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Title: USE OF AERIAL THERMOGRAPHY IN URBAN AREAS

### Abstract

Energy conservation and outdoor climate are becoming of increasing importance in modern community planning. Remote-sensing techniques, especially thermography, could be a valuable tool for surveying heat loss and temperature distributions.

The aim of this study, performed at the National Swedish Institute for Building Research, is to investigate the potential of aerial thermography. A pilot study performed in Uppsala 1975 and 1976 together with an international review of the literature dealing with thermography and an inventory of airborne thermal registration performed in Sweden indicated that thermography might be useful to trace and discover cooling phenomena, shelter effects and losses from district heating culverts.

In order to evaluate the use of aerial thermography in urban areas a series of airborne thermal registrations was made in the community of Upplands Väsby near Stockholm 1977-1979. Simultaneous measurements were made of surface temperatures, air temperature and 'the urban heat islands' of the investigated area. Ground-based indoor thermography has been used to verify the aerial data. During the 1978 registration heat loss simulations were also included.

Our repeated thermal registration of Upplands Väsby together with a registration made by chance in 1976 form a unique time series, by means of which the accuracy and repeatability of aerial thermography can be tested.

An evaluation of the aerial registration and the ground-based measurements indicates that aerial thermography can reveal heat loss from buildings and district heating culverts and can identify stored solar energy and cooled surfaces.

### USE OF AERIAL THERMOGRAPHY IN URBAN AREAS

#### Swedish law on energy planning

A law on energy use and supply was passed in 1977 by the Swedish Parliament. The law states that "the local authorities are responsible for economizing on energy and for a safe and sufficient energy supply".

In the preceding debate it was emphasised that local authorities must pay attention to the relationship between their decisions on energy policy and local physical planning.

In a motion to parliament of 1976 the proposers assert the importance of studying the interplay between factors that can be expected to influence local energy consumption. Factors such as the natural topography, the physical characteristics of buildings, types of buildings and the design of local

road systems. In the Swedish Government Official Reports, 1976, the experts also call attention to the problems of energy production and its effect on the local climate and the physical environment.

The energy law and the reports on which it is based are ambitious and it is questionable whether the local authorities can interpret them correctly. Do they have the necessary information and the knowledge to use it in their decisions?

Our conclusion is that they don't, however, ambitious and skilled they may be, at least not in the widest sense of the energy law. New methods are probably necessary to supply planners and politicians with the information needed for their judgements. New methods does not necessarily mean new technical methods but new well-tested operational methods for obtaining information.

During the last decades a number of remote sensing techniques have been developed. Techniques that make it possible to register and collect data suitable for modern community planning. Remote sensing is perhaps no panacea, but with a purposefulness in applied research, these techniques may become useful tools in local and physical community planning.

### Aerial thermography

Thermography is a technique that gives information about the energy radiated from the surface of different objects in the infrared region. Infrared radiation is electromagnetic radiation with wavelengths longer than those of visible light. Thermography works in wavelengths between 2.5 and 15  $\mu\text{m}$ .

The system of aerial-thermography usually consists of an infrared linear scanner, a portable tape recorder, equipment for the presentation of thermal pictures and of course a suitable aircraft.

The infrared linear scanner registers the heat radiation from the surface in narrow, parallel strips perpendicular to the course of the aircraft. The thermal information is registered on a tape recorder. The registration may be digitized and fed into a computer or converted into photographic pictures. These thermal pictures can either be analogue pictures with a continuous greyscale or digital pictures with a discrete greyscale.

### What can be "seen" - how can aerial thermal information be used?

The basic quantity measured by thermography is neither energy nor temperature. What is measured is the number of photons received, independent of energy content. The intensity of radiation emitted from a specific object depends on wavelength, object temperature and object emissivity. Thus when using aerial thermography in urban areas it is the radiation from the surface of the city landscape that is measured. This radiation pattern received could be used to reveal energy loss from industrial buildings, apartment buildings, small houses, district heating lines, but also to indicate surfaces exposed to solar energy, different kinds of cooling phenomena and shelter effects in built-up areas. There are two important aspects of using thermography in urban areas: one is to increase knowledge about the connection between energy and the shape of built-up structures, and the other is to find out where measures are to be taken in order to decrease energy consumption.

## Brief review of international research results of aerial thermography

The literature in the field of thermography is limited. It is not until the last five years that the information potential of thermography has been recognized. In Sweden it is the Research Institute of National Defence (FOA) that first became interested in developing thermal techniques and operational systems. In the extension of defence research it was soon realized that infrared techniques could also be of interest for civilian use. In the end of the nineteen sixties a few pioneers started to use thermal data in the studies of rural local climate. From about 1975 the research came closer to the physical problems of urban areas. Now it appears that research work for civilian use of thermography has started in earnest, mainly in Canada, USA, Germany and Sweden.

In 1968, Lindqvist, Mattsson, Svensson et al presented results from their first experimental work using airborne and groundbased infrared techniques to study local - and micro-climate phenomena in rural and urban areas. Since this Lindqvist and Mattsson have developed operational thermal methods for survey of roads to detect 'slippery zones' (Lindqvist, 1975, 76) and for mapping surfaces exposed to frost in fruitfarm districts (Mattsson, Börjesson, 1978).

In 1973 the surface temperature pattern of the central part of the Ruhr-district was registered by means of an airborne Daedalus IR-scanner (Hirt, F.H., SVR, 1975). The results of the registration showed that there was a correlation between surface radiation and the building structure of different areas. This study is unique as it is the first attempt to connect surface radiation temperature to the physical structure of a city landscape, e.g. the height and closeness of buildings and the existence of "green surfaces".

1972, Paljak and Pettersson presented the first operational method using thermography to indicate energy loss in buildings. The method has been developed and a hand-book for training operators of thermography has been produced in Sweden (Axén, Pettersson, BFR 1977 T).

In USA, The Environmental Research Institute of Michigan (ERIM, 1976) worked on an operational two-part system for thermographic studies of built-up areas. The two parts of the system are an airborne system for large scale survey of thermal patterns of city landscape, and a ground-based system for more detailed studies of energy loss from separate buildings. The aerial thermal information registered was compared with data regarding roof construction, type and thickness of insulation, and energy consumption for the actual buildings. The ground-based thermal data was compared with ground-reference data making possible verification of energy loss and also the effects of additional insulation. The conclusion expressed in this report is that aerial thermography could be a useful tool for indicating energy loss from large-scale city areas. Furthermore, that aerial thermal data together with information about energy consumption could be used to calculate possible savings in relation to the cost of additional insulation. These opinions are also expressed by Brown, et al, Canada (1978) in their report "Introduction to Aerial Thermography Applications in Energy Conservation Programs". However, Brown et al also describe systematic errors in the thermal picture due to the different emissivity of material, roof pitch, ventilated attics etc. Their conclusions are however similar to those of ERIM; i.e. "Low cost rapid large scale aerial thermography surveys defi-

nately have a role to play in energy conservation programs".

#### A method for the use of aerial thermography in urban planning

As has been pointed out in the previous there are several problems to which aerial thermography could be applied. Use of solar energy, heat loss from district heating lines, urban heat islands and heat loss from dwellings and industrial buildings are a few of them. It is of course not possible to cover all these fields with one single evaluation method. This paper will be limited to heat losses from district heating lines and from buildings.

The process described here aims at producing a list of objects which are interesting from the energy conservation standpoint, e.g. leaks in district heating lines and badly insulated houses. This thermography-based process can be divided into three steps. The first step includes thermal registration and picture production. The second step is interpretation and compilation of thermal information and the third and final step is selection of objects using also other available information e.g. real-estate registers.

The registration procedure does not necessarily differ due to the different problems even if it in certain cases may be useful to use different flying altitudes. The picture production does however, as different phenomena could be amplified or attenuated at the expense of others. It may be advisable to interpret district heating lines in one picture and houses in another.

Interpretation of heat losses from estates/houses is performed according to a pattern where the mean grey level is registered together with certain observations on the thermal structure of the roof, the facade, surrounding houses and the ground. These registrations together with an estate name or number are compiled to form a data base.

Interpretation of district heating lines can probably be made much easier using the drawings together with the thermal pictures. Just following the visible heating lines in the thermogram you can mark out the leaks on your drawing according to a classification system.

Extraction of objects/houses can be made using the thermal data base alone. This is a very rough method as you have a lot of systematic influence in e.g. use of materials due to building age, kind of house and size of house. Thus it would be a more powerful method if the thermal data base could be used together with an estate register containing building age, house size and other relevant figures.

#### Evaluation of the method

Evaluation of the method described above may result in three different statements. They are:

1. The objects sorted out with the method are significantly more interesting from the energy loss point of view than are those of a random sample.
2. As 1 but the thermal information has no significant influence on the result.
3. The objects are not more interesting from the energy loss point of view than a random sample of objects.

Even if we find that 1 is the correct answer it is interesting to find out the difference between 1 and 2 to be able to set a value on the thermal information limiting the acceptable costs of the aerial thermography and thermal interpretation work. To get an answer to the question "is aerial thermography useful in urban planning?", we work along two lines, of which the first is a study of the measurement performance of aerial thermography. This study includes temperature measurement and geometrical properties, and should be a basis for developing rational aerial thermography practice if the method proves to be successful and also a basis for explaining the limits of the method.

The other line incorporates establishment of the previously mentioned thermal data base for Gävle, our home community. This data base makes possible extraction of objects according to variables such as age, size, use, position, kind of house, owner as well as the figures from the thermal interpretation.

Evaluation of the extracted objects is performed by means of inspections made by professionals. Inspections are made in three extraction levels according to the three points above, i.e. one extraction using estate register information and thermal information, a second using only the estate register information and finally a third random sample without the inspectors knowing to which extraction level a certain estate belongs.

#### Research performed

A series of airborne thermal registrations has been performed in the community of Upplands Väsby, near Stockholm, 1976-1979. The main purpose of these registrations was to investigate possible applications of aerial thermography, and to obtain registration experience. The registrations have been performed during night-and daytime och at different flying altitudes. Simultaneous measurements were made of surface temperature of selected objects, air temperature and 'the urban heat islands' of the area investigated. Heat loss simulation from buildings and district heating culverts was made during the airborne registration in 1978. Additional information about building construction, height of buildings, roof pitch, insulation, age of buildings, local climate, etc was collected during the field surveys.

The interpretation of the aerial thermograms was made together with the local building inspectors. The aerial registrations were preceded by laboratory work where the emissivity of different building materials was studied.

To test the method of thermography for use in urban areas we have chosen a new investigation area, the city of Gävle, 200 km north Stockholm. This area was registered by means of aerial thermography in november, 1979. The area consists of about 20 000 buildings which have all been examined and interpreted in the thermal picture according to the method described in this paper.

#### Conclusions

The Upplands Väsby study indicated that the application range of aerial thermography is apparently quite wide. The method could probably be useful to trace and discover heat loss from industrial buildings, small houses and apartment buildings, district heating lines, and to indicate cooling phenomena in built-up areas and to survey solar energy stored in the existing building stock.

These conclusions are similar to those expressed in our review of international research. However, there is still some work to be done before the aerial thermography method is fully operational. In the extension of this study it is also desirable to investigate other applications of aerial thermography, especially bearing in mind the importance of surveying the correlation between energy, buildings and local climate.