INTERNATIONAL

Designation: C680 – 23a

Standard Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs[1]

This standard is issued under the fixed designation C680; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice provides the algorithms and calculation methodologies for predicting the heat loss or gain and surface temperatures of certain thermal insulation systems that can attain one dimensional, steady- or quasi-steady-state heat transfer conditions in field operations.

1.2 This practice is based on the assumption that the thermal insulation systems can be well defined in rectangular, cylindrical or spherical coordinate systems and that the insulation systems are composed of homogeneous, uniformly dimensioned materials that reduce heat flow between two different temperature conditions.

1.3 Qualified personnel familiar with insulation-systems design and analysis should resolve the applicability of the methodologies to real systems. The range and quality of the physical and thermal property data of the materials comprising the thermal insulation system limit the calculation accuracy. Persons using this practice must have a knowledge of the practical application of heat transfer theory relating to thermal insulation materials and systems.

1.4 The computer program that can be generated from the algorithms and computational methodologies defined in this practice is described in Section 7 of this practice. The computer program is intended for flat slab, pipe and hollow sphere insulation systems.

1.5 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation

C177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus

C335 Test Method for Steady-State Heat Transfer Properties of Pipe Insulation

C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus

C585 Practice for Inner and Outer Diameters of Thermal Insulation for Nominal Sizes of Pipe and Tubing

C1055 Guide for Heated System Surface Conditions that Produce Contact Burn Injuries

C1057 Practice for Determination of Skin Contact Temperature from Heated Surfaces Using a Mathematical Model and Thermesthesiometer

2.2 *Other Document:*

NBS Circular 564 Tables of Thermodynamic and Transport Properties of Air, U.S. Dept of Commerce

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this practice, refer to Terminology C168.

3.1.2 *thermal insulation system*—for this practice, a thermal insulation system is a system comprised of a single layer or

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[1] This practice is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

layers of homogeneous, uniformly dimensioned material(s) intended for reduction of heat transfer between two different temperature conditions. Heat transfer in the system is steady-state. Heat flow for a flat system is normal to the flat surface, and heat flow for cylindrical and spherical systems is radial.

3.2 *Symbols:*

3.2.1 The following symbols are used in the development of the equations for this practice. Other symbols will be introduced and defined in the detailed description of the development.

where:

h	=	surface transfer conductance, Btu/(h·ft^2·°F) (W/(m^2·K)) h_i at inside surface; h_o at outside surface
k	=	apparent thermal conductivity, Btu·in./(h·ft^2·°F) (W/(m·K))
k_e	=	effective thermal conductivity over a prescribed temperature range, Btu·in./(h·ft^2·°F) (W/(m·K))
q	=	heat flux, Btu/(h·ft^2) (W/m^2)
q_p	=	time rate of heat flow per unit length of pipe, Btu/(h·ft) (W/m)
R	=	thermal resistance, °F·h·ft^2/Btu (K·m^2/W)
r	=	radius, in. (m); $r_{m+1} - r_m$ = thickness
t	=	local temperature, °F (K)
t_i	=	inner surface temperature of the insulation, °F (K)
t_1	=	inner surface temperature of the system
t_o	=	temperature of ambient fluid and surroundings, °F (K)
x	=	distance, in. (m); $x_{m+1} - x_m$ = thickness
ε	=	effective surface emittance between outside surface and the ambient surroundings, dimensionless
σ	=	Stefan-Boltzmann constant, 0.1714 × 10^{-8} Btu/(h·ft^2·°R^4) (5.6697 × 10^{-8} W/(m^2·K^4))
T_s	=	absolute surface temperature, °R (K)
T_o	=	absolute surroundings (ambient air if assumed the same) temperature, °R (K)
T_m	=	$(T_s + T_o)/2$
L	=	characteristic dimension for horizontal and vertical flat surfaces, and vertical cylinders
D	=	characteristic dimension for horizontal cylinders and spheres
c_p	=	specific heat of ambient fluid, Btu/(lb·°R) (J/(kg·K))
h_c	=	average convection conductance, Btu/(h·ft^2·°F) (W/(m^2·K))
k_f	=	thermal conductivity of ambient fluid, Btu/(h·ft·°F) (W/(m·K))
V	=	free stream velocity of ambient fluid, ft/h (m/s)
υ	=	kinematic viscosity of ambient fluid, ft^2/h (m^2/s)
g	=	acceleration due to gravity, ft/h^2 (m/s^2)
β	=	volumetric thermal expansion coefficient of ambient fluid, °R^{-1} (K^{-1})
ρ	=	density of ambient fluid, lb/ft^3 (kg/m^3)
ΔT	=	absolute value of temperature difference between surface and ambient fluid, °R (K)
Nu	=	Nusselt number, dimensionless
Ra	=	Rayleith number, dimensionless
Re	=	Reynolds number, dimensionless
Pr	=	Prandtl number, dimensionless

4. Summary of Practice

4.1 The procedures used in this practice are based on standard, steady-state, one dimensional, conduction heat transfer theory as outlined in textbooks and handbooks, Refs (**1,2,3,4,5,6**). Heat flux solutions are derived for temperature dependent thermal conductivity in a material. Algorithms and computational methodologies for predicting heat loss or gain of single or multi-layer thermal insulation systems are provided by this practice for implementation in a computer program. In addition, interested parties can develop computer programs from the computational procedures for specific applications and for one or more of the three coordinate systems considered in Section 6.

4.1.1 The computer program combines functions of data input, analysis and data output into an easy to use, interactive computer program. By making the program interactive, little training for operators is needed to perform accurate calculations.

4.2 The operation of the computer program follows the procedure listed below:

4.2.1 *Data Input*—The computer requests and the operator inputs information that describes the system and operating environment. The data includes:

4.2.1.1 Analysis identification.

4.2.1.2 Date.

4.2.1.3 Ambient temperature.

4.2.1.4 Surface transfer conductance or ambient wind speed, system surface emittance and system orientation.

4.2.1.5 *System Description*—Material and thickness for each layer (define sequence from inside out).

4.2.2 *Analysis*—Once input data is entered, the program calculates the surface transfer conductances (if not entered directly) and layer thermal resistances. The program then uses this information to calculate the heat transfer and surface temperature. The program continues to repeat the analysis using the previous temperature data to update the estimates of layer thermal resistance until the temperatures at each surface repeat within 0.1°F between the previous and present temperatures at the various surface locations in the system.

4.2.3 *Program Output*—Once convergence of the temperatures is reached, the program prints a table that presents the input data, calculated thermal resistance of the system, heat flux and the inner surface and external surface temperatures.

5. Significance and Use

5.1 Manufacturers of thermal insulation express the performance of their products in charts and tables showing heat gain or loss per unit surface area or unit length of pipe. This data is presented for typical insulation thicknesses, operating temperatures, surface orientations (facing up, down, horizontal, vertical), and in the case of pipes, different pipe sizes. The exterior surface temperature of the insulation is often shown to provide information on personnel protection or surface condensation. However, additional information on effects of wind velocity, jacket emittance, ambient conditions and other influential parameters may also be required to properly select an insulation system. Due to the large number of combinations of size, temperature, humidity, thickness, jacket properties, surface emittance, orientation, and ambient conditions, it is not practical to publish data for each possible case, Refs (**7,8**).