J. E. Colcord
Department of Civil Engineering
University of Washington
Seattle, WA 98195

Thermal Imagery Energy Surveys

Changes in heat loss from structures, due to actions by the owner or possible failure to comply with government regulations, may be monitored.

Introduction

The concept of conservation of energy is again in vogue and thus the possibility of monitoring apparent changes in thermal emission or the compliance of regulations regarding heating is of interest to government bureaucracy. This paper is presented as an aid for the preparation of specifications for thermal-infrared (TIR) imagery energy surveys performed by airborne imaging systems. The various elements of the "typical specifications" are considered in terms of important parameters that affect the information desired by the monitoring agency.

Site Description

The use of current city line maps, orthophoto maps, or aerial photos is to allow presentation and final recommendation in a format that is compatible with the usual city practice and will allow relatively easy transfer of these data to a modern multi-purpose cadastre base system (ASCE, 1979) if the city is in the process of applying modern computer technology to its property, utility, topography, land use, and the myriad of other information systems needed by the public and the design professions as indicated by the American Public Works Association sponsored program called CAMRAS (Computer Assisted Mapping and Records Activities System), now used in Memphis, Salem, Bellevue, and other cities. It is felt that, at the present time, this is a cost-effective way to add, with reliability, TIR data on a spatially correct data base so that future surveys can correctly show changes caused by action on volunteer or legislated fronts. The metric scale of 1:2500 could, of course, be changed to the 1:2400 scale that is currently common, but this general scale is most adequate to show sufficient detail, and will also allow analyses of slopes and site situations that induce aberrations. As another possibility, aerial photos may also be a base, but scale problems may make them a less reliable source for future use, unless orthophotos are used.

Abstract: *Based on typical specifications for an airborne thermal-infrared survey, the effects and limitations of the specified parameters are discussed. Special emphasis is placed on emissivity and its effects. The results show the possibility of monitoring change in heat loss due to action by the owner or possible failure to comply with regulations by government. The data are recommended to be made compatible with a modern multi-purpose cadastre in computer recorded format.*

Specification and Problem

Typical specifications for aerial TIR detection of heat loss in buildings have been presented by various sources (Colcord, 1978), and an abbreviated sample is shown in Table 1. This example has some special elements that should be expanded to show their relevance. For example, the problem purpose (Table 1, Section 1.1B) indicates a general assessment of the apparent roof insulation condition to only four levels. It is important that the "temperature" of the roof is not required as it cannot be obtained to a sufficient accuracy to allow a survey for a compliance to a statute. More reasoning will follow in the discussion of the various elements and the possible aberrations.

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TABLE 1. SPECIFICATIONS FOR TIR SURVEY

1.1 *Scope*
- A. *Work Covered*
- B. *Purpose:* General assessment of residential roof apparent insulation condition at four levels (poor, fair, good, excellent) based on visual examination of imagery.

1.2 *General Data*
- A. *Site Locations*
- B. *Site Descriptions* (current city maps at $m_k \cong$ 1:2500)
- C. *Time* (of day; of completion)

1.3 *Meterological Data*
- A. *Minimum Guidelines*
- B. *Forecasts* (local sources)
- C. *In-flight Weather:* Ambient air temperature
Wind condition, cloud cover
Precipitation occurrence, pre-flight
Fog, ground fog

1.4 *Ground Support*
- A. *Vehicles*
- B. *Flight Guidance Systems*
- C. *Communications*
- D. *Site Instrumentation:* Ambient temperature, humidity
Control house monitoring—roof, R, T_{interior}
- E. *Site Roof Survey* (Type surface, house style, pitch, ventilation, special conditions)

1.5 *Flight Data Reporting*
- A. *Flight Log* (Line designation, azimuth, altitude, date/time, . . .)
- B. Report Summary (Items *1.3B, 1.5A* shown on maps *1.2B*)

1.6 *Product Quality*
- A. *Data Recording* (Tape/film)
- B. *Processing* (Computer printout at 1:2500/BW continuous line)
- C. *Resolution* (Spatial, thermal)

1.7 *Analysis*
- A. Visual Analysis to at least four levels (see 1.1B) of condition assessment
- B. Presentation: annotated on city maps
- C. Assessment of confidence (based on ground instrumentation and control house; expected aberration due to special site conditions and surfaces)
- D. Recommendations (citation of area of apparent large heat loss or poor insulation; ground survey recommendations)

1.8 *Cost*

METEOROLOGICAL CONDITIONS

The meteorological data are imperative, and often minimum conditions are set. For example, to insure a relatively large temperature difference, ΔT, between roof surfaces and the ambient air conditions, a precondition of 0°C for the air temperature is often included. The sky temperature (Schott, 1978) and hence the sky condition is important because a 30K change at about 250K results in a surface change of approximately 4°C, and a change in air radiant exitance of from 2.5×10^{-3} to 4×10^{-3} watts/cm^2 results in a 12°C change in the TIR (8-14 μm) band pass region. Wind causing convection and wind shadow effect are also important, and thus a wind velocity of <7 kph is often recommended. Site cross-section differences can also result in ambient temperature differences due to gravity cooling. (Evans, 1978). Clouds or overcast conditions tend to reduce the thermal contrast because the radiation transfer may be from the clouds to the roof. For some areas, the pre-flight temperature/precipitation conditions are very important because wet or snow-covered areas will have special effects that will change analysis results due to a change in emissivity, ϵ (Woolley, 1978; Lowe, 1978). Similar problems can be encountered if the time of flight has not been designed to cope with solar heating effects and the considerations of the occupant's "habits." Heavy moisture in the air or ground fog conditions will reduce the apparent thermal contrast because the air temperature with the moisture having an emissivity of ~1.0 will dominate.

SITE INSTRUMENTATION AND DATA

Because the ambient temperatures and humidity and sky effect have a great effect, they should be monitored at critical points in the survey area. If the terrain is hilly, valley as well as hill conditions are important. It would be prudent to have at least one "control house" in typical areas of the coverage. Most important are the roof type and shape as well as the surroundings, such as trees and adjacent buildings, that may affect the lower hemisphere area. This is shown in Figure 1. Specifically, the emissivity, ϵ, of the *in situ* roof surface as seen by the sensor (within an instantaneous field of view or a resolution cell of a^2) using the average temperature, $\bar{T}$, in Kelvin. Since the general equation for exitance in Wm^{-2}, defined by the symbol M, is (Wolfe and Zissis, 1978)

$$M = \sigma \epsilon \bar{T}^4$$

where ϵ and $\bar{T}$ have been defined and σ is the Stefan-Boltzmann constant; or, more commonly, the greybody radiant exitance, R, for a band centered around the peak of the spectral emittance curve is used where

$$R = \sigma \epsilon \bar{T}^4$$

in the usual units of W cm^{-2}; we see that ϵ is important and the use of assumed average values of, say, 0.9 may not be sufficient. Some values of ϵ are shown in Table 2, and from this one may conclude, as did Lowe (1978), that for most residential roofs the emissivity is "high" and thus approximately the same, while industrial buildings are possibly variable. This is, however, based on the assumption that the surfaces are clean, dry, and frost free. In the real world this may not be the case, and an *in situ* evaluation or more research may be necessary.

Thus, the site survey is important to assess variation in emissivity/roof condition and to check for surround effects. The use of color aerial stereophotos may be a logical source as a means of rapid visual checks, or the base reference orthophoto may suffice. As a specific example of the effects of an error in emissivity, Woolley (1978) computed a heat loss of 205 W/m² using an assumed emissivity of 0.91 whereas 145 W/m² was correct for the actual emissivity of 0.96. This results in an error of over 40 percent in the heat loss computation through a 5 percent error in emissivity. This

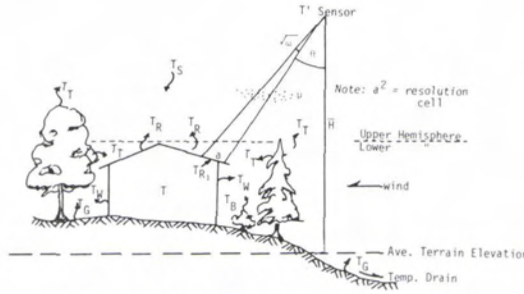

FIG. 1. Surrounding effects $T' \neq T$

example was under normal Seattle conditions (~5°C) and for a norm of an internal temperature of about 20°C with R-10 insulation according to the usual determination. The important point is that, if one underestimates the emissivity, the apparent resulting surface temperature is higher, hence making the corresponding convection loss higher.

PRODUCT QUALITY, SYSTEM, AND ANALYSIS

The key to product quality is to ascertain a reasonable measure of the average roof "temperature." This means the roof must be easily discernable. Evans (1978) recommends a 15 cm spatial resolution cell as the area that should become standard with modern systems; however, about 1 m (see a in Figure 1) appears to be satisfactory for a four level general discrimination system, although this will not discriminate localized differences in most roofs.

The specification of less than a 1-m resolution cell will require a low flying altitude for aerial TIR systems with instantaneous fields of view greater than 2 mrad. This will result in problems in hilly terrain as $\bar{H} < 500$ m (see Figure 1). The temperature resolution should be about 0.8°C for differentiation of an R-10 and R-20 house according to

TABLE 2. VALUES OF EMISSIVITY (ϵ)*

Surface	ϵ	Source
Asphalt Shingle (wet)	0.97	Woolley, 1978
Asphalt Shingle (Wet)	1.00	Woolley, 1978
Cedar Shakes (dry)	0.95	Woolley, 1978
Cedar Shakes (Wet)	1.00	Woolley, 1978
Tar/Stone	0.97	Woolley, 1978
Aluminum (sheet)	0.09	Wolfe and Zissis, 1978
Copper (oxidized)	0.78	Wolfe and Zissis, 1978
Iron (sheet-rusted)	0.69	Wolfe and Zissis, 1978
Tin (tin plated sheet iron)	0.07	Wolfe and Zissis, 1978
Brick (red-common)	0.93	Wolfe and Zissis, 1978
Paint (avg. of 16 colors)	0.94	Wolfe and Zissis, 1978
Sand	0.90	Wolfe and Zissis, 1978
Wood (planed oak)	0.90	Wolfe and Zissis, 1978
Frost Crystals	0.98	Wolfe and Zissis, 1978

* Note: This may also vary with λ.

Canadian results (Brown, 1978) and this is readily attainable even with older systems (Colcord, 1978); hence, most available systems for aerial TIR imagery can adequately discriminate at about four levels.

Another question that may be raised is the system itself. According to the atmospheric transmission window available and the blackbody temperature (Figure 2), the two usable systems are in the 3–5 μm and 8–14 μm range. Theoretically, as most authors have shown, the 8–14 μm is the logical choice as it best fits at a 300K ambient temperature condition.

Some experience in the Pacific Northwest, under conditions of heavy forest and ground cover, showed that a 3–5 μm system appeared superior for discrimination of roofs; however, this is undoubtedly a special case and may also depend on the gain setting of the instrument in the aircraft. At any rate, with the total system envisaged, the hard copy results should be at the base map scale to expedite transfer to a CAMRAS type computer data bank.

In the final analysis, estimates of confidence levels should be stated and the *purpose* should be repeated, i.e., "General Assessment of Residential Apparent Roof Insulation Condition at Four Levels." The imagery and the base/map computer results should then be made available for public scrutiny as long as an expert is also available to discuss results. The major advantage may be in public awareness, with a second advantage in showing effects of an insulation program on specific homes based on before and after data in the computer bank.

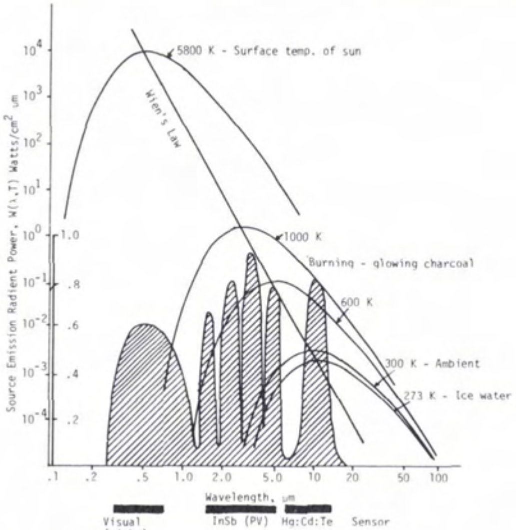

FIG. 2. Atmospheric transmission/blackbody temperature curve

CONCLUSION

A logical series of specifications must be made based on practically attainable results of real need to the user. The meteorological conditions, especially moisture, are important to the final results, and flight specifications must recognize these conditions. Ground support teams for site evaluation and monitoring during the flight must be available, as should control homes in order to insure data reliability. Roof surface emissivity is important, and roof condition/aberrations should be part of the survey until local anomalies are satisfactorily handled. Finally, a reporting system to four or perhaps five levels and that is compatible with a CAMRAS type data system is felt to be essential for future use.

REFERENCES

Colcord, J. E., 1978. *Thermal Infrared Imagery Use in Urban Energy Survey*, ASCE, TE-5, New York, N.Y.

Brown, R. J., 1978. Canadian Experience with the Use of Aerial Thermography, *Proceedings, Thermosense I*, ASP, Chattanooga, Tennessee.

ASCE, 1979. Making Maps by Computer, *Civil Engineering.*

Evans, J. B., 1978. Airborne Thermography—Flight Plans for Tomorrow, *Proceedings, Thermosense I*, ASP, Chattanooga, Tennessee, 1978.

ERIM, 1977. *Thermal Imagery for Evaluation of Construction and Insulation Conditions of Small Buildings*, PB-265 494 FEA (U.S. Department of Commerce, NTIS), Ann Arbor, Michigan.

Lowe, D. S., 1978. Effects of Emissivity, *Proceedings, Thermosense I*, ASP, Chattanooga, Tennessee.

Schott, J. R., 1978. Principles of Heat Loss Determination Using Infrared Thermographic Techniques, *Proceedings, Thermosense I*, ASP, Chattanooga, Tennessee.

Wolfe W. L., and G. Zissis, 1978. *The Infrared Handbook*, ONR/ERIM, Washington, D.C.

Woolley, C. J., 1978. *Thermal Infrared Imagery in Residential Energy Conservation*, MS Thesis (Th 26075), University of Washington, Seattle, Washington.

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