The second part describes the collection of infrared and supporting data for thermal imagery analysis of small buildings.

97. *TEXAS INSTRUMENTS INC. (1978) Aerial infrared thermograms and residential heat loss. Texas Instruments Ecological Services, Dallas, Texas 75222, 13 thermograms, 34 p.*

The production of infrared thermograms as indicators of heat loss in residential and business structures involves the application of thermal infrared technology to the problem of conservation of energy. One approach involves overflying cities and towns at night in an airplane equipped with an infrared scanner which works much like a light meter in the long-wave infrared portion of the electromagnetic spectrum. The scanner, like a television set, generates a picture line by line rather than all at once like a framing camera. One dimension of the image is produced by scanning side to side and the other dimension is produced by the forward motion of the aircraft.

The micro- and macro-environments surrounding a community are a heterogeneous mixture of substances that are continuously reflecting, refracting, absorbing, and emitting infrared energy. The vast majority of the energy in this envelope originates from the sun, whose surface approximates a blackbody radiator at 6000 K.

Energy transfer in the described environmental envelope takes place in many ways. Of these, the infrared interpreter is most concerned with radiation, which in the classical sense involves converting internal energy (heat) into the radiant form (radiance) and the revision of radiant energy into internal energy where the energy is absorbed. A second important process of energy transfer is conduction, a point-by-point process in which one part of a body is heated by direct contact with the heat source and neighboring parts become successively heated.

Other methods of energy transfer include: convection, which involves a bodily movement of the material heated and applies to a liquid or gas; advection, which generally refers to air mass movements resulting in a change in thermal energy at a point in the atmosphere; and evaporation/condensation processes, which involve the latent heat released/absorbed due to a change in state (e.g., water vapor changing to dew).

The earth's surface is warmed primarily by radiation from the sun. Differences in temperatures of objects on the terrain result from variations in radiation, conduction, convection, and evaporation/condensation heat transfer processes.

Interpretation of an infrared thermogram for heat-loss information involves a great deal more than merely looking at the picture and making general statements about the observation. It must be remembered that the thermogram is a recording of emitted electromagnetic energy in the infrared portion of the spectrum and that the tonal differences perceived are a function of object temperature and emissivity, and that these differences are only relative. For example, an object or roof that shows extremely light in tone is often referred to as HOT, and one that shows extremely dark is called COLD, when their temperatures actually may vary by only a few degrees and both could be what would usually be termed COLD (e.g., in the neighborhood of 25^{o}F). The contrast between the light tones and dark tones is not only a function of the actual temperature and emissivity differences that exist for the objects, but a function of image recording and image printing settings and techniques.

Because image tones are relative, certain guidelines must be adopted in heat-loss interpretations. First, the interpreter must know the overflight conditions, primarily aircraft altitude, since optical resolution is a function of altitude. Second, the interpreter must know the environmental conditions prevailing at the time of data collection, i.e., air temperature, relative humidity or dew point, wind and sky conditions. Third, the interpreter must know the time-of-night the data were collected, since relative scene changes occur during the nighttime cooling cycle. Fourth, ground conditions, including roofs, must be known; i.e., whether the ground or roof is snow-covered, dry, or wet. Fifth, the interpreter must have knowledge of the structure he is evaluating. This information obviously must come from the homeowner or business owner.

If the heat-loss survey is to be effective, the message must be communicated to the individual home- and business owners, who alone can remedy any problems uncovered by the survey. Most people are anxious to "see" their own homes on the thermograms, and response can be good if the public is made aware of the type of information available and where and how the thermograms can be viewed. Public information presentations, e.g., mailed information included in utility bills, newspaper, radio, and television, can be used effectively - particularly if good examples of the thermograms can be shown in an informative way.

Aerial infrared scanning of residential and business structures is a cost-effective way to provide heat-loss information useful to energy conservation efforts and is a first step in helping homeowners meet rising utility bills. But the effectiveness of these programs can be lost if the information gained does not reach the public.

98. *TOBIASSON, W.N. and S.N. Flanders. Reinsulating old wood frame buildings with urea-formaldehyde foam (1977). Preprint Second International Symposium on Cold Regions Engineering, University of Alaska.*

Urea-formaldehyde (UF) foam was investigated for use as an insulation retrofit material in very cold regions. A test installation of the material was made in stud frame walls at Fort Greely, Alaska, in August 1975. Two months later, a nondestructive survey of these walls, employing thermopiles, thermocouples and an infrared camera, revealed a marked improvement in the wall's insulating performance. Cuts in test areas eight months later revealed excellent filling and showed shrinkage to be under 2%.

Thermograms taken from the inside of the retrofitted buildings by a portable infrared camera showed some dramatic differences between well and poorly insulated wall areas. One example showed a dark (cold) patch above a window that was not retrofitted with UF foam. The other portions of the wall were insulated with UF and they appeared uniformly warmer.

In another example taken from inside a building containing 2 1/2 in. of glass fiber insulation the fire barrier inside wall could be detected where light and dark meet in the upper third of the picture. A great deal of inconsistency was apparent among different portions of the stud spaces, suggesting that the glass fiber insulation varies in thermal effectiveness depending on its situation in the wall. A lower stud cavity was discovered to be filled with UF foam up to the wooden molding, but not all the way up to the fire barrier inside wall. Here the foam installer drilled no spew hole, and guessed incorrectly when the space would be full of foam.

99. *TOBIASSON, W.N., C.J. Korhonen and T.J. Dudley (1977) Roof moisture survey: Ten state of New Hampshire buildings, CRREL 77-31, 18 thermograms, 29 p.*

Ten roofs in Concord, New Hampshire, were surveyed for wet insulation using a hand-held infrared camera. Suspected wet areas were marked on the roof with spray paint and roof samples were obtained to verify wet and dry conditions. Recommendations for maintenance and repair were made based on infrared findings, water contents, and visual examinations. An incremental economic study is presented to serve as a guide in determining the most cost-effective approach.

100. *TOBIASSON, W., C. Korhonen and A. VandenBerg (1977) Hand-held infrared systems for detecting roof moisture. Symposium on Roofing Technology, National Bureau of Standards, Gaithersburg, Maryland.*

Four Infrared cameras were evaluated for use in detecting roof moisture: AGA Model 750, Inframetrics Model 510, Hughes Probeye, and Magnavox AN/PAS-10. Portable nonscanning radiation thermometers were also considered.

The AGA and Inframetrics systems were used extensively to detect temperature differences on roofs and correlate these locations with core samples. Many roofs which appeared to be in excellent condition contained wet insulation which was thermally ineffective and contributed to excessive energy losses. The techniques developed in conducting numerous roof surveys to determine the causes of warm areas on roofs and isolate those caused potentially by moisture are described in detail.

Some reasons for warmer roof areas are: 1) hot air exhaust onto a roof from a fan or vent, 2) heaters suspended just below a roof with minimal insulation, 3) hot rooms below the roof (boiler rooms), 4) differences in the amount and type of insulation in the roof, 5) wind shelter and radiated warmth from walls of higher portions of the same building, 6) significant differences in the thickness of the built-up membrane, 7) wet insulation.

Infrared surveys were compared with nuclear moisture surveys. Nuclear surveys require more time and effort and cover only about 2% of the roof area. It is essentially impossible to produce a nuclear survey with as detailed coverage as an infrared survey.

101. *TREADO, S.J. and D.M. Burch (1978) Evaluation of hand-held infrared thermometers for "R" measurement. Center for Building Technology, National Bureau of Standards, 20 p.*

Hand-held infrared thermometers were not recommended for use in determining the thermal resistance (R) values of walls. Under steady-state conditions, measurements of the R-value of an insulated wall showed

an average error of more than 50%. Under dynamic conditions, the error approximately doubled.

Some of the error in R determination using radiometers is due to inaccurate temperature measurement. However, even if the instruments were perfect in indicating surface temperatures, substantial error in R determination would occur due to other factors, such as uncertainty in the surface heat transfer coefficient and emissivity, and transients due to cyclic operation of the furnace and outdoor conditions.

The best application of the hand-held temperature indicators is as a qualitative measuring device. It should be possible to determine whether or not a wall is insulated or if voids or other insulation failures are present. Great care should be taken to ensure accurate calibration of the devices which require that procedure. Separate indoor and outdoor calibrations should result in increased accuracy. Care should be exercised to minimize uncertainties due to transients. For greatest accuracy, measurements should be made under conditions which produce a 20 to 30^{o}F temperature difference across the wall, and the cold-side surface of the wall should be above 32^{o}F.

102. *VOGEL, P.E.J. (1974) Infrared NDT and energy conservation. Army Materials and Mechanics Research Center, Watertown, Massachussetts, 14 thermograms, 14 p.*

The development of infrared equipment for nondestructive testing has been refined to the point that instruments are available to detect any loss of energy that can be expressed in terms of heat flow to the surface or airborne particulate matter. A brief introduction to infrared nondestructive testing is given, followed by a number of thermograms of insulation problems, leaking steam valves, stack losses, extravagant cooling, random leaks, etc. It is shown that periodic plant checks by infrared will not only contribute to the national energy conservation effort but will also result in significant operational economies.

103. *WILSON, G. (1978) Managing the residential thermal imagery program. Thermosense I. First National Conference on the Capabilities and Limitations of Thermal Infrared Sensing Technology in Energy Conservation Programs, Chattanooga, Tennessee, 20-21 September, 1978, The American Society of Photogrammetry, 105 Virginia Ave., Falls Church, Virginia 22046.*

Project Aero-Scan is designed to graphically identify insulation-deficient homes and to stimulate homeowners to take energy conservation measures in residential buildings. Although the program provides a

minimal amount of "technical information" to the homeowner by means of a hard-copy display of a particular home's heat loss characteristics, its real value lies in the interest generated in energy conservation. The by-product of the program, i.e., an increased awareness of and concern for improved efficiency in residential heating/cooling, is, therefore, more important than the mere product of thermography. This former area is where most management time should be expanded, not the latter.

Project Aero-Scan is funded through an E.P.C.A. grant to Tennessee's Energy Authority through 1980; the program has been funded since 1 June 1977, and management responsibilities began 1 October 1977. The program calls for thermal scanning of all densely populated areas in the state, the presentation of thermograms to interested citizens, and the compilation of evidence suggesting how much energy savings have resulted from the program.

Thus far, Project Aero-Scan has been tested in Memphis (pop. 667,150), Millington (pop. 21,177), and Jackson (pop. 40,744), Tennessee. Other areas of the state have been scanned (Nashville, Gallatin, Madison), but the thermograms have not been released for public viewing. Plans call for the scanning of: Chattanooga, Clarksville, Murfreesboro (all in winter, 1978-79); Oak Ridge, Knoxville, and Johnson City (all in winter, 1979-80).

Previous residential thermal scanning programs have allowed public access to the thermograms in basically two ways: either through local utilities as a tool in high billing complaints or through existing government offices. Tennessee's approach utilizes branches of the public library system for dissemination of the information. The advantages of this system are: reliance on an established information delivery system, personnel trained to deal with all levels of populations, strategically located dissemination points with established use patterns, affiliation with a neutral/positive credibility source, and (usually) a delivery organization positively attuned to strategies designed to increase participation in their services.

Management areas of concern center on these program aspects: thermogram preparation, interpreter training, map usage, house analysis, record-keeping, publicity efforts, printing requirements, technical support systems, thermogram security, and local governmental support.

Beyond these areas of normal concern, particular program areas need added attention: presentation of the program in such a way as to dissuade arguments concerning "the invasion of privacy," policies regulating access to potentially profitable information for private enterprise, exaggerated claims for information utility, and massive manpower requirements for correct dissemination procedures.

104. WINTHERS, D.J. (1978) Thermographic analysis by the conservation consultant. Northern Illinois Gas, Aurora, Illinois.

Northern Illinois Gas uses an infrared imaging system to survey school buildings as a service to their customers. The unique feature of their procedure is a word processing machine program that automatically types out a finished report, thus solving the most frustrating aspect of infrared building surveys, the timely preparation of a finished report to the customer.

The energy consultant, after surveying the facility, lists various phrase codes on a work sheet which are relevant to the heat loss evaluation of a particular building. These phrase codes are chosen from a master list of 86 codes, which are essentially succinct sentences describing typical building heat loss situations. The word processor operator then types the phrase codes into the word processing system, and the phrases are automatically assembled and printed out in a report tailored especially for the surveyed school. The report is assembled in a special folder, along with conventional photos, thermograms, and other miscellaneous materials on energy conservation. This unique breakthrough has given one man and camera the ability to survey hundreds of school buildings in a year's time.

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