Heat Transmission Coefficients for Walls, Roofs, Ceilings, and Floors

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I. INTRODUCTION

This manual is the result of ASHRAE research project 453-RP, "Manual of Heat Transmission Coefficients for Building Components," conducted by the University of Massachusetts for ASHRAE Technical Committee TC 4.4, Thermal Insulation and Vapor Retarders. The manual provides a single source of measured and verified by calculation, steady-state (no transient behavior is included) thermal transmission coefficients (U-value, U-factor, or overall coefficient of heat transfer) for opaque building components (walls, roofs, ceilings, floors) typical of past, present, and anticipated future construction practices for all climates. Windows, doors, curtain walls, ventilated and unventilated attics, basements, crawlspaces, and slabs-on-grade are excluded. The heat transmission coefficient data sheets of this manual do not cover all the potential building components currently existing. As a result, the manual is in looseleaf form to provide a dynamic publication that can be updated easily.

The layout of the heat transmission coefficient data sheets is similar to Tables 4A through 4K in Chapter 23 of the ASHRAE *Handbook*, 1981 *Fundamentals*. The thermal transmission coefficient information provided here is based on experimental data from published and unpublished test results from organizations in the United States and Canada who have a laboratory calibrated hot box (ASTM *Standard* C 976) or guarded hot box (ASTM *Standard* C 236). Some of the hot box experimental data examined for possible inclusion in this manual's first edition was excluded because the information was incomplete—no calculation could be made to verify the experimental results. An acceptance criterion initially was developed to evaluate the experimental data, since rarely more than one set of experimental data for a particular building component is available. Initially, TC 4.4 decided that the experimental results should agree with the calculated results to within 10%; that is:

$$\left| \frac{\text{Calculated results} - \text{Experimental results}}{\text{Experimental results}} \right| \leq 10$$

The experimental data were compared first with either the results from one-dimensional or, if necessary, the ASHRAE Zone Method of calculation (see Section III). Since the building component can be made of various materials and may also include confined air spaces, a source of thermal conductivity and thermal resistance is necessary for calculation. The thermal properties (solid material thermal conductivity, air space thermal resistance, air surface heat transfer coefficients) used in the computer analysis are taken from the appropriate values in the tables of Chapter 22 of the 1989 ASHRAE *Handbook—Fundamentals*, unless the properties were measured experimentally in conjunction with the hot box tests. In that case, the measured thermal properties were used.

In most cases, the calculated results compared well with the experimental data (*i.e.*, within the 10% acceptance criterion). The experimental thermal transmission coefficients then were modified to standard ASHRAE air surface heat transfer coefficients to arrive at a recommended ASHRAE thermal transmission coefficient for a particular building component. If the acceptance criterion was not met, a two-dimensional finite difference calculation (see Section III) was used to determine the calculated thermal transmission coefficient. If the acceptance criterion was still not met, an attempt was made to contact the individual(s) who supplied the hot box data or to directly contact the laboratories that performed the tests to obtain more specific information about the building component assembly and the experimental conditions. Finally, if the calculation using the additional information still gave results outside the 10% range of acceptance, the experimental data were considered unacceptable and the results were rejected.

However, in some situations the calculations might not accurately model the building component due to problems such as thermal bridges (see Section V), unusual geometry air spaces, inappropriate building material thermal conductivity information, and experimental error. Therefore, TC 4.4 decided to accept all reasonable experimental data, but to use the higher of the experimental or calculated thermal transmission coefficient to calculate the recommended ASHRAE thermal transmission coefficient.

Other Sections of This Manual

Section II, How to Use This Manual, should be studied to use the manual most effectively. Section III, Methods of Analysis, describes the methods used to calculate the thermal transmission coefficients, which were a basis of comparison with the experimental thermal transmission coefficients considered for inclusion. Section IV, Thermal Bridges, discusses the effect of thermal bridges on transmission coefficient data analyzed and presented in Section VI. Section V, References, lists pertinent references.

Section VI, Heat Transmission Coefficients, is the core of this manual, presenting the heat transmission coefficient data sheets and including detailed information on the experimental data, the calculation result, and the ASHRAE recommended thermal transmission coefficients. By no means is this manual a complete listing of all possible past, present, and future opaque building components (walls, roofs, ceiling, floors). Also, to properly use this information in building energy analysis studies, thermal transmission coefficients are needed at three mean temperatures. Only some of the building components have thermal transmission coefficients given at three temperatures.

Additional Data Needed

As emphasized previously, the data sheets presented here do not represent all possible or existing opaque building assemblies. Several construction assemblies are not included for several reasons.

- The data may be incomplete so that a calculation cannot by run to compare with the experimental results. This was true for much of the data used in this edition, requiring many telephone calls to the researchers who did the tests. As a result, much of the data from references earlier than 1970 was not used because the individuals no longer worked for the same organization.

- Many new building assemblies have never been tested in the hot box.

- Some specifically identified thermal transmission data was unavailable until after the submission deadline for data to be included in the first edition of this manual.

- Hot boxes in many industrial building research laboratories are no longer in service; thus, the potentially useful thermal transmission data are no longer available.

Some of the specific types of building assemblies identified as being needed are:

- Fiberglass and rockwool insulation products installed in a variety of building assemblies
- Reflective insulation products installed in wall, floor, and roof cavities
- Stress skin panels used in post and beam buildings
- Insulated panels and finishes that are applied to the exterior of commercial buildings
- Log cabin constructions

II. HOW TO USE THIS MANUAL

List of Building Components

The end of this section includes two lists of the building components. One list is arranged in ascending numerical order according to the assigned building component code within each of the five building construction groups as follows:

1. Residential Walls (RW)

2. Residential Roofs (RR)

3. Commercial Walls (CW)

4. Commercial Roofs (CR)

5. Commercial Floors (CF)

The list in Table I contains the building component codes (RW1, RW2, etc.), a description of the building construction, and the ASHRAE design thermal transmittance. The next subsection, "Heat Transmission Coefficient Data Sheets," gives the definition of the ASHRAE design U-factor.

The second list (Table II) serves as an index to the building component list in Table 1. It is organized by increasing thermal transmittance for each construction group and includes the following entries:

1. Building component code

2. ASHRAE design U-factor

3. Experimental U-factor

4. Calculated (or Numerical) U-factor

Together these two lists identify all building components that meet or exceed specific thermal performance criteria. For example, several residential walls meeting a required thermal transmittance of 0.10 Btu/h·ft^2·°F (R = 10), may be identified by looking in Table 2 under the heading "Residential Walls" for an U_{ASHRAE} entry near 0.10. All of the building component codes above that line meet the thermal performance requirement, and then a description of those walls is found in Table 1.

Heat Transmission Coefficient Data Sheets (Section VI)

The data sheets detailing each building components, are divided into three major sections:

1. Description of Building Component

2. Thermal Performance Results

3. Detailed Experimental Data

Description of building component. This portion of the data sheet describes the building materials used in the assembly of the building component, including dimensions and thermal conductivity. The solid material thermal conductivity values listed are taken from the appropriate tables of Chapter 22 of the 1989 ASHRAE *Handbook—Fundamentals*, unless the thermal conductivity was measured experimentally in conjunction with the hot box tests. In that case, the measured thermal conductivity is listed and designated by an asterisk (*). If surface emittance values were also measured, they are included in the material's description. In addition, a sketch of the building component's cross section (through which heat flows) is also provided. The information in the description of building assembly section is sufficient to calculate the building component's thermal transmittance (U-factor) when combined with appropriate surface heat transfer coefficients.

Thermal performance results. This portion gives the results of the building component's thermal transmittance (U-factor). Three results are listed: experimental, analytical, and ASHRAE-recommended. The experimental U-factor (U-value) is determined from the hot box test data. The analytical U-factor is calculated using one of the methods described in Section III, Methods of Analysis. A comparison of the analytical result is expressed as percent deviation from the experimental result. Finally, the ASHRAE-recommended thermal transmittance is calculated by subtracting the actual surface heat transfer coefficients from the larger of the experimental and analytical thermal transmittance and adding the ASHRAE standard indoor and outdoor surface coefficients (Table 1, Chapter 22 of the 1993 ASHRAE *Handbook—Fundamentals*). The ASHRAE-recommended thermal transmittance may then be used to compare the performance of similar building components (walls, roofs, etc.).

Detailed experimental data. The back page of each data sheet includes the following information regarding the experimental test.

- Heat flow rate and direction
- Test section (building component) area
- Surface and air temperatures
- Air velocity in test chamber
- Hot and cold side surface description
- Data reference and year of publication
- Location and type of test facility
- Organization that supplied test data

This information can be used directly to calculate the experimental thermal transmittance or surface heat transfer coefficients.

Table I. List of Building Components
1. Residential Walls

Code	Description of Construction	U_{ASHRAE} Btu/h·ft^2·°F
RW1	2×3 inch double wood stud wall: polyisocyanurate with fiberglass batts in cavity 21.2°F (−6.0°C) mean temperature	0.040
RW1A	2×3 inch double wood stud wall: polyisocyanurate with fiberglass batts in cavity 39.6°F (4.2°C) mean temperature	0.027
RW1B	2×3 inch double wood stud wall: polyisocyanurate with fiberglass batts in cavity 56.9°F (13.8°C) mean temperature	0.043
RW1C	2×3 inch double wood stud wall: polyisocyanurate with fiberglass batts in cavity 101.5°F (38.6°C) mean temperature	0.051
RW5	2×3 inch double wood stud wall: polyisocyanurate with fiberglass batts in cavity 21.8°F (−5.7°C) mean temperature	0.028
RW5A	2×3 inch double wood stud wall: polyisocyanurate with fiberglass batts in cavity 36.1°F (2.3°C) mean temperature	0.029
RW5B	2×3 inch double wood stud wall: polyisocyanurate with fiberglass batts in cavity 50.2°F (10.1°C) mean temperature	0.029
RW5C	2×3 inch double wood stud wall: polyisocyanurate with fiberglass batts in cavity 100.6°F (38.1°C) mean temperature	0.027
RW11	2×4 inch wood stud wall with fiberglass batts in cavity 74.8°F (23.8°C) mean temperature	0.090
RW12	2×4 inch wood stud wall: polyisocyanurate with fiberglass batts in cavity 73.8°F (23.2°C) mean temperature	0.060
RW13	2×4 inch wood stud wall: polyisocyanurate with fiberglass batts in cavity 75.0°F (23.9°C) mean temperature	0.055
RW13A	2×4 inch wood stud wall: polyisocyanurate with fiberglass batts in cavity 40.0°F (4.4°C) mean temperature	0.068
RW13B	2×4 inch wood stud wall: polyisocyanurate with fiberglass batts in cavity 74.9°F (23.8°C) mean temperature	0.052
RW16	2×4 inch wood stud wall: polyisocyanurate with fiberglass batts in cavity 39.7°F (4.2°C) mean temperature	0.050
RW17	2×4 inch wood stud wall: foil-faced cardboard with fiberglass batts in cavity 74.6°F (23.7°C) mean temperature	0.085
RW18	2×4 inch wood stud wall: polyisocyanurate with fiberglass batts in cavity 74.9°F (23.8°C) mean temperature	0.080
RW21	2×4 inch wood stud wall: polyisocyanurate with polyurethane in cavity 40.9°F (4.9°C) mean temperature	0.036
RW22	2×4 inch wood stud wall: polyisocyanurate with polyurethane in cavity 41.1°F (5.1°C) mean temperature	0.039
RW23	2×4 inch wood stud wall with polyurethane in cavity 74.8°F (23.8°C) mean temperature	0.056

Table I. List of Building Components
1. Residential Walls

Code	Description of Construction	U_{ASHRAE} Btu/h·ft²·°F
RW24	2×4 inch wood stud wall with fiberglass batts in cavity 36.2°F (2.4°C) mean temperature	0.080
RW24A	2×4 inch wood stud wall with fiberglass batts in cavity 53.6°F (12.0°C) mean temperature	0.083
RW26	2×4 inch wood stud wall 38.4°F (3.6°C) mean temperature	0.326
RW26A	2×4 inch wood stud wall 55.9°F (13.2°C) mean temperature	0.334
RW28	Nominal 4 inch concrete block wall with brick facade and extruded polystyrene insulation 34.8°F (1.6°C) mean temperature	0.078
RW28A	Nominal 4 inch concrete block wall with brick facade and extruded polystyrene insulation 49.2°F (9.6°C) mean temperature	0.080
RW30	Nominal 8 inch concrete block wall with gypsum board and airspace 36.6°F (2.6°C) mean temperature	0.245
RW30A	Nominal 8 inch concrete block wall with gypsum board and airspace 56.5°F (13.6°C) mean temperature	0.250
RW32	7 inch thick log wall with tongue and groove locking system 40.5°F (4.7°C) mean temperature	0.105
RW32A	7 inch thick log wall with tongue and groove locking system 60.9°F (16.0°C) mean temperature	0.106
RW34	Nominal 8 inch concrete block wall with 4 inch brick and perlite insulation in block-brick cavity 35.3°F (1.8°C) mean temperature	0.080
RW34A	Nominal 8 inch concrete block wall with 4 inch brick and perlite insulation in block-brick cavity 50.0°F (10.0°C) mean temperature	0.082
RW39	2×4 inch wood stud wall with fiberglass batt insulation in cavity 98.7°F (37.1°C) mean temperature	0.084
RW39A	2×4 inch wood stud wall with fiberglass batt insulation in cavity 83.5°F (28.6°C) mean temperature	0.084
RW39B	2×4 inch wood stud wall with fiberglass batt insulation in cavity 55.3°F (12.9°C) mean temperature	0.084
RW39C	2×4 inch wood stud wall with fiberglass batt insulation in cavity 33.0°F (0.6°C) mean temperature	0.085
RW43	2×4 inch wood stud wall with fiberglass batt insulation in cavity 103°F (39.5°C) mean temperature	0.100
RW43A	2×4 inch wood stud wall with fiberglass batt insulation in cavity 39.6°F (17.2°C) mean temperature	0.087
RW45	2×4 inch wood stud wall with fiberglass batt insulation in cavity and clay brick veneer 98.6°F (37.0°C) mean temperature	0.083
RW45A	2×4 inch wood stud wall with fiberglass batt insulation in cavity and clay brick veneer 84.7°F (29.3°C) mean temperature	0.084

Table I. List of Building Components
1. Residential Walls

Code	Description of Construction	U_{ASHRAE} Btu/h·ft^2·°F
RW45B	2×4 inch wood stud wall with fiberglass batt insulation in cavity and clay brick veneer 54.9°F (12.7°C) mean temperature	0.074
RW45C	2×4 inch wood stud wall with fiberglass batt insulation in cavity and clay brick veneer 33.5°F (0.8°C) mean temperature	0.060
RW49	2×4 inch wood stud wall with fiberglass insulation in cavity 43.3°F (6.3°C) mean temperature	0.080
RW49A	2×4 inch wood stud wall with fiberglass insulation in cavity 29.8°F (−1.2°C) mean temperature	0.078
RW49B	2×4 inch wood stud wall with fiberglass insulation in cavity 17.3°F (−8.2°C) mean temperature	0.076
RW52	2×4 inch wood stud wall with fiberglass insulation in cavity and vinyl siding 43.2°F (6.2°C) mean temperature	0.077
RW52A	2×4 inch wood stud wall with fiberglass insulation in cavity and vinyl siding 30.0°F (−1.1°C) mean temperature	0.075
RW52B	2×4 inch wood stud wall with fiberglass insulation in cavity and vinyl siding 17.1°F (−8.3°C) mean temperature	0.073
RW55	2×4 inch wood stud wall with fiberglass insulation in cavity and aluminum siding 43.1°F (6.2°C) mean temperature	0.078
RW55A	2×4 inch wood stud wall with fiberglass insulation in cavity and aluminum siding 30.0°F (−1.1°C) mean temperature	0.075
RW55B	2×4 inch wood stud wall with fiberglass insulation in cavity and aluminum siding 17.1°F (−8.3°C) mean temperature	0.074
RW58	2×4 inch wood stud wall with fiberglass insulation in cavity and extruded polystyrene sheathing 43.5°F (6.4°C) mean temperature	0.051
RW58A	2×4 inch wood stud wall with fiberglass insulation in cavity and extruded polystyrene sheathing 30.6°F (−0.8°C) mean temperature	0.050
RW58B	2×4 inch wood stud wall with fiberglass insulation in cavity and extruded polystyrene sheathing 17.8°F (−7.9°C) mean temperature	0.050
RW61	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 43.3°F (6.3°C) mean temperature	0.058
RW61A	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 30.3°F (−1.0°C) mean temperature	0.058
RW61B	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 17.5°F (−8.0°C) mean temperature	0.058
RW64	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 43.8°F (6.5°C) mean temperature	0.040
RW64A	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 30.7°F (−0.7°C) mean temperature	0.040

Table I. List of Building Components
1. Residential Walls

Code	Description of Construction	U_{ASHRAE} Btu/h·ft²·°F
RW64B	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 18.0°F (−7.8°C) mean temperature	0.039
RW67	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 43.5°F (6.4°C) mean temperature	0.044
RW67A	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 30.7°F (−0.7°C) mean temperature	0.043
RW67B	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 18.0°F (−7.8°C) mean temperature	0.043
RW70	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 43.6°F (6.4°C) mean temperature	0.039
RW70A	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 30.7°F (−0.7°C) mean temperature	0.039
RW70B	2×4 inch wood stud wall with polyurethane foam in cavity and extruded polystyrene sheathing 18.0°F (−7.8°C) mean temperature	0.039
RW73	2×4 inch wood stud wall with fiberglass batts in cavity 25.0°F (−3.9°C) mean temperature	0.099
RW74	2×4 inch steel stud wall with fiberglass batts in cavity 25.0°F (−3.9°C) mean temperature	0.122
RW75	2×4 inch steel stud wall with fiberglass batts in cavity 25.0°F (−3.9°C) mean temperature	0.139
RW76	2×4 inch steel stud wall with fiberglass batts in cavity 25.0°F (−3.9°C) mean temperature	0.122
RW77	2×4 inch steel stud wall with fiberglass batts in cavity 25.0°F (−3.9°C) mean temperature	0.150
RW78	2×4 inch steel stud wall with fiberglass batts in cavity 25.0°F (−3.9°C) mean temperature	0.108

Table I. List of Building Components
2. Residential Roofs

Code	Description of Construction	U_{ASHRAE} Btu/h·ft^2·°F
RR1	Aluminum mobile home roof with fiberglass insulation in cavity 74.3°F (23.5°C) mean temperature	0.052
RR1A	Aluminum mobile home roof with fiberglass insulation in cavity 74.0°F (23.3°C) mean temperature	0.045
RR3	Aluminum mobile home roof with fiberglass insulation in cavity 77.2°F (25.1°C) mean temperature	0.077
RR3A	Aluminum mobile home roof with fiberglass insulation in cavity 75.1°F (23.9°C) mean temperature	0.072
RR5	Aluminum mobile home roof with fiberglass insulation in cavity 75.1°F (23.9°C) mean temperature	0.078
RR5A	Aluminum mobile home roof with fiberglass insulation in cavity 75.1°F (23.9°C) mean temperature	0.076
RR7	Aluminum mobile home roof with fiberglass insulation in cavity 73.7°F (23.2°C) mean temperature	0.169
RR7A	Aluminum mobile home roof with fiberglass insulation in cavity 74.2°F (23.4°C) mean temperature	0.149
RR9	2×6 inch ceiling system with fiberglass insulation in cavity and reflective airspace 44.4°F (6.9°C) mean temperature	0.065
RR10	2×6 inch ceiling system: fiberglass insulation in cavity with air gaps on either side facing studs 40.6°F (4.8°C) mean temperature	0.094
RR11	2×6 inch ceiling system: fiberglass insulation in cavity with air gaps on either side facing studs filled with vermiculite 41.3°F (5.2°C) mean temperature	0.065
RR12	2×6 inch ceiling system: fiberglass insulation in cavity with air gaps on either side facing studs 43.0°F (6.1°C) mean temperature	0.227
RR13	2×6 inch ceiling system: fiberglass insulation in cavity with air gaps on either side facing studs filled with vermiculite 41.1°F (5.2°C) mean temperature	0.064
RR14	2×6 inch ceiling system: fiberglass insulation in cavity with air gaps on either side facing studs 46.0°F (7.8°C) mean temperature	0.312
RR15	2×6 inch ceiling system: fiberglass insulation in cavity with air gaps on either side facing studs filled with vermiculite 41.5°F (5.3°C) mean temperature	0.064

Table I. List of Building Components
3. Commercial Walls

Code	Description of Construction	U_{ASHRAE} Btu/h·ft^2·°F
CW1	8 inch (203 mm) normal weight structural concrete wall with board insulation 101.5°F (38.6°C) mean temperature	0.144
CW2	8 inch (203 mm) insulated normal weight concrete sandwich panel walls 103.5°F (39.7°C) mean temperature	0.112
CW2A	8 inch (203 mm) insulated normal weight concrete sandwich panel walls 34.0°F (1.1°C) mean temperature	0.099
CW4	8 inch (203 mm) insulated normal weight concrete sandwich panel walls 103.5°F (39.7°C) mean temperature	0.121
CW4A	8 inch (203 mm) insulated normal weight concrete sandwich panel walls 34.0°F (1.1°C) mean temperature	0.104
CW6	8 inch (203 mm) insulated normal weight concrete sandwich panel walls 105.0°F (40.6°C) mean temperature	0.098
CW6A	8 inch (203 mm) insulated normal weight concrete sandwich panel walls 35.5°F (1.9°C) mean temperature	0.098
CW8	10 inch (254 mm) block-brick cavity wall 97.6°F (36.5°C) mean temperature	0.322
CW8A	10 inch (254 mm) block-brick cavity wall 83.6°F (28.7°C) mean temperature	0.314
CW8B	10 inch (254 mm) block-brick cavity wall 55.6°F (13.1°C) mean temperature	0.300
CW8C	10 inch (254 mm) block-brick cavity wall 35.6°F (2.0°C) mean temperature	0.302
CW12	8 inch (203 mm) normal weight concrete block wall with reflective airspace 35.3°F (1.8°C) mean temperature	0.170
CW12A	8 inch (203 mm) normal weight concrete block wall with reflective airspace 100.2°F (37.9°C) mean temperature	0.180
CW14	10 inch (254 mm) concrete block-brick cavity wall with loose-fill insulation 98.1°F (36.7°C) mean temperature	0.120
CW14A	10 inch (254 mm) concrete block-brick cavity wall with loose-fill insulation 83.7°F (28.6°C) mean temperature	0.117
CW14B	10 inch (254 mm) concrete block-brick cavity wall with loose-fill insulation 55.1°F (12.8°C) mean temperature	0.117
CW14C	10 inch (254 mm) concrete block-brick cavity wall with loose-fill insulation 33.0°F (0.5°C) mean temperature	0.120
CW18	12 inch (305 mm) concrete block-brick cavity wall 100.1°F (37.8°C) mean temperature	0.301
CW18A	12 inch (305 mm) concrete block-brick cavity wall 32.4°F (0.23°C) mean temperature	0.274