Building and Environment 44 (2009) 2046–2055

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

A rational approach to the harmonisation of the thermal properties of building materials

J.A. Clarke [a,*], P.P. Yaneske [b]

[a] Department of Mechanical Engineering, University of Strathclyde, Glasgow, UK
[b] Department of Architecture, University of Strathclyde, Glasgow, UK

ARTICLE INFO

Article history:
Received 22 December 2008
Received in revised form
13 February 2009
Accepted 16 February 2009

Keywords:
Material thermo-physical properties
Test methods
CIBSE guide data

ABSTRACT

The Energy System Research Unit at the University of Strathclyde in Glasgow was contracted by the Building Research Establishment to review existing datasets of thermo-physical properties of building materials and devise vetting and conflation mechanisms. The UK Chartered Institute of Building Service Engineers subsequently commissioned a project to extract a sub-set of these data for inclusion in Guide A, Section 3. This paper reports the project process and outcome. Specifically, it describes the source of existing data, comments on the robustness of the underlying test procedures and presents a new approach to data classification and conflation.

1. Introduction

By the early 90s several modelling systems had emerged that were capable of predicting the environmental states and energy demands of a building on the basis of inputs defining form, fabric and operation. In support of this capability, the Building Research Establishment commissioned the Energy System Research Unit at the University of Strathclyde in Glasgow to compile a quality-assured collection of material thermo-physical properties. The project had the following objectives.

- To review existing datasets in terms of data source, underlying test procedures and degree of consensus.
- To devise and apply a conflation mechanism.
- To comment on the underlying test procedures and the need for harmonisation.
- To extract a robust sub-set of data for inclusion in Section 3 of CIBSE Guide A.

Six material properties were included within the project's scope: thermal conductivity (W/m K), density (kg/m^3), specific heat capacity (J/kg K), surface emissivity (–), surface shortwave absorptivity (–), and vapour resistivity or resistance (MN s/g m and MN s/g, respectively). In particular, an attempt was made to obtain data that described the variation of these properties as a function of temperature and moisture content. Note that the project excluded some significant material properties – such as those relating to moisture absorption/desorption and liquid water transport. Should such properties be available, it is possible to use a specialist modelling tool to adjust, for example, the thermal conductivity as a function of moisture content. Clearly, understanding the limits of a program in a particular application is an important part of the modelling process.

2. Project process

The project comprised four stages. First, model users/developers and material testing groups were contacted in order to obtain information on the datasets in current use and their underlying test procedures. A wide range of organisations were polled: professional bodies (such as CIBSE, ASHRAE and IBPSA), architectural and engineering practices, government agencies, research organisations, academic groups, software vendors, material manufacturers, and testing laboratories. In total 400 questionnaires were despatched and 100 replies received. Second, a selective follow-up was initiated to obtain significant datasets identified in the questionnaire returns and to appraise these in terms of source, content and associated test procedures. Third, a mechanism for merging the datasets was elaborated. Finally, a set of rules was devised to guide the extraction of a sub-set of data suitable for inclusion in Section 3 of CIBSE Guide A.

* Corresponding author. Tel.: +44 141 548 3986; fax: +44 141 552 5105.
E-mail address: joe@esru.strath.ac.uk (J.A. Clarke).

0360-1323/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2009.02.008

On analysing the collected datasets, it was apparent that some collections were derivatives of other, more authoritative ones. In essence some 13 independent datasets were identified: ASHRAE (US), BRE (UK), BS5250 (UK), CIBSE (UK), CSTC (Belgium), DOE-2 (USA), ESP-r (UK), Leeds University (UK), Leuven University (Belgium) and national datasets from France, Germany, India, Italy and The Netherlands.

From the questionnaire returns from testing organisations, it was apparent that there existed little information on specific heat capacity, indicating that the measured thermal conductivities were intended for use in steady-state applications. The decision by ASHRAE in 1985 to quote only recommended *U*-values for building assemblies, as determined by hot-box tests, is consistent with this conclusion. This suggests that the then extant testing procedures were not well matched to the requirements of dynamic building performance modelling.

Vapour resistivity was determined by under two-thirds of the respondents, with the quoted test standards leading, at most, to a two point result, which is insufficient to generate a differential permeability curve of the kind required to define the behaviour of hygroscopic materials.

Few testing organisations measured longwave emissivity and even fewer measured material shortwave properties. In the case of glazing systems, manufacturers are relied on to provide specific product values. It other cases, such measurements are likely to be subcontracted to research institutions or reliance placed on published results from various sources.

Thermal conductivity apart, the evidence suggested that organisations concerned with the use of thermo-physical property values do not generate the information first hand. This raises the question of the quality control of such data. The fact that a standard exists does not guarantee that it is actually in use. Standards tend to vary by material and there are, for example, hundreds of standards in the USA alone. Any one organisation is likely to test only a limited sub-set of what is possible. A listing, by thermo-physical property, of standards that were quoted in the questionnaire returns is given in Table 1.

While standards evolve – an examination of the BSI and ASTM yearbooks revealed that, typically, standards change every 3–5 years – a current standard will not affect data already in use for some time to come. For example, much of the CIBSE thermal properties dataset predated 1970 and several amendments of BS 874 – methods for determining thermal insulating properties (now withdrawn). Further, particular national standards may not cover certain areas and, in any case, a catalogue of standards would fail to reveal the use of in-house testing procedures.

Table 1
Standards relating to thermo-physical property measurement.

Thermal conductivity	
UK	BS 874, BS 1142, BS 3837, BS 3927, BS 4370, BS 4840, BS 5608, BS 5617
USA	ASTM C-158, ASTM C-177, ASTM C 236, ASTM C 335, ASTM C 518, ASTM C 687, ASTM C 691
West Germany	DIN 52612
Belgium	NBN B62-200, NBN B62-201, NBN B62-203
Density	
UK	BS 874, BS 2972, BS 4370, BS 5669
USA	ASTM C-158, ASTM C-177, ASTM C-209, ASTM C-302, ASTM C-303, ASTM C-519, ASTM C-520, ASTM C-1622
Belgium	STSO8.82.41, STSO8.82.5
Specific heat capacity	
UK	Yarsley: in-house
USA	ASTM C-351
East Germany	TGL 20475
Longwave emissivity	
UK	Draft BS 87/12988
USA	ASTM E-408, Manville: in-house
Australia	CSIRO: in-house
Shortwave properties	
UK	BS 87/12988
USA	ASHRAE 74-73
East Germany	Sonntag's Pyranometer
Vapour resistivity	
UK	BS 2782, BS 2972, BS 3177, BS 4370: 1973, Part 2, DD 146
USA	ASTM C755, ASTM E96
West Germany	DIN 52615
Austria	ONORM B 6016

3. Review of collected datasets

The following observations can be made on the structure and contents of the collected datasets.

- There is no consensus on the manner in which materials are grouped for presentation of data to users. What is needed is a common system such as the CIB Master List of Materials [1], which integrates thermal properties within a broad material classification system.
- The range of properties for which values are quoted is generally restricted. Commonly, the properties are thermal conductivity, density and vapour resistivity, as required for simple steady-state heat loss and condensation calculations.
- Data source is generally not identified and, where it is, little information is presented on the underlying experimental conditions. Data merging is therefore an uncertain process because it is difficult to ensure compatibility between different entries.
- It is suspected that much of the agreement that does exist between different datasets can be attributed to a degree of historical 'borrowing'. This, in turn, is likely to lead to an optimistic assessment of the inherent uncertainty.
- Many values are quoted without any statement as to whether they correspond to single or multiple measurements. A random inspection of several referenced works would suggest that values are usually derived from the work of a single researcher on the basis of a small sample size.
- Much of the data is derived from work carried out with non-standard apparatus and from a date that precedes modern standards of equipment and operation.
- No guidance is given on the variation in properties such as density and internal structure as inherent in the production of many building materials.
- There is no agreement on the procedure for the determination of the thermal conductivity of materials in the moist state.
- There is tacit agreement that the uncertainty within the data is use-context dependent. The various calculation methods proposed are clearly expected to yield no more than crude estimates of real conditions.
- For any material, density, moisture content and internal structure are the major determinants of its thermal and hygroscopic behaviour. In some cases, the effects of temperature and ageing can also be significant.

The following sub-sections consider how and where these properties and environmental conditions give rise to uncertainties in the data. A scheme for data classification and conflation is subsequently introduced that reflects this uncertainty.