Convective Heat Exchange of a Three-dimensional Object Placed in the Open Field

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With 8 Figures

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Summary

For a three-dimensional block-shaped object, placed in the open field an experimental relation was found between the convective heat-exchange coefficient $h$ for the different surfaces and the free windspeed $v$. This relation which holds for a horizontal as well as for a vertical surface is of the form $h = b(v)^m$; $b$ and $m$ determined by experiment. Also the dependence of the convective heat exchange coefficient $h$ on wind direction $\phi_v$ was determined for the different orientated surfaces.

1. Introduction

To evaluate the usefulness of infrared (IR) techniques for remote sensing purposes it is necessary to understand the temperature behaviour of targets and backgrounds. Experiments in this area often are expensive and time consuming due to the diversity of objects, backgrounds and weather conditions. Therefore often models are used evaluating the heat balance of a surface [1, 2]. This method fully depends on the accuracy of the analytical (numerical) equations used to describe the physical processes involved.
One of these processes is the convective heat exchange i.e. the heat exchange by movement of air. Since people started working in this area, back in Reynold's days, many experiments were carried out under well defined conditions (laboratory, windtunnel) and have led to many (semi) empirical expressions for the convective heat exchange for various geometries [3]. Until now not many experiments of this kind have been carried out under outdoors conditions [4, 5] perhaps because theory is quite complicated and experiments are strongly depending on the prevailing weather which cannot be ordered on command.

This report gives the results of an experiment to measure the convective heat exchange at the different surfaces of a block-shaped object, placed in an outdoor environment. It has been tried to obtain results which are of practical use.

2. Theory

Convective heat exchange $Q_c$ is given by

$$Q_c = h(T_s - T_a) \quad (\text{W m}^{-2})$$

(1)

where $h = \text{convective heat exchange coefficient (W m}^{-2} \text{ K}^{-1})$, $T_a = \text{ambient temperature (K)}$, $T_s = \text{surface temperature (K)}$.

The coefficient $h$ is determined by geometry, fluid dynamics and fluid properties. In general four modes of heat exchange are distinguished:

I) free convection: a) laminar, b) turbulent;
II) forced convection: a) laminar, b) turbulent.

Criteria to separate between these modes are given in many textbooks [3, 6] and will not be dealt with here. The prevailing mode of heat exchange in an outdoor environment is forced, turbulent convection.

From windtunnel experiments it is known that in many cases $h$ can be related to the Reynolds number, however to avoid the problem of a scaling length, $h$ will be related to the mean windspeed $v$ (m s$^{-1}$)

$$h = b(v)^m \quad (\text{W m}^{-2} \text{ K}^{-1}), \quad b, m \text{ constants.}$$

For the geometry chosen nothing is known about the dependence of $h$ on the wind direction $\phi_v$, so in general terms $h$ will be of the form

$$h = b(v)^m f(\phi_v, n) \quad (\text{W m}^{-2} \text{ K}^{-1})$$

$\phi_v = 0^\circ$: north, $\phi_v = 90^\circ$: east, $n$: vector normal to the surface.

$Q_c$ is solved from the heat balance equation of a surface as $Q_c = Q_n - Q_x$, where $Q_n = \text{net irradiance at the surface}$, $Q_x = \text{heat conducted through the surface (W m}^{-2})$.