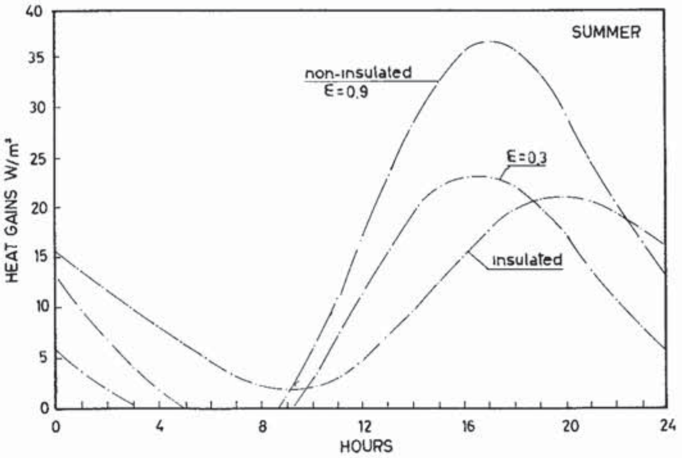

Fig. 3 Comparison of hourly heat gains between different non-ventilated attic roofs.

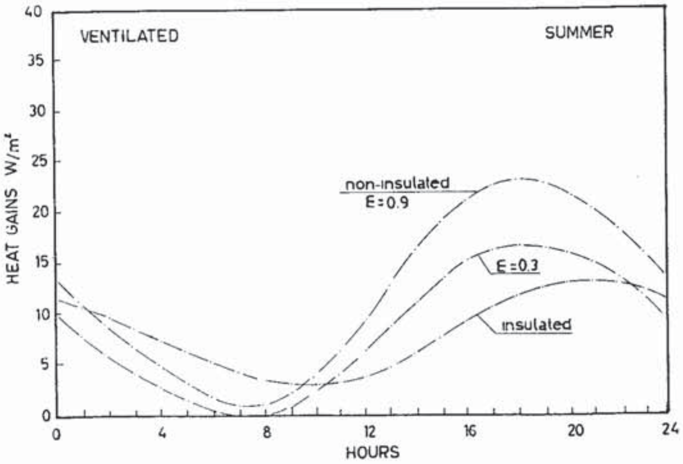

Fig. 4 Comparison of hourly heat gains between different ventilated attic roofs.

An Appraisal of Convection Coefficient Algorithms in Dynamic Thermal Models.

Dr. J.P. Allen and Dr. J.K. Whittle

Department of Architecture
University of Nottingham
University Park
Nottingham, NG7 2RD UK

KEYWORDS

Algorithms Review, Convection Heat Transfer Coefficients, Dynamic Thermal Models, Sensitivity Studies, Validation.

Heat transfer coefficients are used to represent the complex interactions of conduction, convection and radiation at the surfaces of the building envelope. Many of the dynamic thermal computer simulation models developed to date use one dimensional representations of the heat conduction equations. This fact forces the form of the heat transfer coefficients to also be one dimensional, although in reality this manifestly is not the case. In order to utilse such one dimensional heat transfer coefficients approximations must be made. One facet of the thermal model validation exercise has been to look in detail at the various sub-processes and algorithms of some discrete dynamic thermal models. An extensive review of heat transfer coefficient algorithms has been performed. Sensitivity studies have been performed on for example surface roughness, wind speed, direction, profile and turbulence, the building dimensions, the thermophysical properties of the air, etc. This has enabled the various algorithms to be assessed in the context of dynamic thermal modelling of buildings and should allow the significance of heat transfer coefficients in whole building simulations to be defined.

Une Evaluation des Algorithmes des Coefficients de Transfert de Chaleur dans des Modeles Thermiques Dynamiques.

Dr. J.P. Allen and Dr. J.K. Whittle

Department of Architecture
University of Nottingham
University Park
Nottingham, NG7 2RD UK

KEYWORDS

Les Etudes de Sensibilite, l'Examen des Algorithmes, les Modeles Thermiques Dynamiques, la Validation,

Des coefficients de transfert de chaleur servent a representer l'interaction complexe de conduction, convection et rayonnement aux surfaces du cadre du batiment. Un grand nombre de modeles de simulation d'ordinateur thermiques dynamiques developpes jusqu'a ces dernier temps se servent des representations a une dimension des equations de conduction thermique. Aussi les coefficients de transfert de chaleur prennent-ils une forme a une dimension, bien qu'il n'en soit evidemment pas ainsi en realite. Afin de se servir de tels coefficients de transfert de chaleur a une dimension, des approximations doivent etre faites. Une partie de l'exercise de la validation du modele thermique a ete de regarder en detail les divers sou-processus et algorithmes de plusieurs modeles thermiques dynamiques discrets. Un examen approfondi des algorithmes des coefficients de transfert de chaleur a ete execute. Des etudes de sensibilite ont ete executees sur, par exemple, la rugosite de la surface, la vitesse, direction, profil et turbulence du vent, les dimensions des batiments, les proprietes thermophysiques de l'air etc. Cela a permis aux chercheurs d'evaluer les divers algorithmes dans le contexte du dessein thermique des batiments et devrait laisser determiner l'importance des coefficients de transfert de chaleur dans des simulations des batiments entiers.

Introduction

At every exposed surface of every building convective transfer of heat takes place. It is a fundamental process, yet it is that which is most often simplified in building energy simulations. The validity of this simplification is one of the many topics addressed by the SERC/BRE (UK Science and Engineering Research Council/ Building Research Establishment) research team working on model validation. The overall methodology adopted by the team is based on the pioneering work of SERI (Solar Energy Research Institute, Boulder, Colorado) and is reported elsewhere [1]. Under this methodology the task of model validation has been split into three sections of which one is analytical testing. It was realised at an early stage that to derive the maximum amount of information about the behaviour of the model from these test results a thorough review of all the individual algorithms and their implementations was required. It is from this work that the material presented here is drawn. The algorithm review consists of 5 parts.

1)Algorithm complexity

The first task is to determine the range of complexity for the algorithm under test. In the case of building energy simulation codes this complexity is controlled by several factors, the more important of which are:

a) The intended applications of the model which the program authors foresaw

b) Limitations imposed by the availability of suitable input data,

c) Limitations imposed by the solution scheme adopted.

The range of model applications varies from the annual energy audit calculation; where the time constants of the driving forces are very much shorter than those of the averaged building response, to the one or two day building component simulation where building and driving force have similar time constants. It is also assumed that the structures which can be simulated by the models under test are limited to regular buildings, habitable structures or components thereof and that the climatic conditions to which they will be exposed are terrestrial. In general conditions the amount of input data available to the person using the simulation model is often limited in extent. For example, it may just be a standard climate tape and a half complete building specification. It is this limitation which is the main constraint on the convection algorithms employed in simulation models. The numerical solution schemes for wall conduction are restricted in this study to the usual modelling assumption of one-dimensional heat flow. Although this is patently not the case in the real world, there would be little data to support a more detailed approach for convective heat transfer.

2)Limits of validity

The next step in the adopted methodology is to identify those parts of the modelling process which define the ranges of application of the algorithm under consideration. Three headings were considered:

a) Duration of the simulation; if long relative to the building fabric thermal time constants the average or constant part of the algorithm is important, if similar to the fabric time constants then it is the dynamic properties of the algorithm which are of greater importance.
b) Building fabric; in the case of convection it is low emissivity surfaces and thin structures which are important hence typical domestic UK wall constructions are relatively insensitive to the dynamic part of the algorithms.
c) Simulation output parameters; Surface temperature calculations place the greatest demands upon the convection algorithm accuracy, followed in importance by plant load in convectively heated zones.

3)Review of published algorithms

The scope of the review is defined by the limits identified in the first two stages of the study. In the case of convective heat transfer, four situations must be considered; free (or bouyant) convection with laminar and turbulent flow regimes and forced convection with laminar and turbulent flow regimes. Free convection is defined here as convection due to air motion driven only by bouyant forces. The currently accepted expression is an empirical correlation derived by Churchill and Chu [2] which applies to both the laminar and turbulent regimes, providing a smooth transition between the two. The expression is applicable to a wide range of fluids and conditions, but if one restricts its application to the range identified in (2) it can be simplified to:

$$hc = 0.3L^{-0.5}(dT)^{0.166}+1.3(dT)^{0.33} W/m^2/K \qquad (1)$$

Where: L - surface length & dT - (Tair-Tsurface)

For forced convection two analytical expressions apply [3], again simplification is possible, giving:

laminar flow; $hc=(0.0153Re^{0.5})/L$ (2)

turbulent flow; $hc=(0.00083Re^{0.8})/L$ (3)

Where: Re - Reynolds no. for the flow

Before these theoretical expressions can be applied it is necessary to know whether the flow is laminar or turbulent. The flow conditions under which the laminar flow regime changes to the turbulent one is described by the critical Reynolds number, reported values for which lie between 200,000 and 3,000,000. If the wind speed is 4m/s, this implies that the changeover takes place at some point between 0.7m and 11.5m from the leading edge of the wall. This clearly presents a problem. For example, if the wall length is 4m and one assumes that the flow is fully laminar, eqn.(2), then the coefficient evaluates to hc=3.9 $W/m^2/K$, whereas if one assumes fully turbulent flow, eqn.(3), the coefficient would be hc=13.5 $W/m^2/K$, a 250% difference. Several factors contribute towards the magnitude of the critical Re value, the following causing a reduction; a) free stream turbulence, b) surface roughness and c) an increase in the wall surface temperature above the air temperature. Intuition, observation and wind-tunnel testing (eg. [4]) all indicate that in general the flow regime over a building will tend to be turbulent, however, the probabilistic component in this conclusion must be recognised. Four other parameters which affect the magnitude of the convection coefficient and which the average modeller can be reasonably expected to provide were also studied, these were; surface roughness, wind direction, building height and an estimate of the approaching air-steam turbulence.

4)Model implementations

The simplest approach used in the models examined was a direct implementation of design guide (CIBS & ASHRAE) practice for steady-state calculations, by treating the convection coefficient as a surface resistance lumped with the radiation resistance. Thus implying that both convective and radiative energy flows are in the same direction. This may be valid when considering daytime energy losses, but for night-time conditions the assumption will no longer hold as radiation losses take the surface temperature below the air temperature. An example of where this constant value approach is used is the model SERIRES.

The next level of complexity uses wind-speed data from a meteorological tape to provide a dynamic coefficient more representative of the actual environment surrounding a building (or at least of the site where the data was recorded). The form of the algorithm is usually based on the expressions of Juerges [5] with a constant value for low velocity buoyant transfer and a linear (or near linear) velocity related forced convection component. A distinction may be made between windward and leeward surfaces, the latter having either a reduction in the velocity dependant component (as in HTB2) or no velocity dependance (as in NBSLD). Alternatively a smooth transition between windward and leeward coefficients may be used (eg. ESP, which modifies the forced convection component using a sinusoidal function).

The final example, of a relatively complex approach, is the algorithm implemented in DEROB-IUA. The wind velocity is corrected for site location and building height with a power law algorithm, using the centroid of the volume connected to the inside surface of the wall as the reference height. The convection coefficient is then evaluated using a combination of the turbulent free convection expression (given earlier) with a correction for surface tilt and the standard Juerges expressions [5]. The processing overhead in this implementation is clearly far greater than in the simplest algorithms described.

5)Sensitivity studies

The final stage of the validation study to be reported here is an assessment of the appropriateness of the various approaches to the simulation of convective heat transfer. The technique used for this task is sensitivity analysis which, for the convection study, was considered best performed by being separated into three steps:
i) steady-state analysis,
ii) dynamic analysis; in which the time dependent properties of the driving forces are evaluated and applied to the algorithms in isolation,
iii) combined dynamic; using experimental data and simulations with whole thermal models.

From stage (2) we know that it is when the wall resistance is low, eg. single leaf brick wall, that the steady-state coefficient is most significant. If one assumes an annual mean wind speed of approximately 4 m/s and forced turbulent transfer, eqn.(3), convection forms around 10% of the overall wall resistance. For walls built according to current UK building regulations this falls to less than 4%. The convective component has in this case become smaller than the typical error associated with measurements of the thermophysical properties of the wall. In the case of thin (4mm) glazing, under similar conditions, the proportion is 30%. The overall significance of convective transfer thus depends primarily on the glazed area.

For (ii) one first needs to characterise the wind and its velocity distribution with time. This information clearly varies according to the site characteristics and the period of data considered, therefore is only of use for building a general picture of a structure's dynamic thermal behaviour. For example, one finds that short period (1 minute or so) fluctuations in temperature caused by the variations in wind speed are attenuated by up to 90% when passing through 4mm glazing, whereas for diurnal oscillations the glazing can be represented by a small pure resistance. Short period turbulence in the convective heat transfer

process thus would not produce measurable fluctuations in the inside conditions of the structures. However, changes with periods of several hours will produce detectable variations if a substantial proportion of the structure is glazed.

For the dynamic response studies (iii) the experimental approach is clearly the more desirable, however the limited amount of such data currently available makes it impossible to develop general conclusions. The data does, however, provide truth values which must be taken into account when formulating conclusions based on the simulation approach.

The simulation approach is not without its own problems. The first concerns the validity of the results; other studies have shown that there can be large (>50%) discrepancies between the results of simulations using different models, even though the structure being simulated was identical in each case. It is therefore essential to perform the simulations with several models. The second problem concerns the form of the output from the simulations. Too many of the sensitivity studies performed to date have relied on inappropriate statistical techniques to analyse the simulation output, revealing little about the actual dynamic behaviour of the structure or physics of the phenomena being investigated. The techniques employed in the present study rectify this situation, placing greater emphasis on the time dependent relationship between the input functions and model outputs. Finally there is the problem of deciding which structures to simulate. A goal of the validation is to provide findings which are of value to the widest possible audience, thus a representative subset of the possible structures had to be chosen. Full descriptions of these structures have been prepared as part of the output from the validation study, making it possible for future workers to perform comparisons with the findings of the study and thus extend the knowledge base.

Conclusions

(1) In the overall energy budget of modern domestic buildings the significance of external convection is small.
(2) The turbulence of air movements around the external surfaces of buildings makes it inappropriate to use algorithms which produce a single valued output for studies on short term phenomena, a probabilistic approach must be adopted.
(3) For longer term simulations (one week upwards) a single valued algorithm is possible, however, insufficient data (measured, wind-tunnel, simulation) exists at present for such an algorithm to be formulated with confidence.
(4) Existing models must place greater emphasis on alerting the user of the shortcomings of the algorithms employed
(5) Future models should employ a range of algorithm complexities, with

the user able to select the algorithm appropriate to the application. This would enable the experienced user to achieve the best performance from the model, by varying computation speed and solution accuracy.

Versions/listing date of models cited & acknowledgement

DEROB-IUA 1.0, Jan.1985; ESP (ABACUS,UK), Jan.1985; HTB2 1.0 (UWIST,UK), Nov.1984; NBSLD Sep.1980; SERIRES Jun.1984.

This work was funded by the Science and Engineering Research Council, under contract no. GR/C/62864.

References

1) D.Bloomfield, Appraisal techniques for methods of calculating the thermal performance of buildings, Building Services Engineering Research & Technology, 6, (1), pp. 13-20, (1985).
2) S.W.Churchill,H.H.S.Chu, Correlating equations for laminar and turbulent free convection from a vertical plate, Int.J.Heat Mass Transfer,18, pp. 1323-1329, (1975).
3) J.R.Welty,C.E.Wicks,R.E.Wilson, Fundamentals of momentum, heat and mass transfer,(JOHN WILEY & SONS, 1984), 3rd Edn.
4) B.E.Lee,R.A.Evans, The measurement of wind flow patterns over building roofs, Building and Environment,19,(4), pp.235-241, (1984).
5) W.Juerges, Der Waermeuebergang an einer ebenen Wand, (in german), Gesundheit Ingenieur,19, pp.5-52, (1924).

Computerized Decision-aids for Warehouses and Light Industrial Buildings

Eric F.P. Burnett

Building Engineering Group
Civil Engineering Department
University of Waterloo
Waterloo, Ontario, N2L 3G1, Canada

KEY WORDS

Building Data Base, Energy Analysis, Light Industrial Buildings, Shipping Doors, Software, Warehouses.

ABSTRACT

Over the past four years the Building Engineering Group has conducted a program of R and D directed at energy conservation in warehouses and light industrial buildings (WLIBs). This structured program of research has largely been funded under the Buildings Energy Technology Transfer (BETT) Program administered by the Government of Canada. During the course of this work, the following computer-based packages were developed:

BEGEN	- an energy-analysis procedure
dbBEG	- a data base management system for storing information on surveyed buildings and a data base of WLIBs
BEGFIT	- an energy-analysis procedure for the statistical interpretation of fuel records
BEGDOR	- an energy-analysis procedure for industrial or shipping doors
BEGSCI	- a thermal and vapour-pressure analysis procedure for enclosure elements

All the programs have been developed for use on a personal computer. They are separate but complementary software items, and three (BEGEN, BEGDOR and BEGSCI) are suitable for widespread use. We have also developed procedures for subgrade thermal analysis and passive solar analysis that run on a mainframe computer. Together with two readily available programs, these five programs provide an integrated set of aids for both design and analysis. It will be demonstrated that the needs of people doing research, the needs of the design profession, and the needs of contractors and equipment vendors can be met with a structured set of computerized decision-aids.