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THERMAL PERFORMANCE OF BUILDINGS AND BUILDING ENVELOPE SYSTEMS: AN ANNOTATED BIBLIOGRAPHY

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Lawrence Berkeley Laboratory University of California/Berkeley

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NOTICE

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ABSTRACT

A bibliography of published papers describing models, measurement techniques, apparatus, and data for the thermal performance of whole buildings and building envelope systems has been collected (aggregate energy consumption of whole buildings, performance of HVAC equipment, and solar technologies are not included). Summary descriptions of the content of each citation are provided. Measurements on whole buildings or on systems other than walls are sparse. However, new and recently completed measurement facilities are increasing these capabilities. Measurements under dynamic conditions are difficult to accomplish and few reliable data exist. Some analogs have been explored experimentally and analytically. Citations on analytical models are selective and concentrate on methodology that forms the basis of computer programs for whole-building energy analysis. Interesting future directions include new approaches to dynamic measurements, both in the laboratory and in the field, for envelope systems and for whole buildings.

Key Words: Analytical models; Annotated bibliography; Bibliography; Building envelope systems; Buildings; Computer models; Energy performance; Heat transmission; Thermal performance data; Thermal performance measurement.

1. Introduction

This bibliography is the result of a literature search undertaken by the Building Envelopes Group of the Energy and Environment Division of the Lawrence Berkeley Laboratory (LBL), University of California. The primary purpose of the search was to determine the extent of published data measurement methods, and performance models based on data and/or first principles for the heat transmission and thermal performance characteristics of building envelope systems (walls, roofs, floors, etc.), whole buildings, and the relationship between the two. This information will be used to determine useful approaches to the development of dynamic test methods for envelope thermal performance which are reliable, and sufficiently portable to be used for field testing. Because no comprehensive collection of such subject matter was found in the literature, it was felt that this bibliography would be a useful addition.

The scope of the bibliography is indicated by Figure 1. The intent was to include papers describing test methods and apparatus, measured data, and analytical and empirical models of the heat transmission of building envelope systems. The boundary of the technical subject matter selected for inclusion is necessarily "fuzzy" because of the overlap between materials and systems performance on one hand, and because of the interrelationship between the thermal performance of systems and whole buildings on the other. Some individual papers cross those (somewhat artificial) subject divisions. In some cases individual papers were included because of descriptions of relevant techniques or apparatus, that would not have been otherwise. In particular the citations that deal with whole building energy performance modeling are selective and emphasize methods that form the basis of computer programs now becoming widely used for that task, and not the computer programs themselves.

The bibliography is limited to building applications. No papers dealing with industrial or cryogenic applications are included. The bibliography also concentrates almost exclusively on heat transmission and thermal performance. HVAC systems, air infiltration, active and passive solar energy technologies, durability, and health and safety issues are not addressed. Efficiencies of energy conversion processes and equipment, and energy consumption characteristics of whole building aggregates are also excluded. However, reviews, surveys, collections, and bibliographies dealing with these related subjects are referenced when the author was aware of them.

Sources of material considered for the bibliography were limited to the published literature. This limitation may be a severe one because this is a technical area in which the private sector is active, and has generated much data which is not generally available. On the other hand, it is felt that the state of the art for measurement technology is in fact well represented. Despite the author's best intentions to cover the literature as thoroughly as possible, time limitations have necessarily caused gaps. There was a limited effort at searching in foreign journals, in particular. It is hoped that later versions of the bibliography will be more complete in this regard.

The bibliography is organized both by subject matter and alphabetically. Table 1 following the introduction identifies citations in each subject category by the unique citation number assigned in the alphabetical section. The alphabetical section consists of complete citations arranged by the last name of the primary author, together with annotations.

No attempt was made to critically evaluate the papers in this bibliography. Rather, the annotations attempt to summarize the contents of each paper as concisely as possible. In some cases, annotations were not included either because the title of the paper was sufficiently descriptive, or because the paper itself could not be obtained. While the annotations are short, every attempt was made to make the bibliographic informaton as complete as possible. When the actual paper itself could not be obtained, the citations may not contain page numbers. Great care was taken to make the citations error free. However, a bibliography with no errors is almost impossible to achieve in practice. The author accepts responsibility for errors that still remain.

The author wishes to thank R. C. Diamond, R. C. Kammerud, P. Hillis, and A. H. Rosenfeld of the Lawrence Berkeley Laboratory, W. G. Colborne of the University of Windsor, P. R. Achenbach of the U. S. National Bureau of Standards, and F. C. Wilson of the Owens-Corning Fiberglas Corp. for their helpful and constructive reviews of this bibliography. C. Wodley and C. Backhus of the Lawrence Berkeley Laboratory Engineering Library deserve special recognition for their highly successful efforts in obtaining copies of the papers cited here.

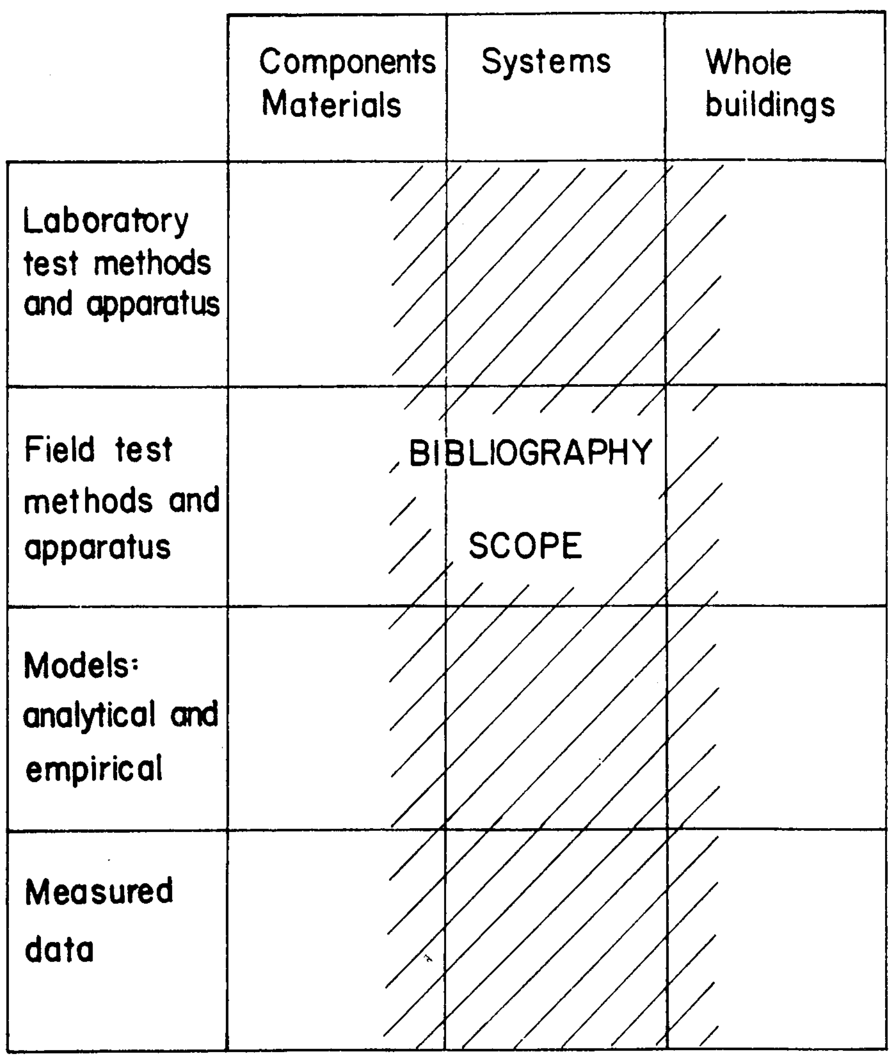

Fig. 1 Bibliography Scope

Table 1. Subject Index for Citations

Technical Approach	Components and Materials	Envelope Systems: Attics, Roofs	Envelope Systems: Walls	Envelope Systems: Floors, Basements	Envelope Systems: Other	Whole Buildings
Laboratory Experimental:						
Apparatus/Instrumentation	6, 10, 16, 60, 127, 128, 131, 143	88, 117, 164	6, 10, 16, 17, 54, 60, 82, 83, 86, 87, 88, 96, 101, 106, 113, 114, 118, 122, 131, 135, 136, 137, 138, 143, 145, 147, 154, 167	88, 94	28, 82	55, 69, 83, 111
Data	10, 25, 60, 127, 128, 139, 168, 169	88, 117, 164	9, 10, 25, 54, 82, 83, 86, 87, 88, 101, 112, 114, 118, 119, 124, 126, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 147, 154, 163, 165, 168, 169	94	28, 82	55, 69, 83, 111, 126
Dynamic Performance		123	14, 39, 76, 113, 114, 119, 123, 124, 126			125
Field Experimental:						
Apparatus/Instrumentation		22, 23, 52, 106	22, 23, 30, 46, 49, 52, 73, 106	34, 40, 66, 106	33	22, 23, 49
Data		22, 44, 64, 68	1, 22, 46, 47, 64, 67, 73, 77, 118	40, 64, 66	33	1, 4, 22, 26, 78, 146, 147
Dynamic Performance		52, 158	30, 52	34	33	146
Models:						
Analytical		29, 56, 63, 65, 81, 85, 90, 91, 92, 97, 99	2, 14, 15, 30, 31, 35, 37, 39, 47, 50, 56, 61, 63, 65, 74, 80, 81, 85, 90, 91, 92, 95, 97, 99, 100, 102, 103, 115, 119, 120, 121, 125, 149, 154, 155, 156, 159, 160	48, 56, 104, 152	116, 130	7, 18, 27, 36, 50, 51, 57, 74, 79, 81, 85, 98, 99, 102, 105, 107, 125, 142, 146, 147, 149, 160
Analog		58, 108	38, 42, 45, 76, 108, 110, 124, 166		109	3, 11, 19, 20, 21, 24, 41, 108, 166
Computerized		81, 97, 99	74, 81, 97, 99, 148, 149, 161, 166	81, 152		3, 7, 11, 18, 74, 79, 81, 97, 99, 105, 107, 149, 161, 166
General References and Bibliographies:						
	5, 8, 13, 43, 53, 59, 70, 71, 72, 93, 144, 150, 151	5, 8, 13, 32, 44, 53, 59, 62, 71, 72, 81, 89, 129				12, 32, 44, 53, 62, 71, 81, 84, 144

2. Bibliographic Citations and Annotations

[1] P. R. Achenbach, E. M. Tierney, "A Study of a Baseboard Convector Heating System in a Test Bungalow," U. S. National Bureau of Standards, Building Materials and Structures Report No. 115, August 1949.

Contains data on the heat loss of the various envelope components of a house used for testing of heating equipment.

[2] J. S. Alford, J. E. Ryan, F. O. Urban, "Effect of Heat Storage and Variation in Outdoor Temperature and Solar Intensity on Heat Transfer Through Walls," Trans. ASHVE, **45,** 369-395, 1939.

Mathematical description of transient heat transmission characteristics for walls, which includes the effects of thermal mass.

[3] J. R. Anders, "An Approach to the Digital Simulation of Room Dynamic Thermal Performance Using Thermal Circuit Techniques," pp. 1-8 in <u>Heat Transfer In Energy Conservation</u>, R. J. Goldstein, <u>et</u> <u>al</u>., Eds., ASME, New York, 1977.

Describes methodology for digital simulation of room dynamic thermal circuit analogs, rather than analog simulation. An application compares results from this method with other results published in the literature for the NBS experimental block house.

[4] D. B. Anderson, "Heat Loss Studies in Four Identical Buildings to Determine the Effect of Insulation," Trans. ASHVE, **48,** 471-492, 1942.

This report describes measurements of heat losses and interior temperatures (for comfort purposes) made in four identical houses, differing only by the amount of insulation in the walls. Although the insulation levels, ranging from 0.9 in to 2.3 in thickness are low by current standards, the results are useful in illustrating typical performance of houses of that time period.

[5] <u>Annual Book of ASTM Standards, Part 18: Thermal and Cryogenic Insulating Materials; Building Seals and Sealants; Fire Tests; Building Constructions; Environmental Acoustics</u> , American Society for Testing and Materials, Philadelphia, 1977.

Contains texts of ASTM standard test methods related to thermal performance measurements of building materials and systems.

[6] A. G. Arend, "Research On Heat Transmission ... gh Building Materials," Heating and Ventilating Engineer, 35, 53 ..., 1962.

Summary descriptions of several measurement techniques to determine heat flow through walls in buildings.

[7] F. Arumi, "Multispace Thermal Coupling of the DEROB System," pp. 9-15 in Heat Transfer In Energy Conservation, R. J. Goldstein, et al., Eds., ASME, New York, 1977.

Theoretical approach to a representation of the generalized dynamic, coupled, multizone thermal performance model for buildings.

[8] "An Assessment of Thermal Insulation Materials and Systems for Building Applications," Brookhaven National Laboratory, Report BNL-50862, June, 1978.

A recent comprehensive survey and assessment of the state-of-the-art knowledge of the thermal performance of building insulating materials and envelope systems. Present status and future requirements for testing methodology development, and the influence of building codes and standards on improving building envelope performance is also discussed.

[9] C. G. Bankvall, "Natural Convective Heat Transfer in Insulated Structures," Lund Institute of Technology, Report 38, 1972.

Experimental measurement of steady-state heat transfer for full scale wall sections, including a determination of the contribution of internal convection to the overall heat transfer.

[10] C. G. Bankvall, "Forced Convection: Practical Thermal Conductivity in an Insulated Structure Under the Influence of Workmanship and Wind," pp. 409-425 in Thermal Transmission Measurements of Insulation, ASTM STP 660, R. P. Tye, Ed., American Society for Testing and Materials, Philadelphia, 1978.

This paper describes the effective heat resistance in an insulated wall structure, as influenced by workmanship and forced convection. Experimental investigations of typical wall constructions are compared with calculations. Examples show the influence of insulation installation practices on heat transmission, air flow along the insulation, and air flow through the insulation.

[11] P. Basnett, "Modelling the Effects of Weather, Heating and Occupancy on the Thermal Environment Inside Houses," pp. 353-365 in Mathematical Models for Environmental Problems: Proceedings, (International Conference held at the University of Southampton, England, September 3-12, 1975), C. A. Brebbia, Ed., Halstead, New York, 1976.

Description of a lumped-parameter network analysis technique for modeling whole-building dynamic performance for residences. Results are compared with measured data from a set of buildings constructed as part of the effort.

[12] "Bibliography on Passive Solar Energy Designs and Systems," National Solar Heating and Cooling Information Center, Rockville, Maryland, Report DC120, January 1978.

A selected bibliography of current literature describing passive solar designs, devices, and systems.

[13] N. S. Billington, Building Physics: Heat , Pergamon, Oxford, 1967.

Classic text, developing from physical origins a comprehensive description of thermodynamics, heat transfer processes, and thermal performance characteristics of buildings.

[14] P. Bondi, C. Codegone, V. Ferro, A. Sacchi, "Experiments on Stationary and Oscillating Heat Transfer in Large Walls," pp. 217-229 in Heat transfer-Current applications of air conditioning, International Institute of Refrigeration, Pergamon, Oxford, 1971.

Contains measured data from dynamic hot box tests, which characterize the transient performance of selected wall constructions by determining elements of the wall thermal admittance matrix as a function of frequency.

[15] B. A. Borresen, "Heat Storage In Walls," Building Services Engineer, **41**, 17-18, 1973.

Analytical determination of the optimum thickness of a thermally massive wall, considering its transient heat transfer properties.

[16] E. Brendeng, P. E. Frivik, "New Development in Design of Equipment for Measuring Thermal Conductivity and Heat Flow," pp. 147-166 in Heat Transmission Measurements in Thermal Insulations, ASTM STP 544, American Society for Testing and Materials, Philadelphia, 1974.

Description of equipment design and operational capabilities of Trondheim University for various heat transmission measurement apparatuses. Included is a hot box facility description, used primarily for convection studies in insulation systems, as well as several hot plate apparatuses used for various materials property measurement applications.

[17] W. P. Brown, K. R. Solvason, A. G. Wilson, "A Unique Hot-Box Cold-Room Facility," Trans. ASHRAE, **67**, 561-577, 1961.

Description of the design and operational characteristics of a guarded hot box apparatus at the Canadian National Research Council Division of Building Research. The apparatus is capable of measuring 1.2 m x 2.4 m wall specimens. A detailed error analysis is presented.

[18] R. J. A. van der Bruggen, J. T. H. Lammers, "Computer Program 'KLI'," pp. 449-463 in Energy Conservation in Heating, Cooling and Ventilating Buildings, Vol. 1, C. J. Hoogendoorn and N. H. Afgan, Eds., Hemisphere, Washington, 1978.

Description of a generalized, comprehensive dynamic building energy analysis program.

[19] H. Buchberg, "Electric Analogue Prediction of the Thermal Behavior of an Inhabitable Enclosure", Trans. ASHVE, **61**, 339-386, 1955.

This paper presents a thermal circuit analysis of the thermal response of a simple dwelling to dynamic climate parameters and shows how solutions of the circuit are obtained by electrical analogy. Consideration was given only to the transient temperature response of the space and to the rate of heat loss or gain without considering moisture transfer or latent heat effects of the air.

[20] H. Buchberg, "Sensitivity of Room Thermal Response to Inside Radiation Exchange and Surface Conductance," Building Science, **6**, 133-144, 1971.

Calculated examination of the effect of neglecting radiative heat interchange between room internal surfaces, and using constant values of inside surface conductance, on the prediction of inside surface temperatures, inside air temperature, heating loads and cooling loads.

[21] H. Buchberg, "Sensitivity of the Thermal Response of Buildings to Perturbations in the Climate," Building Science, **4**, 43-61, 1969.

Transient thermal calculations of a one-zone building model to determine fluctuations in inside air temperature due to changes in weather parameters. The analysis was done for three different wall designs.

[22] D. M. Burch, C. M. Hunt, "Retrofitting An Existing Wood Frame Residence For Energy Conservation -- An Experimental Study," U. S. National Bureau of Standards NBSIR 77-1274, July, 1977.

Carefully instrumented and documented measurement of heat losses and gains through envelope components and systems in a wood frame residence. Comparisons of energy consumption are made before and after selected retrofit actions to improve performance.

[23] D. M. Burch, T. Kusuda, D. G. Blum, "An Infrared Technique for Heat-Loss Measurement," U. S. National Bureau of Standards Tech. Note 933, April 1977.

Describes a calibration technique to enable quantification of infrared thermograms directly in terms of heat loss from building envelopes.

[24] G. Burnand, "The Study of the Thermal Behavior of Structures by Electrical Analogy," Brit. J. Appl. Phys., **3**, 50-53, 1952.

Description of an electrical analog circuit for a house, and how component values for circuit elements are chosen. Comparisons with observed temperature data in a room agreed with the analog model results when the model was modified to account for the presence of temperature gradients and hot air streams in the actual room.

[25] P. J. Burns, L. C. Chow, C. L. Tien, "Convection In A Vertical Slot Filled With Porous Insulation," Int. J. Heat Mass Transfer, **20**, 919-926, 1977.

Analytical study of heat transfer through insulation in cavity wall geometries. Results discuss the effects of infiltration and fiber orientation on internal convection in the cavity, and the subsequent effect on overall heat transfer.

[26] M. L. Carr, R. A. Miller, L. Orr, D. Shore, "A Study of the Heat Requirements of a Single-Glazed Test House and a Double-Glazed Test House," Trans. ASHVE, **45**, , 195-212, 1939.

Reports the results of a study of the relative heat requirements necessary to maintain a fixed temperature in each of two similar test houses, with single- and double-glazing, respectively. Effects of temperature, wind velocity, and solar radiation are estimated from the data.

[27] N. K. D. Chaudhury, Z. U. A. Warsi, "Weighting Function and Transient Thermal Response Of Buildings: Part I - Homogeneous Structure," Int. J. Heat Mass Transfer, **7**, 1309-1321, 1964.

A theoretical investigation of the transient thermal response of enclosures (single rooms) to arbitrary outdoor air temperature variations. The concept of a room "weighting function" is developed to characterize the thermal response. Assumptions require the properties of all surfaces enclosing the structure to be the same.

[28] G. Christensen, W. P. Brown, A. G. Wilson, "Thermal Performance of Idealized Double Windows, Unvented," Trans. ASHRAE, **70**, 408-418, 1964.

Results of measurements on a double pane window configuration in a guarded hot box facility at the Canadian National Research Council are presented as a basis for improved window design. Detailed descriptions of test procedures and data are given.

[29] P. M. Chung, C. E. Lund, "Downward Heat Transfer Through a Joist Space," Trans. ASHRAE, **65**, 245-258, 1959.

A theoretical study of heat transfer downward through an uninsulated joist space, including effects of convection, radiation, and conduction. Comparison is made with selected experimental data in the literature, showing good agreement.

[30] P. E. Condon, W. L. Carroll, R. C. Sonderegger, "A New Measurement Strategy for In-Situ Testing of Wall Thermal Performance," University of California, Lawrence Berkeley Laboratory, Report LBL-8822, April 1979.

Contains the mathematical analysis forming the basis of a new approach for in situ measurement of the transient thermal performance of walls. A conceptual design of the apparatus and methods of use are proposed.

[31] K. W. Cooper, D. R. Tree, "A Re-evaluation of the Average Convection Coefficient for Flow Past a Wall," Trans. ASHRAE, **79** (1), 48-51, 1973.

Presents an analytical method for determining the average heat transfer coefficient for air flow past a wall where the wind may strike the wall at any angle. Equations are presented by which the average forced convection heat transfer coefficient may be determined for a wall of any length.

[32] G. C. P. Crall, "Bibliography on Available Computer Programs in the General Area of Heating, Refrigerating Air Conditioning and Ventilating," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1975.

This bibliography of computer programs includes the following areas: heating/cooling load calculations, energy analysis, duct design, piping design, equipment selection, solar simulations.

[33] R. D. Cramer, L. W. Neubauer, "Solar Radiant Gains Through Directional Glass Exposure," Trans. ASHRAE, **65**, 499-514, 1959.

Description of measured solar radiant heat gains through windows in an orientable, portable structure. Interior temperatures are presented as a function of orientation and time of day, and shows the results of certain shading strategies for the climate of Davis, California.

[34] R. D. Cramer, L. W. Neubauer, "Thermal Effects of Floor Construction," Trans. ASHRAE, **67**, 214-227, 1961.

Experimental description of the hourly variation of interior temperature in a portable cubicle with a south-facing wall of glass and two different floor constructions: uninsulated wood-frame over exposed crawl space and uninsulated slab on grade. Has consequences for passive solar buildings.

[35] M. G. Davies, "The Thermal Admittance of Layered Walls," Building Science, **8**, 207-220, 1973.

A procedure is developed and presented for computing the thermal admittance, a measure of dynamic thermal performance, of layered envelope constructions. Methods are presented to enable computation of the change in admittance which results when an air film is added to some pre-existing construction of known admittance.

[36] M. G. Davies, "A Thermal Circuit for Radiant Exchange," Building and Environment, **14**, 43-46, 1979.

Representation of the internal radiative heat exchange in a room in terms of a lumped parameter network. The relationship to previous work on the subject in the literature is discussed.

[37] J. H. de Boer, P. Euser, "Calculation of the Solar Heat Gain Through Composite Constructions by the Matrix Method," pp. 93-100 in Heat transfer-Current applications of air conditioning, International Institute of Refrigeration, Pergamon, Oxford, 1971.

Description of the application of a lumped parameter network in a matrix representation, and its application to the numerical determination of the transient behavior of composite envelope constructions.

[38] F. De Ponte, G. Zorzini, "Electrical Analog Model of a System With Transient Radiation Heat Transfer," pp. 179-187 in Heat transfer-Current applications of air conditioning, International Institute of Refrigeration, Pergamon, Oxford, 1971.

Description of an electrical analog model used to determine the transient characteristics of heat flow through cavity walls. Detailed aspects of the transient behavior of conduction, convection, and radiation heat transfer are considered.

[39] P. Di Filippo, M. Sovrano, G. Zorzini, "Thermal Behavior of Composite Walls Under Transient Conditions. Their Characterization by Two Parameters. Simplified Calculation Method," pp. 47-58 in Heat transfer-Current applications of air conditioning, International Institute of Refrigeration, Pergamon, Oxford, 1971.

Developes an approximate characterization of the transient behavior of composite walls in terms of homogeneous walls with equivalent total heat transfer and response time. A guarded hot box is described, and measured values of the dynamic heat flow characteristics of several walls are presented.

[40] R. S. Dill, W. C. Robinson, H. E. Robinson, "Measurements of Heat Losses from Slab Floors," NBS Building Materials and Structures Report BMS 103, 1945.

Experimental determination of heat losses through seven different floor constructions. Results showed that edge losses through concrete slab floors, either on grade or above grade are considerable and can be significantly reduced by edge insulation. Losses from wood frame floors over crawl spaces are relatively smaller. Some methods are suggested for estimating floor heat losses.

[41] W. B. Drake, H. Buchberg, D. Lebell, "Load Calculations Using Pretabulated Admittance Functions," Trans. ASHRAE, **65**, 515-522, 1959.

Descriptions of a dynamic thermal performance model for multiple surface spaces using a lumped-parameter model for heat transfer representations, which allows for pre-calculation of the relevant parameters for known constructions. Results using analogue electrical circuits are described. Contains a comprehensive bibliography of earlier work leading to the development of this methodology.

[42] W. B. Drake, H. Buchberg, D. Lebell, "Transfer Admittance Functions for Typical Composite Wall Sections," Trans. ASHRAE, **65**, 523-540, 1959.

Tabulation of precalculated admittance function parameters for typical building envelope constructions, for use in predicting dynamic thermal performance by the admittance procedure described in the paper above by Drake.

[43] E. R. G. Eckert, E. M. Sparrow, W. E. Ibele, R. J. Goldstein, "Heat Transfer Bibliography," Int. J. Heat Mass Transfer, **6**, 91-112, 1963.

Bibliography of Traditional engineering heat transfer subjects. Citations consist of technical papers in the published literature grouped by subject.

[44] "Energy Conservation: Buildings," U. S. Dept. of Commerce, National Technical Information Service, Report PS-77/0396, June, 1977.

Bibliography of government reports available from NTIS in the area of buildings energy conservation.

[45] F. M. Flanigan, "How Periodic Heat-Flow Problems Can Be Solved Through Use of an Hydraulic Analogue," ASHRAE Jour., **3** (8), 45-50, 1961.

An experimental method for measurement of dynamic heat flow through composite walls using a hydraulic analogue circuit. The wall is modeled as an equivalent lumped parameter R-C network. Measured results show close agreement with analytically calculated values.

[46] J. B. Funkhouser, "Air Infiltration Effects On The Thermal Transmittance Of Concrete Building Systems," Trans. ASHRAE, **85** (1), to be published in 1979.

Description of a portable hot box apparatus developed to make field measurements of wall thermal performance. Results are described for the thermal transmittance of two types of concrete construction. The effect of infiltration on thermal transmittance has been determined for these same constructions in laboratory measurements and are reported here.

[47] F. E. Giesecke, "The Flow of Heat Through Walls," Trans. ASHVE, **45**, 441-458, 1939.

Early application of a finite-difference approach to graphically estimate the dynamic heat transmission of a thermally massive wall, and a simplification of the method used to obtain approximate estimates. Comparison of results from the two methods is made to measured data.

[48] A. G. Gindoyan, V. Ya. Grushko, "Study of Temperature Conditions of Heated Floor Structures and Buildings Foundation Soils with Negative Temperature of Internal Media," pp. 671-682 in Energy Conservation in Heating, Cooling and Ventilating Buildings, Vol. 2, C. J. Hoogendoorn and N. H. Afgan, Eds., Hemisphere, Washington, 1978.

Analytical determination of transient heat and moisture flow in the coupled floor-ground model.

[49] R. A. Grot, D. T. Harrje, L. C. Johnston, "Application of Thermography for Evaluating Effectiveness of Retrofit Measures," pp. 103-117 in Proc. Third Biennial Infrared Information Exchange, (St. Louis, Mo., August 24-26, 1976), AGA Corp., Secaucus, N. J., 1977.

Description of an experimental field study of residential retrofits for energy conservation, which used infrared thermography as an evaluative tool.

[50] G. Guglielmini, U. Magrini, "Periodic Heat Flow Through Lightweight Walls: Influence of the Heat Capacity of Solid Bodies upon Room Temperature," pp. 153-162 in Heat transfer-Current applications of air conditioning, International Institute of Refrigeration, Pergamon, Oxford, 1971.

Describes the effect of internal thermal mass on indoor, transient, room temperatures. A method is presented which provides the amplitude ratio and the time lag of the indoor air temperature variation with respect to a time-varying outdoor air temperature.

[51] C. L. Gupta, M. L. Gupta, S. P. Jain, B. C. Raychaudhuri, "Indoor Climate Prediction by Matrix Method of Circuit Analysis," Indian Jour. Technology, **3** , 166-170, 1965.

Describes a lumped parameter thermal analog model for dynamic thermal performance. Results of the model are compared with measured data.

[52] M. L. Gupta, C. L. Gupta, S. P. Jain, . . Raychaudhuri, "Periodic Flow in Conditioned Structures," Indian . . Technology, **3**, 323-328, 1965.

Contains measured heat transmission . .a for roofs and walls of four specially designed and air conditioned structures. Comparisons of measured results with calculations based on the method of Mackey and Wright are made, with reasonable agreement. Observations based on the data include the greater effectiveness of insulation on the outside, rather than on the inside, of masonry, and decreased heat flow through constructions with cavities.

[53] Handbook of Fundamentals , American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., New York, 1977.

[54] G. O. Handegord, N. B. Hutcheon, "Thermal Performance of Frame Walls," Trans. ASHVE, **58**, 171-188, 1952.

Description of an apparatus for measurement of heat transfer through wood frame cavity walls under winter conditions. Resultant experimental data, is presented. The effect of internal convection in the cavity is estimated and found to be significant. The effectiveness of insulation in the cavity can be significantly decreased by improper installation which does not totally prevent convection.

[55] J. Hannay, L. Laret, J. LeBrun, D. Marret, P. Nusgens, "Thermal Comfort and Energy Consumption in Winter Conditions — A New Experimental Approach," Trans. ASHRAE, **84** (1), 150-175, 1978.

Contains experimental measurements from a specially constructed room which quantify the relationship between thermal comfort and energy requirements for different kinds of heating devices in winter conditions. Generalized thermal comfort conditions take into account wall surface temperatures, non uniform air temperatures, and internal air movement.

[56] K.-E. Hassan, G. M. Zaki, "A Method for Calculating the Thermal Load on Air-Conditioned Buildings," pp. 405-418 in Energy Conservation in Heating, Cooling and Ventilating Buildings," Vol. 1, C. J. Hoogendoorn and N. H. Afgan, Eds., Hemisphere, Washington, 1978.

Analytical, transient heat flow analysis for building envelope components.

[57] G. Hauser, "Method for Calculation of Therma[l Be]havior in Buildings," pp. 419-427 in Energy Conservation in Heatin[g, C]ooling and Ventilating Buildings, Vol. 1, C. J. Hoogendoorn and N. [H. Af]gan, Eds., Hemisphere, Washington, 1978.

Numerical approach to the generalized, coupled multizone problem in building energy analysis programs.

[58] J. B. Headrick, D. P. Jordan, "Analog Computer Simulation of the Heat Gain through a Flat Composite Roof Section," Trans. ASHRAE, **75**, 21-33, 1969.

Description of an analog computer model used to compute the dynamic heat gains through flat, layered roofs into a space below maintained at constant conditions.

[59] Heat Transmission Measurements in Thermal Insulations, ASTM STP 544, American Society for Testing and Materials, Philadelphia, 1974.

[60] F. G. Hechler, E. R. McLaughlin, E. R. Queer, "Simultaneous Heat and Vapor Transfer Characteristics of an Insulating Material," Trans. ASHVE, **48**, 505-516, 1942.

Description of a rotatable guarded hot box at the Pennsylvania State University. Tests are discussed and data presented for simultaneous heat and moisture transmission measurements for a specimen fabricated from wood fiber board.

[61] P. R. Hill, "A Method of Computing the Transient Temperature of Thick Walls From Arbitrary Variation of Adiabatic-Wall Temperature and Heat Transfer Coefficient," National Advisory Committee For Aeronautics, NACA Tech. Note 4105, October 1957.

[62] C. J. Hoogendoorn, N. H. Afgan, Eds., Energy Conservation in Heating, Cooling and Ventilating Buildings: Heat and Mass Transfer Techniques and Alternatives. Vols. 1 and 2, Hemisphere, Washington, 1978.

Proceedings of a conference sponsored by the International Centre for Heat and Mass Transfer and held in Dubrovnik, Yugoslavia, Aug. 29-Sept. 2, 1977. Although some of the most interesting papers are cited individually in this bibliography, many of them are relevant. These proceedings are very useful.

[63] F. C. Houghton, J. L. Blackshaw, E. M. Pugh, P. McDermott, "Heat Transmission As Influenced by Heat Capacity and Solar Radiation," Trans. ASHVE, **38,** 231-254, 1932.

Presents calculation method for determining transient heat transmission through homogeneous walls and roofs, for dynamic outside temperatures and solar radiation.

[64] F. C. Houghton, C. Gutberlet, "Additional Coefficients of Heat Transfer as Measured Under Natural Weather Conditions," Trans. ASHVE, **35,** 151-164, 1929.

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[65] F. C. Houghton, E. C. Hach, S. I. Taimuty, C. Gutberlet," Heat Gain Through Walls and Roofs As Affected by Solar Radiation," Trans. ASHVE, **48,** 91-106, 1942.

Description of results of an experimental study to measure the heat flow and temperatures for wall and roof constructions exposed to outside weather, including solar radiation. Dynamic characteristics are presented. Contains references to earlier, related work.

[66] F. C. Houghton, S. I. Taimuty, C. Gutberlet, C. J. Brown, "Heat Loss Through Basement Walls and Floors," Trans. ASHVE, **48,** 369-384, 1942.

Description of temperature and heat flow measurements made on an experimental basement, which had both insulated and uninsulated wall parts. Ground temperatures surrounding the basement are also reported. Measurements differ signicantly from calculations made according to accepted methods in use at the time.

[67] F. C. Houghton, C. G. F. Zobel, "Coefficients of Heat Transfer as Measured Under Natural Weather Conditions," Trans. ASHVE, **34,** 397-414, 1928.

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[68] F. C. Houghton, C. G. F. Zobel, "Heat Transfer Through Roofs Under Summer Conditions," Trans. ASHVE, **34,** 415-438, 1928.

Contains results of heat transmission measurements for three types of commercial building roof constructions, as determined by the Nicholls Heat Flow Meter. Transient heat flow, solar radiation, and reradiation to the sky are discussed.

[69] A. T. Howarth, A. S. Morton, A. F. C. Sheratt, "Air Movement in an Enclosure with a Single Heated Wall," Building Services Engineer, **40** (10), 149-156, 1972.

Description of experimental technique and data for air movement in a room with special boundary conditions: one wall heated by various amounts above the room ambient. Comparisons with theory and earlier experiments are made.

[70] A. S. Hundemann, Ed., "Energy Conservation: Industry (A Bibliography with Abstracts)," U.S. Department of Commerce, National Technical Information Service, Report NTIS/PS-78/0570, June, 1978.

[71] "International Building Services Abstracts" (formerly "Thermal Abstracts"), Building Services Research and Information Association, Bracknell, U.K.

An abstract journal, published quarterly, which scans many European technical publications as sources. All aspects of building technology are abstracted.

[72] International Institute of Refrigeration, Heat transfer-Current applications of air conditioning, Pergamon, Oxford, 1971.

[73] N. Ito, K. Kimura, J. Oka, "A Field Experiment Study on the Convective Heat Transfer Coefficient on Exterior Surface of a Building," Trans. ASHRAE, **78** (1), 184-191, 1972.

Description of a field test methodology using heat flow meters to determine the convective heat transfer coefficient of the exterior surface of a building.

[74] S. Jaeger, F. Arumi, "A Comparison of Thermal Requirements of Buildings," Energy and Buildings, **1**, 159-165, 1977.

Presents computed results of the dynamic heat transfer for walls of various thermal masses, and compares their effectiveness, in terms of cumulative heat loss for standard temperature histories.

[75] H. A. Johnson, "Periodic Heat Transfer At the Inner Surface of a Homogeneous Wall", Trans. ASHVE, **54**, 143-164, 1948.

Reports calculated values of the temperature decay and time lag of cyclic temperatures applied to homogeneous wall constructions with varying assumptions for air film coefficients.

[76] V. Korsgaard, "Thermal and Electrical Models for Solving Problems of Non-Stationary Heat Transfer Through Walls," pp. 87-92 in Heat transfer-Current applications of air conditioning, International Institute of Refrigeration, Pergamon, Oxford, 1971.

Description of the transient behavior of walls represented as a lumped parameter network. Thermal and electrical analog experimental techniques are described. Comparison between these two experimental approaches and calculated results for a typical wall construction are presented.

[77] A. P. Kratz, S. Konzo, M. K. Fahnestock, E. L. Broderick, "Study of Summer Cooling in the Research Residence Using a Small Capacity Mechanical Cooling Unit," Trans. ASHVE, **44**, 439-470, 1938.

Description of cooling load measurements, and temperature variations at fixed cooling capacity in a typical residence. Heat flow through walls was measured, and structural heat storage was estimated.

[78] A. P. Kratz, J. F. Quereau, "Analysis of the Overall Efficiency of a Residence Heated by Warm Air," Trans. ASHVE, **35**, 361-376, 1929.

Contains measured data for the overall system efficiency of a number of residences which are heated with forced warm air systems and central furnaces.

[79] T. Kusuda, "Fundamentals of Building Heat Transfer," J. Res. NBS, **82** (2), 97-106, 1977.

Survey discussion of the generalized conceptual problem of modeling the thermal performance of whole buildings by detailed consideration of its design and the properties of its constituent components.

[80] T. Kusuda, "Thermal-Response Factors for Multi-Layer Structures of Various Heat Conduction Systems," Trans. ASHRAE, **75** (1), 246-71, 1969.

Generalized formulas for calculating thermal response factors for multi-layer structures in plane, cylindrical and spherical geometries are described and tabulated. For selected cases heat fluxes calculated from the derived response factors are compared with analytical solutions, with favorable agreement.

[81] T. Kusuda, Ed., "Use of Computers for Environmental Engineering Related to Buildings," U. S. National Bureau of Standards, Building Science Series 39, October, 1971.

Proceedings of the first International Symposium on the title subject. Many papers dealing with all aspects of computer applications in the fields of building design, analysis, operation, and control.

[82] G. L. Larson, D. W. Nelson, C. Braatz, "Air Infiltration Through Various Types of Wood Frame Construction," ASHVE Jour., **2**, 509-526, 1930.

Description of laboratory infiltration test apparatus and measured data for a number of wall constructions.

[83] J. LeBrun, D. Marret, "Heat Losses of Buildings with Different Heating Systems," pp. 471-478, in Energy Use Management: Proceedings of the International Conference, Vol. I, R. A. Fazzolare, C. B. Smith, Eds., Pergamon, Oxford, 1977.

Description of measurements of heat losses from the "exposed" wall of an experimental room in a specially constructed laboratory apparatus. The effect of the use of different types of heating sources in the room is examined, as well as a more generalized definition of comfort than simply interior air temperature.

[84] G. E. Liepens, M. A. Smith, A. B. Rose, K. Haygood, "Building Energy Use Data Book: Edition 1," Oak Ridge National Laboratory, Report ORNL-5363, April, 1978.

Comprehensive compilation of statistics, economic factors, equipment and appliance efficiencies, and distribution of building types in the U.S. and the relationship of these parameters to energy use.

[85] M. Lokmanhekim, Ed., "Procedure for Determining Heating and Cooling Loads for Computerized Energy Calculations: Algorithms for Building Heat Transfer Subroutines," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1971.

Standardized methodology recommended by ASHRAE for dynamic heat transfer calculations for building components. Comprehensively based on the state-of-the-art at the time of publication. Forms a basis for many existing computer programs that model the energy consumption performance of buildings.

[86] G. Lorentzen, E. Brendeng, "The Design and Performance of a Large Scale Guarded Hot Box," International Institute of Refrigeration, Bulletin Annexe 1962-1, 29-42, 1962.

Description of a guarded hot box designed and built at NTH, Trondheim, Norway. Test results for several walls typical of cold-room construction are presented.

[87] G. Lorentzen, E. Brendeng, P. Frivik, "On the Development of Methods for Measuring Heat Leakage of Insulated Walls with Internal Convection," pp. 495-506 in Proceedings of the Seventh Conference on Thermal Conductivity, D. R. Flynn and B. A. Peavy, Eds., U. S. National Bureau of Standards Special Publication 302, 1968.

Description of test methods and results obtained in a series of research projects to study thermal performance of insulated walls with significant internal convection. A hot box apparatus for measuring thermal performance is described. Some analytical approaches (computerized) are discussed and their predictions are compared with experimental results, with good agreement.

[88] C. E. Lund, R. M. Lander, "Heat Transfer Through Mineral Wool Insulation In Combination with Reflective Surfaces," ASHRAE Jour., **3** (3), 47-104, 1961.

Description of guarded hot box test apparatus and test data acquired for summer and winter conditions for selected wall, ceiling and floor constructions. In these studies, mineral fiber insulation between reflective surfaces was extensively studied.

[89] O. Lyng, "Heat Transfer Through Windows - A Literature Study With Bibliography," Byggforskningen (Stockholm), Report 15:1965, 1965.

A comprehensive critical review of the field of heat transfer characteristics of windows. An extensive bibliography is included.

[90] C. O. Mackey, L. T. Wright, Jr., "Summer Comfort Factors as Influenced by the Thermal Properties of Building Materials", Trans. ASHVE, **49,** 148-174, 1943.

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[91] C. O. Mackey, L. T. Wright, Jr., "Periodic Heat Flow - Homogeneous Walls Or Roofs," Trans. ASHVE, **50**, 293-312, 1944.

Application of theory developed in an earlier paper to the approximate determination of design cooling loads for homogeneous wall and roof constructions, based on a determination of the maximum fluxes at the inside surfaces of the walls.

[92] C. O. Mackey, L. T. Wright, Jr., "Periodic Heat Flow - Composite Walls or Roofs," Trans. ASHVE, **52**, 283-304, 1946.

Extension of work done in a previous paper to the estimation of the maximum trasient heat fluxes for walls and roofs of composite construction.

[93] J. F. Malloy, <u>Thermal Insulation</u>, Krieger, New York, 1969.

Comprehensive text on the manufacture, characteristics, performance, and applications of thermal insulation including industrial, commercial, building, and cryogenic applications.

[94] H. R. Martin, P. R. Achenbach, R. S. Dill, "Effect of Edge Insulation upon Temperature and Condensation on Concrete-Slab Floors," NBS Building Materials and Structures Report BMS 138, 1953.

Experimental study of heat losses through concrete slab-on-grade floors. Results show that heat losses are significantly greater near the edges, and that the effect can be significantly reduced by the use of edge insulation. Reccmmendations for use of edge insulation are made for various conditions.

[95] N. O. Milbank, J. Harrington-Lynn, "Thermal Response and The Admittance Procedure," Building Research Establishment Current Paper CP61/74, June, 1974.

Definition, origins, and application of the thermal admittance procedure as an analytical methodology to calculate the dynamic performance of building components. The three factors necessary for application of this procedure are calculated for a number of standard building constructions and presented in tables.

[96] R. G. Miller, E. L. Perrine, P. W. Lineham, "A Calibrated/Guarded Hot-Box Test Facility," pp. 329-341 in Thermal Transmission Measurements of Insulation, ASTM STP 660, R. P. Tye, Ed., American Society for Testing and Materials, Philadelphia, 1978.

Description of the design and operating capabilities and characteristics of a hot box built at the Jim Walter Research Corp., St. Petersburg, Florida. The apparatus is capable of operating in both the guarded and calibrated modes.

[97] G. P. Mitalas, "Calculation Of Transient Heat Flow Through Walls And Roofs," Trans. ASHRAE, **74,** 182-188, 1968.

Description of the response factor method of modeling the transient heat flow through walls and roofs. The development of a representation which facilitates computerization for the method is summarized.

[98] G. P. Mitalas, D. G. Stephenson, "Room Thermal Response Factors," Trans. ASHRAE, **73,** III.2.1-III.2.10, 1967.

Summary of the methodology for determining room thermal response factors, which characterize the transient thermal response of whole enclosures, based on their geometry and the thermal properties of the enclosing surfaces.

[99] G. P. Mitalas, "Comments on the Z-Transfer Function Method for Calculating Heat Transfer in Buildings," Trans. ASHRAE, **84** (1), 667-674, 1978.

Recapitulation and summary of the results contained in a series of papers describing Canadian National Research Council research on transient heat transfer calculations through building envelopes and resultant cooling loads. Expands on the Z-transfer function techniques for dynamic heat transfer and building space load and internal temperature calculations. Contains references to earlier work.

[100] E. D. Mouen, "Equivalent Thermophysical Properties of Hollow Elements Found via Thermal Response Factor Method," Trans. ASHRAE, **81** (1), 365-373, 1975.

Analytical methodology is presented for extending response factor calculation to the dynamic performance of non homogenous envelope constructions. Method is based on determining equivalent one-dimensional thermal properties of a fictitious homogenous construction with the same overall dynamic performance.

[101] J. R. Mumaw, "Calibrated Hot Box: An Effective Measure for Measuring Thermal Conductance in Large Wall Sections," pp. 193-211 in Heat Transmission Measurements in Thermal Insulations, ASTM STP 544, American Society for Testing and Materials, Philadelphia, 1974.

Description of the design and operating features of a large (2.7m by 4.2m) calibrated hot box wall testing facility at Owens-Corning Fiberglass Corp. research laboratories. Comparison of measured data on specimens with known properties is discussed.

[102] R. W. R. Muncey, "The Thermal Response of a Building to Sudden Changes of Temperature or Heat Flow," Aust. Jour. Applied Science, **14**, 123-128, 1963.

The thermal response of a building to a sudden (step-function) change in outside temperature is calculated analytically. It is shown that heavy buildings may take a long time to respond completely to such changes.

[103] R. W. R. Muncey, "The Conduction of Fluctuating Heat Flow," Applied Scientific Research, **18**, 9-14, 1967.

Mathematical model for the transient response of walls, based on conduction equations. Wall performance is characterized as a complex transfer matrix relating temperatures and fluxes at inside and outside surfaces.

[104] R. W. R. Muncey, J. W. Spencer, "Heat Flow into the Ground Under a House," pp. 649-660 in Energy Conservation in Heating, Cooling and Ventilating Buildings, Vol. 2, C. J. Hoogendoorn and N. H. Afgan, Eds., Hemisphere, Washington, 1978.

Calculations of the transient flow from slabs on grade into the ground for various slab configurations, with results presented in such a way as to facilitate estimating results for arbitrary configurations.

[105] R. W. R. Muncey, J. W. Spencer, C. L. Gupta, "Method for Thermal Calculations Using Total Building Response Factors," pp. 114-115 in Use of Computers for Environmental Engineering Related to Buildings, T. Kusuda, Ed., U. S. National Bureau of Standards Building Science Series 39, October, 1971.

Presentation of a methodology for determining overall thermal response factors for whole buildings, from which heating and cooling loads can be calculated when external environment conditions are known for the building. An alternative approach to determining response factors and loads for separate building envelope components on an individual basis.

[106] P. Nicholls, "Measuring Heat Transmission [illegible] Building Structures and a Heat Transmission Meter," Trans. ASHVE, **3[illegible]** [illegible]5-104, 1924.

[107] H. J. Nicolaas, K. Th. Knorr, P. Euser, "A Digital Computer Program for the Calculation of Yearly Room Energy Demands and Temperature Exceeding Rates, Using Hourly Weather Data," pp. 37[illegible]-389, in Energy Conservation in Heating, Cooling and Ventilating Buildings, Vol. 1, C. J. Hoogendoorn and N. H. Afgan, Eds., Hemisphere, Washington, 1978.

Description of the characteristics of a computer program for modeling the dynamic thermal performance of buildings.

[108] H. B. Nottage, G. V. Parmelee, "Circuit Analysis Applied To Load Estimating," Trans. ASHVE, **60**, 59-102, 1954.

Presents a basic methodology of analyzing transient thermal behavior of building envelopes, and the effect on cooling loads, by use of electrical circuit analogs. Results from a simple example are given.

[109] H. B. Nottage, G. V. Parmelee, "Circuit Analysis Applied To Load Estimating: Part II - Influence of Transmitted Solar Radiation," Trans. ASHVE, **61**, 125-150, 1955.

Describes experimental results of modeling the heat transfer and heat capacity effects on loads by electrical circuit analogs. This paper describes, for an illustrative example structure, the load component due to solar radiation transmitted through windows.

[110] V. Paschkis, "Periodic Heat Flow In Building Walls Determined By Electrical Analogue Method," Trans. ASHVE, **48**, 75-90, 1942.

Application of an electrical circuit analog to estimation of transient heat transfer through walls. Results were found to agree well with direct thermal measurements on actual walls of the same construction as the designs modeled in this effort.

[111] B. A. Peavy, F. J. Powell, D. M. Burch, "Dynamic thermal Performance of an Exerimental Masonry Building," U. S. National Bureau of Standards Building Science Series 45, 1973.

Classic paper describing an experiment which measured heat transfer through walls and interior temperatures in a geometrically simple massive masonry structure under carefully controlled dynamic temperature conditions. The results were also used to validate the response factor space load prediction methodology for a limited range of conditions.

[112] M. F. Peck, V. B. Phelan, R. S. Dill, P. H. P[illegible]en, "Structural, Heat Transfer, and Water-Permeability Properties of 'Speedbrik' Wall Construction Sponsored by the General Shale Products Corporation," NBS Building Materials and Structures Report BMS [illegible] 1942.

Contains experimental test data on the steady-state heat transfer coefficients of a particular masonry wall construction. One of a continuing series of NBS thermal and structural properties tests sponsored by industry.

[113] C. O. Pedersen, E. D. Mouen, "Application of System Identification Techniques to the Determination of Thermal Response Factors from Experimental Data," Trans. ASHRAE, **79** (2), 127-36, 1973.

Presents a method of analysis and an experimental procedure for measuring heat flux through common building wall sections under dynamic conditions, and for determining their response factors. Details of a test facility to make measurements are also given.

[114] C. O. Pedersen, G. H. Younker, "An Experimental Study of Equivalent Thermal Properties of A Wall Section With Air Cavities," Trans. ASHRAE, **84** (1), 703-710, 1978.

Description of experiments and resultant data used to determine equivalent dynamic thermal properties for selected wall sections with air cavities. Experimental results for measured steady state equivalent thermal conductance of the same constructions are given, and compared for consistency with results of the dynamic experiments.

[115] L. A. Pipes, "Matrix Analysis of Heat Transfer Problems," J. Franklin Inst., **263,** 195-206, 1957.

Presents a matrix representation for the analysis of heat conduction in solids. Use is made of the analogy that exists between the thermal problem and the flow of electricity in a transmission line. The matrix representation greatly facilitates the calculation of transient and periodic heat flow in composite solids.

[116] J. Pleiss, E. Hahne, "Heat Storage and Transient Temperature Distribution in Three Dimensional Composite Solid Systems," pp. 661-669 in <u>Energy Conservation in Heating, Cooling and Ventilating Buildings</u>, Vol. 2, C. J. Hoogendoorn and N. H. Afgan, Eds., Hemisphere, Washington, 1978.

Presents an analytical method for estimating the effects of one-dimensional heat flow near edges, corners, etc., in solid objects.

[117] F. J. Powell, H. E. Robinson, "The Effect of Moisture on the Heat Transfer Performance of Insulated Flat-Roof Constructions," U. S. National Bureau of Standards Building Science Series 37, October, 1971.

Describes the results of a nine-year experimental study of the effect of varying moisture content on the thermal performance characteristics of 73 insulated roof deck specimens. Two new measurement methods developed during the effort are described. On the basis of the experimental results, design criteria and recommended ranges of significant design parameters with regard to allowable moisture levels, were developed.

[118] A. W. Pratt, "Thermal Transmittance of Walls Obtained by Measurement on Test Panels in Natural Exposure," Building Science, **3**, 147-169, 1969.

Comprehensive summary of measurements of the heat transmission of 72 wall and window constructions exposed to natural outdoor conditions.

[119] A. W. Pratt, R. E. Lacy, "Measurement of the Thermal Diffusivities of Some Single-Layer Walls in Buildings," Int. J. Heat Mass Transfer, **9**, 345-353, 1966.

Develops analytical solution for periodic heat flow through a large slab of isotropic material. The results are used to calculate thermal diffusivity for plane brick and concrete constructions using measured values for the time delay of a steady periodic temperature variation.

[120] E. M. Pugh, "Some Applications of Physics to Air-Conditioning Physics," Physics, **7**, 85-90, 1936.

Presents an analytical solution for the transient heat flow through homogeneous walls, given outside surface temperatures, due to the influence of both outside air temperature and solar radiation.

[121] E. M. Pugh, "Transient Heat Load in Calculating Air Conditioning Loads," Refrigerating Engineering, **42**, 29-33, 1941.

Presents a simplified version of a dynamic method for determining heat transfer through homogeneous walls, based on calculation methods referred to in the literature.

[122] E. R. Queer, "Importance of Radiation in Heat Transfer Through Air Spaces," Trans. ASHVE, **38,** 77-96, 1932.

Experimental work, using a hot plate apparatus, to quantify the relative contribution of radiation to the overall heat transfer in air spaces, for horizontal and vertical heat fluxes. Conclusions are made regarding effect of surface emissivity and optimum air cavity spacing. An assertion is made that under the conditions studied, radiation is the dominant heat transfer mode in air-filled cavities. There is considerable written discussion concerning this last assertion immediately following the paper.

[123] E. R. Queer, F. G. Hechler, "A Laboratory Method for Cyclic Heat Measurements on Walls and Roofs," Trans. ASHVE, **47,** 225-238, 1941.

Description of a guarded hot box apparatus and its use for dynamic testing of walls. Results of dynamic tests on a wood frame wall of typical construction are given.

[124] K. R. Rao, P. Chandra, "A Study of Thermal Performance of Concrete Hollow Blocks by an Electrical Analogue Method," Building Science, **5,** 31-40, 1970.

Electrical analogue representations of selected masonry wall constructions were developed and measurements conducted.

[125] B. C. Raychaudhuri, "Transient Thermal Response of Enclosures: The Integrated Thermal Time-Constant," Int. J. Heat Mass Transfer, **8,** 1439-1449, 1965.

General analytical method for representing the dynamic thermal characteristics of an enclosure with surfaces of arbitrary geometry and properties in terms of an integrated thermal time constant.

[126] B. C. Raychaudhuri, "Simultaneous Determination of Overall Thermal Diffusivity and Conductivity of Composite Building Elements in situ," Building Science, **5,** 1-10, 1970.

An analytical model of dynamic heat transfer, based on Fourier analysis of temperatures and heat fluxes is developed. Experimental data from three special experimental air conditioned buildings include inside and outside surface temperatures and inside surface heat flux. Resultant properties calculated for the experimental constructions are presented.

[127] H. E. Robinson, L. A. Cosgrove, F. J. Powell, "Thermal Resistance of Airspaces and Fibrous Insulations Bounded by Reflective Surfaces," National Bureau of Standards, Building Materials and Structures Report 151, 1957.

Experimental results for the steady-state thermal resistance of 28 test panels are presented. The measurement apparatus and test procedures are described in detail, and includes orientation effects. results are compared to calculated resistances using a previously published methodology described at NBS, with agreement within ten percent in most cases. Reasons for differences in measured and calculated values are discussed.

[128] H. E. Robinson, F. J. Powlitch, R. S. Dill, "The Thermal Insulating Value of Airspaces," U. S. Housing and Home Finance Agency, Division of Housing Research, Housing Research Paper 32, 1957.

Detailed description of experimental test procedures and results for measured air-space thermal resistances. Features of a rotatable guarded hot box are given. Experimental conditions include different heat flux-air cavity orientations, surface emissivities, and temperature differences.

[129] H. D. Ross, D. T. Grimsrud, "Air Infiltration in Buildings: Literature Survey and Proposed Research Agenda," University of California, Lawrence Berkeley Laboratory, Report LBL-7822, February, 1978.

Description of the state-of-the-art in technical understanding and research in building air infiltration. Contains a recently compiled bibliography. Identifies gaps in the state-of-the-art, and recommends needed research.

[130] F. B. Rowley, "A Theory Covering the Transfer of Vapor Through Materials," Trans. ASHVE, **45**, 545-560, 1939.

Explores the limitations of an analogy between the flow of heat and water vapor as a basis for a model of moisture transfer through building materials.

[131] F. B. Rowley, A. G. Algren, "Thermal Conductivity of Building Materials," University of Minnesota Engineering Experiment Station, Bulletin No. 12, 1937.

Comprehensive summary of experimental measurements on heat transmission through wall constructions conducted at the U. of Minn. Engineering Experiment station and described in part in other citations in this bibliography. Presents data, discusses factors affecting wall heat transmission and tabulates calculated values. This useful report is still in print.

[132] F. B. Rowley, A. B. Algren, "Thermal Resistance of Air Spaces," Trans. ASHVE, **35**, 165-181, 1929.

Experimental study of the thermal resistance of interior air spaces in cavity walls for various cavity widths and temperature differences. Measurements were made in both a guarded hot plate and guarded hot box with good agreement. Interior surface film coefficients of thermal resistance were found to depend only weakly on the type of wall material used.

[133] F. B. Rowley, A. B. Algren, "Thermal Properties of Building Materials," Trans. ASHVE, **38**, 491-510, 1932.

Summary presentation of results of hot box measurements (steady-state heat transfer) for 40 test walls, under various temperature conditions. The effect of mean temperature on heat transfer properties for a given wall is presented graphically, based on the data.

[134] F. B. Rowley, A. B. Algren, J. L. Blackshaw, "Over-All Heat Transmission Coefficients Obtained by Tests and by Calculation," Trans. ASHVE, **35**, 443-456, 1929.

Comparison of heat transfer data for test walls measured in the hot box method with values calculated using measured constituent properties and wall geometry. The agreement over the specimens studied was quite good, showing typical differences of about 2 percent and maximum differences of no more than about 5 percent.

[135] F. B. Rowley, A. B. Algren, J. L. Blackshaw, "Surface Conductances as Affected by Air Velocity, Temperature and Character of Surface," ASHVE Jour., **2**, 501-508, 1930.

Apparatus and test procedure description for measuring thin air film thermal resistances on wall surfaces. Experimental results are given for several wall types (roughnesses), surface temperatures, and surface wind speeds (parallel to surface only).

[136] F. B. Rowley, A. B. Algren, C. Carlson, "Thermal Properties of Concrete Construction," Trans. ASHVE, **42**, 33-57, 1936.

Hot box measurements of the steady-state thermal conductances of a number of masonry wall constructions are presented. Results include effects of composition, addition of insulation to surfaces or internal cavities, and cement paint, on thermal conductance.

[137] F. B. Rowley, W. A. Eckley, "Surface Coefficients as Affected by Direction of Wind," ASHVE Jour. **3,** 870-874, 1931.

Extension of earlier work on the measurement of the thermal resistance of exterior air films of building walls. In this study, the direction of the wind velocity incident on the wall surface could be varied continuously from parallel (as in the earlier study) to perpendicular.

[138] F. B. Rowley, C. E. Lund, "Heat Transmission Through Insulation As Affected by Orientation of Wall," Trans. ASHVE, **49,** 331-344, 1943.

Description of a rotatable guarded hot box and test results for several wall and ceiling constructions. Some specimens have results reported for both horizontal and vertical orientations.

[139] F. B. Rowley, F. M. Morris, A. B. Algren, "Heat Transmission Research," Trans. ASHVE, **34,** 439-474, 1928.

Comparison of steady-state heat transmission properties of walls measured by the hot box method, and calculated based on construction design and hot-plate-measured properties of constituent materials. A discussion of reasons for observed differences is given.

[140] H. J. Sabine, M. B. Lacher, D. R. Flynn, T. L. Quindry, "Acoustical and Thermal Performance of Exterior Residential Walls, Doors and Windows," U. S. National Bureau of Standards Building Science Series 77, November, 1975.

Unique experimental determination of the heat and sound transmission properties of selected residential wall sections, with and without windows and doors. Correlations between the two properties are explored.

[141] J. R. Sasaki, "Thermal Performance of Exterior Steel-Stud Frame Walls," Trans. ASHRAE, **78** (1), 192-198, 1972.

Comparison of measured and calculated heat transfer properties of five frame walls constructed with steel studs of various designs. The calculation method is outlined in the ASHRAE Handbook of Fundamentals. Results show reasonable agreement for overall wall thermal resistance prediction, but not for interior surface temperatures.

[142] E. Shaviv, G. Shaviv, "Modelling the Thermal Performance of Buildings," Building and Environment, **13**, 95-108, 1978.

Description of a mathematical procedure and its computerized implementation for prediction of the thermal performance of whole buildings.

[143] A. Shaw, "An Engineering System for Determining Thermal and Moisture Transfer Properties of Structural Materials," pp. 83-92 in Energy Conservation in Heating, Cooling and Ventilating Buildings, Vol. 1, C. J. Hoogendoorn and N. H. Afgan, Eds., Hemisphere, Washington, 1978.

Description of a proposed design for a laboratory chamber for the simultaneous measurement of heat and moisture transfer through building materials and constructions.

[144] "Solar Energy: A Bibliography," U. S. Energy Research and Development Administration (two volumes), Reports TID-3351-R1P1, TID-3351-R1P2, March, 1976.

A comprehensive bibliography of solar energy technical papers, supplemented by the periodical "Solar Energy Update," published monthly by the Technical Information Center, Oak Ridge National Laboratory.

[145] K. R. Solvason, "Large-Scale Wall Heat Flow Measuring Apparatus," Trans. ASHRAE, **65**, 541-550, 1959.

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[158] D. J. Vild, M. L. Erickson, G. V. Parmel A. N. Cerny, "Periodic Heat Flow Through Flat Roofs," Trans. ASHRAE, 397-412, 1955.

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