Development of a NIST Standard Reference Database for Thermal Conductivity of Building Materials

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ABSTRACT

The development of a National Institute of Standards and Technolgy (NIST) Standard Reference Database for the thermal conductivity of building materials is presented. The source of the data is the collection of thermal conductivity measurements produced by NIST from 1932 to 1983 using the NIST 200 mm guarded-hot-plate apparatus. During its service, the apparatus was considered the U.S. National Standard for measurements of thermal conductivity of building materials and was instrumental in the early development of ASTM Test Method C 177 for the guarded-hot-plate method. The database currently contains 2175 records of thermal conductivity data for a variety of thermal insulations including cellular plastics, corkboard, glass fiber and other mineral fiber insulations as well as other building materials such as fiberboard and light-weight concrete. The final product will be available for public distribution on the Internet through the World Wide Web.

INTRODUCTION

For most of its history, NIST (formerly the National Bureau of Standards) has used guarded-hot-plate technology to measure thermal conductivity data of building materials. With time, NIST accumulated a valuable and comprehensive collection of thermal conductivity data from measurements performed with the NIST 200 mm guarded-hot-plate apparatus. The data were recorded in test log books (or secondary sources) and, unfortunately, were not in a convenient usable form. Moreover, while some of the data had been published, much of the data had been reported only to an individual sponsor or researcher. In the late 1980s, we recognized the value of preserving these data and began compiling the data into an electronic format. The purpose of the database was envisioned as a primary reference for tabulated handbook data. With the advancement of the Internet, a vehicle for displaying the database is now available. This paper describes the history and measurement method for obtaining the thermal conductivity data, a brief overview of the data, and discussion of the database.

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BACKGROUND

The development of the guarded-hot-plate apparatus began at NIST [1] about 1910 when the American Society of Refrigerating Engineers requested "usable data pertaining to heat transmission in insulation needed for design purposes." In 1916, Dickinson and Van Dusen [2] published an account of accurate determinations of heat flow through air spaces and thirty building materials. Subsequent measurements of insulating materials were reported by Van Dusen in 1920 [3] and Van Dusen and Finck [4] in 1928 (using similar apparatus). About 1929, Van Dusen built a version (known internally as hot plate #5) of this guarded-hot-plate apparatus which, thereafter, operated consistently for NIST for more than fifty years until 1983. The thermal conductivity data obtained from this apparatus constitute the subject of this paper. As a side note, this particular apparatus was entrusted to the NIST Museum in 1988.

From 1932 to 1983, the NIST 200 mm guarded-hot-plate apparatus contributed over 2200 measurements of thermal conductivity for building materials and thermal insulation. Throughout its history of operation, the apparatus was used to provide measurement data upon request for government agencies and private industry. In 1951, Robinson and Watson [5] published the results of an interlaboratory comparison of corkboard that demonstrated the need for suitable reference materials for calibration purposes. As a result, NIST began providing measurements of reference materials of fibrous-glass board, natural gum and silicone rubber. Later, the data for fibrous glass board was compiled by Siu [6] for Standard Reference Material 1450, Thermal Resistance - Fibrous Glass Board. The apparatus was maintained by several operators of whom six are known and listed here chronologically; Harold W. Wooley, J. Gillman Reed, Warren A. Knudeson, Henry E. Robinson, Thomas W. Watson, and Chock I. Siu.

TEST METHOD

A diagram of the NIST 200 mm guarded-hot-plate apparatus is illustrated in Figure 1. For traditional guarded-hot-plate tests involving heat flows through one pair of specimens, the determination of thermal conductivity (λ) is given by:

$$Q = 2A\lambda\frac{\Delta T}{L} \qquad (1)$$

where Q is the heat flow through the meter area of the guarded hot plate, $2A$ is the meter area for a pair of specimens, ΔT is the average temperature difference measured by thermocouples, and L is the average thickness measured with calipers. Ideally, the pair of specimens is well matched (i.e., nearly identical) so that the differences between specimens for ΔT and L are quite small. For thermal insulations and some building materials, the term "apparent" thermal conductivity is often used to indicate that more than one mechanism of heat transmission is present. For brevity, the term thermal conductivity will be used in this paper. Values of λ are typically reported for a mean

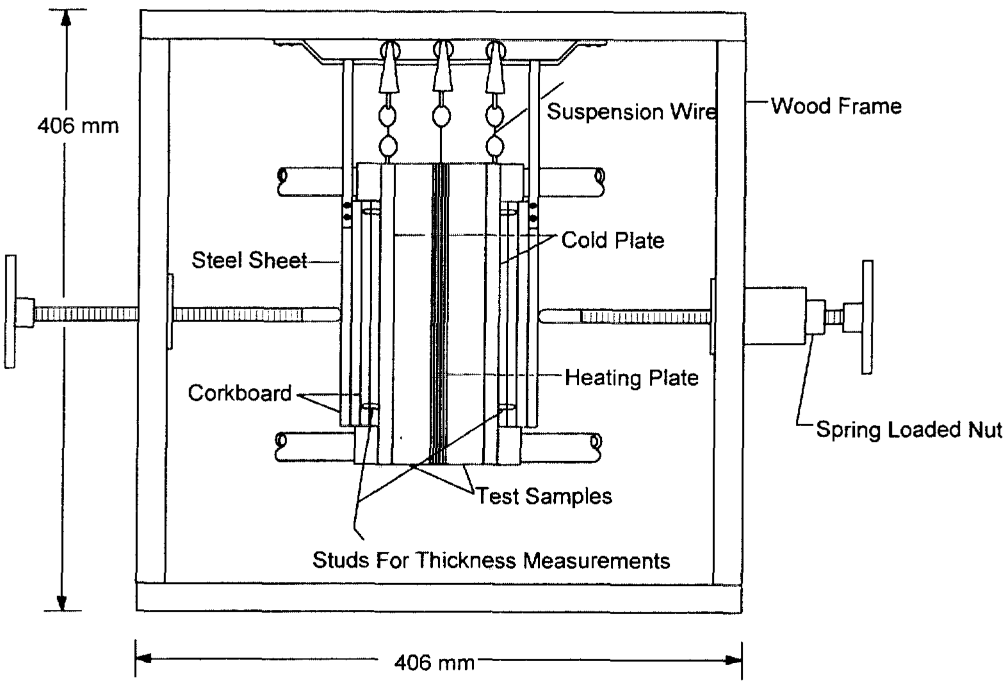

Figure 1. NIST 200 mm guarded-hot-plate apparatus

temperature, T_m which is the mathematical average of the hot and cold plates. The bulk density (ρ) of the test specimens was determined from the following equation:

$$\rho = \frac{m}{V} \qquad (2)$$

where m and V are the specimen mass and volume, respectively. It should be noted that in some cases, particularly measurements prior to 1941, values for L or ρ may not be included for every measurement of λ. The (expanded, $k = 2$) uncertainty for values of λ vary with material, ranging from 2 % to 3 % for heat insulators such as corkboard to 10 % for other materials [2].

OVERVIEW OF DATA

After careful review, the database was edited to 2175 records covering the years 1932 to 1983. Each record represents a time-average measurement of λ for a particular T_m. At present, there are 109 generic materials in the database, ranging alphabetically from acoustic spray insulation to zirconia. A breakdown, by measurement count, of the first 25 materials is given in Figure 2. The material, NBS Fibrous Glass, which was used for several years as a reference material (and later as a Standard Reference Material), represents 24 % of the data; followed by corkboard (7 %), wood fiber board (6 %), etc. Measurements for the other 84 materials (shown collectively) in the

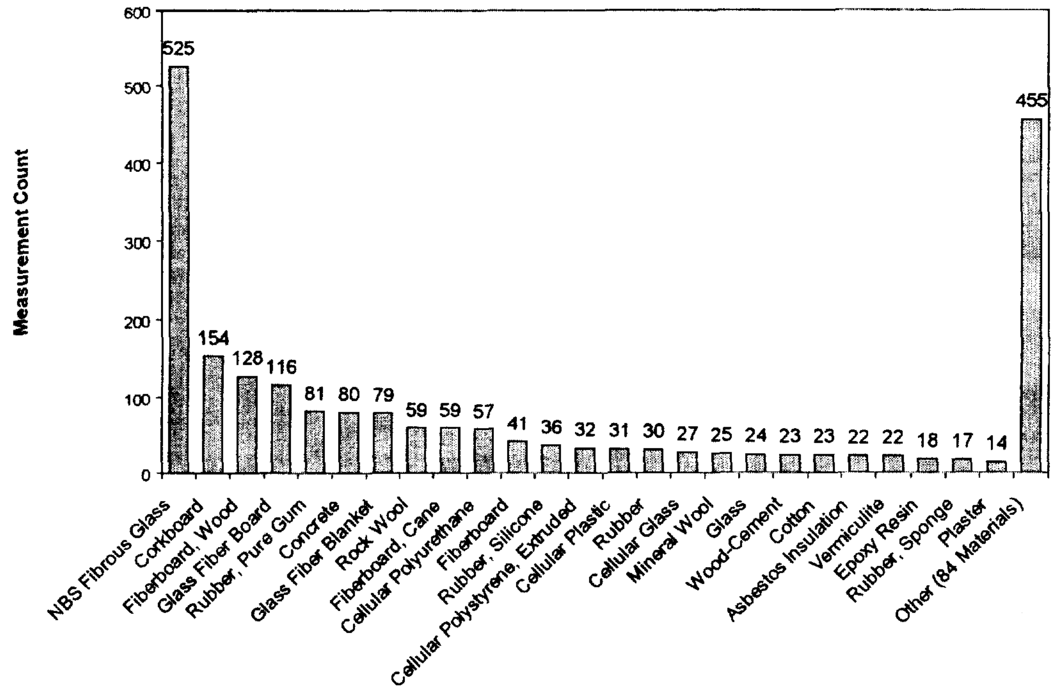

Figure 2. Breakdown of database materials by measurement count

database represent almost 21 % of the data. As noted in Figure 2, the breakdown of data is not balanced because measurements of different materials were performed as requested. The count tallies above also include replicate measurements.

Each record in the database includes information, if available, on material trade name, form, specimen description, sample number, and manufacturer (or third party). The material form is either blanket, block (rigid), board, loose, pipe (i.e., flat specimens taken from pipe insulation), slab (semi-rigid), spray, or woven. When available, information is included on specimen conditioning, moisture content, test mode, test variations, and general comments about the test or material. Numeric data (see Table 1) is available for bulk density (ρ), thickness (L), mean temperature T_m, temperature difference (ΔT), and thermal conductivity (λ). The thermal resistance, conductance, or resistivity are computed and displayed upon request.

TABLE I. STATISTICAL SUMMARY OF DATA

Measurement Parameter	Number of Measurements	Minimum	Maximum
Bulk Density, ρ	1992	4.2 kg·m^{-3}	2990 kg·m^{-3}
Thickness, L	2149	0.5 mm	32.8 mm
Mean Temperature, T_m	2175	-19.0 °C	58.6 °C
Temperature Difference, ΔT	1923	1.5 K	42.0 K
Thermal Conductivity, λ	2175	0.016 W·m^{-1}·K^{-1}	2.23 W·m^{-1}·K^{-1}

DATABASE

Building the NIST Standard Reference Database for thermal conductivity of building materials involved considerable effort for three items: 1) electronic preparation of the data; 2) quality review of the data; and, 3) development of a user-friendly graphical interface (GUI). The electronic preparation of the data required several years while data from the test log books and secondary data sheets were typed into an electronic spreadsheet. The quality review required checking the data by recomputing values of ρ, L, T_m, and λ using spreadsheet formulae as well as consistency checks by plotting λ versus independent variables. The GUI was developed after careful planning by the authors.

An overview of the GUI is illustrated in Figure 3. The interface design includes five main screens; a welcome page, search menu, tabulated search results, detail record page, and *x-y* plotting screen (not shown). The search menu provides select-lists for material, material category, and manufacturer, and numerical input boxes for ρ, L, T_m, and thermal transmission property. Numerical selections that are entered outside the range of data are trapped. The user can select either SI (default) units or conventional engineering inch-pound (IP) units. Retrieved data is sorted by either material, manufacturer, ρ, L, T_m, or the thermal transmission property selected by the user.

Figure 3c shows the search results for NBS Fibrous Glass Board for a temperature range from 20 °C to 26 °C and bulk density range from 65 $kg{\cdot}m^{-3}$ to 80 $kg{\cdot}m^{-3}$. The thickness range was unspecified. The search results have been sorted by bulk density. Each record includes an internal identification number (ID), material name, date of test, and data for ρ, L, T_m, and λ. Further information on any record can be obtained by clicking on the ID number. A detail page is shown for Record 1255, Figure 3d. Using a Java graphing applet, values of λ can be plotted versus the following independent variables, ρ, L, T_m, or year of measurement. When possible, technical terms have been linked to a definition glossary.

SUMMARY

NIST has recently developed a Standard Reference Database for the thermal conductivity of building materials for use on the Internet through the World Wide Web. The source of the data is the thermal conductivity measurements produced by NIST from 1932 to 1983 using the NIST 200 mm guarded-hot-plate apparatus. The database is intended as a resource tool for building designers, researchers, and students of heat transfer. Although the database can be used as a design tool, it is important to note that the database is intended primarily as a supplement for handbook data on design thermal transmission coefficients. The database has been designed using a graphical user interface to provide dynamic search and plotting capabilities for the user. Steady-state thermal transmission properties such as thermal conductivity can be plotted dynamically versus mean temperature, or bulk density providing a graphical interpretation of the data. A detailed summary page of the test data is available for each measurement.

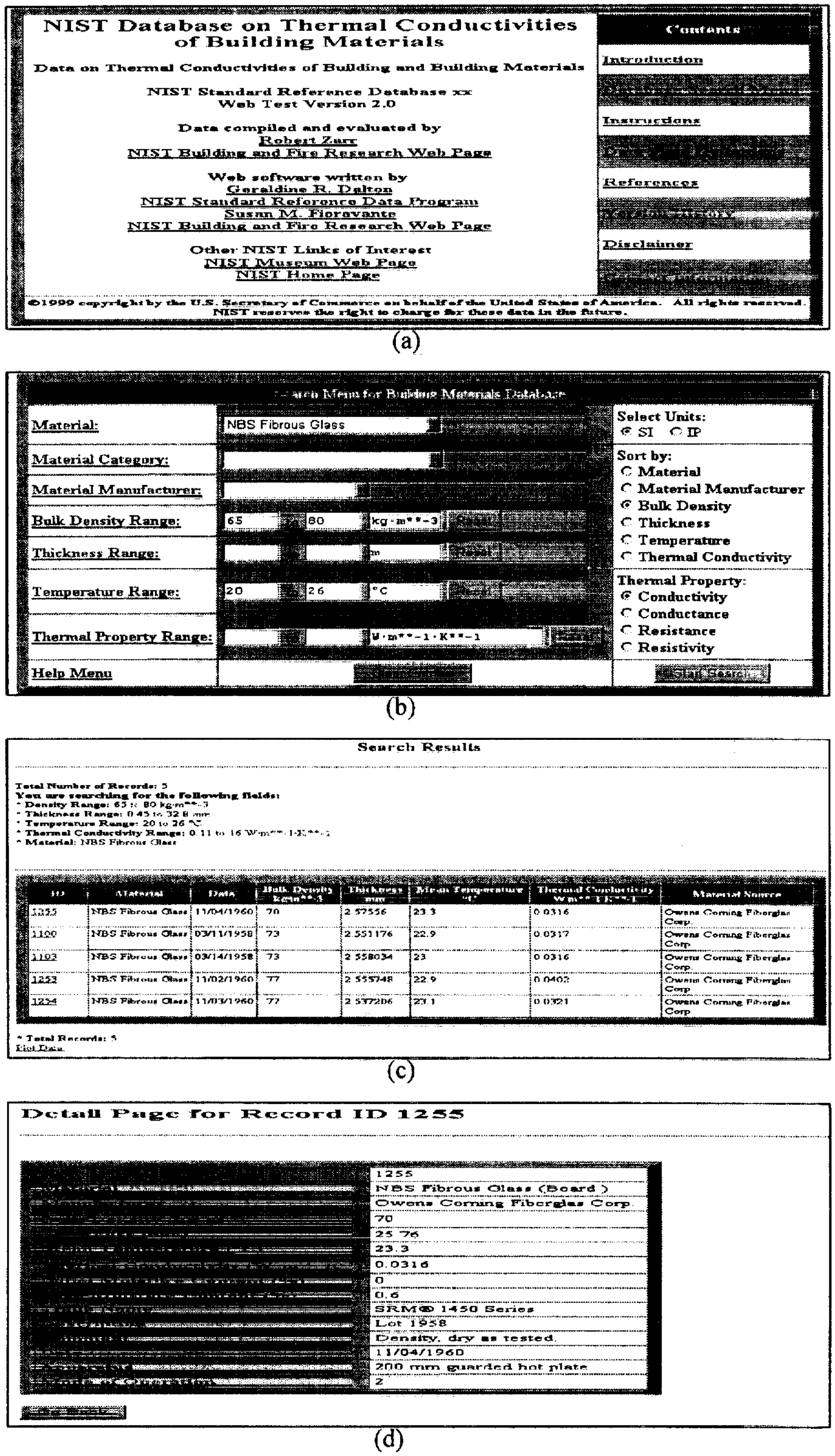

Figure 3. Graphical user interface: (a) welcome page, (b) search menu, (c) search results, and (d) detail page.

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