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**Determination of steady-state
thermal transmission properties—
Hot box method**

ICS 91.120.10

Descriptors : thermal insulating materials, insulating boards, thermal testing,
housing, domestic facilities, construction materials, thermal resistance

Reference number : JIS A 1420 : 1999 (E)

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Foreword

This translation has been made based on the original Japanese Industrial Standard revised by the Minister of International Trade and Industry through deliberations at the Japanese Industrial Standards Committee in accordance with the Industrial Standardization Law. Consequently **JIS A 1420 : 1994** is replaced with this Standard.

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Determination of steady-state thermal transmission properties—Hot box method

Introduction This Japanese Industrial Standard has been prepared based on the first edition of **ISO 8990** *Thermal insulation—Determination of steady-state thermal transmission properties—Calibrated and guarded hot box* published in 1994, with the exception of Annex B, without modifying the technical contents.

Portions with continuous sidelines and dotted underlines are the matters not stated in the original International Standard.

1 Scope This Standard specifies the method for determining thermal transmittance and thermal resistance as the thermal insulating performance of building components such as mainly walls, roofs, ceilings, floors, etc. according to Guarded Hot Box (GHB) Method and Calibrated Hot Box (CHB) Method.

NOTE : This Standard specifies minimum requirements for designing the test apparatus, and dimensions, etc. of the apparatus are determined according to specimens to be measured.

2 Normative references The following standards contain provisions which, through reference in this Standard, constitute provisions of this Standard. The most recent editions of the standards indicated below shall be applied.

JIS A 1412-1 *Test method for thermal resistance and related properties of thermal insulations—Part 1 : Guarded hot plate apparatus*

JIS A 1412-2 *Test method for thermal resistance and related properties of thermal insulations—Part 2 : Heat flow meter apparatus*

ISO 7345 *Thermal insulation—Physical quantities and definitions*

3 Definitions For the purposes of this Standard, the following definitions apply.

- a) **mean radiant temperature, T_r :** Appropriate weighting of the temperatures of surfaces “seen” by the specimen for the purpose of determining the radiant heat flow rate to the surface of the specimen (see Annex A).
- b) **environmental temperature, T_a :** Appropriate weighting of air and radiant temperatures, for the purpose of determining the heat flow rate to the surface of the specimen (see Annex A).

4 Symbols, units and relationships The following recommended symbols are used:

- i : Interior, usually hot side
- e : Exterior, usually cold side
- s : Surface
- n : Environmental
- λ : Thermal conductivity

[W/(m · K)]

h :	Surface coefficient of heat transfer	[W/(m ² · K)]
Φ :	Heat flow rate	(W)
Φ_p :	Total power input, heating or cooling	(W)
Φ_1 :	Heat flow rate through specimen	(W)
Φ_2 :	Imbalance, heat flow rate parallel to specimen	(W)
Φ_3 :	Heat flow rate through metering box walls	(W)
Φ_4 :	Flanking loss, heat flow rate flanking specimen	(W)
Φ_5 :	Peripheral loss, heat flow rate, parallel to specimen surface at the edges of the specimen	(W)
A :	Area perpendicular to heat flow	(m ²)
q :	Density of heat flow rate	(W/m ²)
d :	Specimen thickness	(m)
T_a :	Air temperature	(K)
T_r :	Mean radiant temperature	(K)
T_n :	Environmental temperature	(K)
T_s :	Surface temperature	(K)
$R = A(T_{si} - T_{se})/\Phi_1$:	Thermal resistance	(m ² · K/W)
$R_s = 1/h$:	Surface heat transfer resistance	(m ² · K/W)
$R_{si} = A(T_{ni} - T_{si})/\Phi_1$:	Interior surface heat transfer resistance	(m ² · K/W)
$R_{se} = A(T_{se} - T_{ne})/\Phi_1$:	Exterior surface heat transfer resistance	(m ² · K/W)
$R_u = R_{si} + R + R_{se}$:	Resistance of heat transmission	(m ² · K/W)
$R_u = 1/U$		(m ² · K/W)
$U = \Phi_1/A(T_{ni} - T_{ne})$:	Thermal transmittance	[W/(m ² · K)]
$\Phi_1 = \Phi_p - \Phi_3 - \Phi_2$ (for guarded hot box)		(W)
$\Phi_1 = \Phi_p - \Phi_3 - \Phi_4$ (for calibrated hot box)		(W)

NOTE : This method does not directly measure the thermal conductivity although it can be derived in case of opaque, homogeneous, flat specimens using the relationship $\lambda = d/R_s$.

Information : Celsius' temperature scale (°C) may be used as a unit of temperature excluding a unit of temperature difference. For a unit of temperature difference, symbol θ shall be used.

5 Principle

5.1 Guarded hot box In the guarded hot box (see figure 1), the metering box is surrounded by a guard box in which the environment is controlled to minimize lateral heat flow in the specimen, Φ_2 , and heat flow through the metering box walls, Φ_3 . Ideally, when a homogeneous specimen is mounted in the apparatus and when both inside and outside the metering box the temperatures are uniform and furthermore

when cold side temperatures and surface coefficients of heat transfer are uniform, a temperature balance for air both inside and outside the metering box would imply a balance on the specimen surface and vice versa, i.e. $\Phi_2 = \Phi_3 = 0$. The total heat flow through the specimen will then be equal to the heat input to the metering box.

In practice, for each equipment and each specimen under test, there will be a limit in detecting imbalance (imbalance resolution, see 6.1.1).

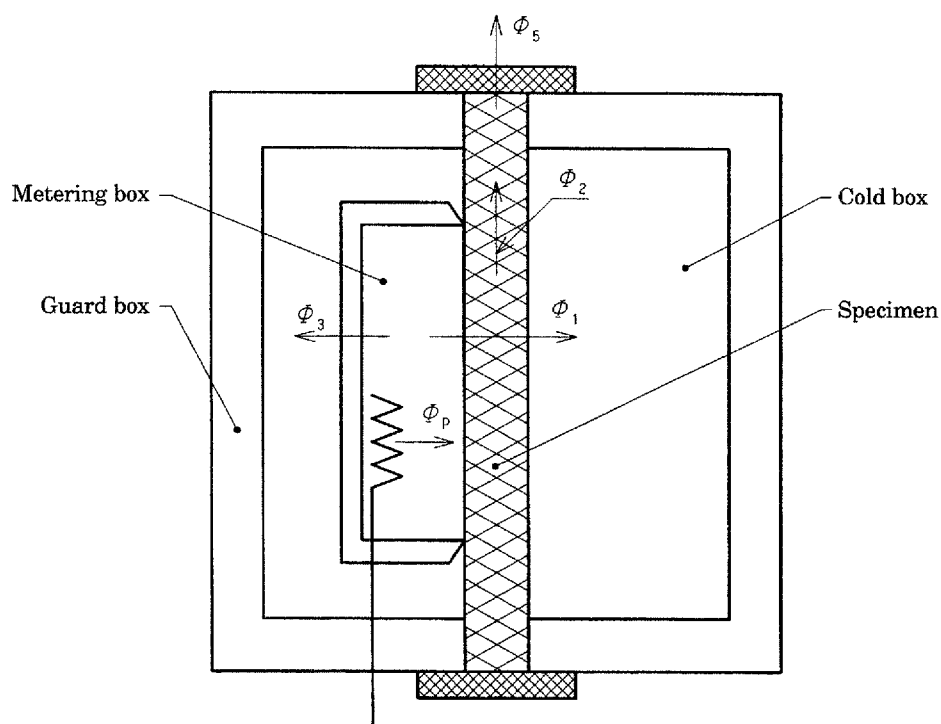


Figure 1 Guarded hot box

5.2 Calibrated hot box The calibrated hot box (see figure 2) is surrounded by a temperature-controlled space not necessarily at the same air temperature as that inside the metering box. The heat losses through the box walls, Φ_3 , are kept low by using a construction of high thermal resistance. The total power input, Φ_p , shall be corrected for the wall losses, Φ_3 , and for the flanking losses, Φ_4 . The flanking heat flow path is illustrated in figure 3, which shows details of the specimen and specimen frame with the adjacent hot and cold side box walls. The correction for box wall losses and flanking losses are determined by tests on calibration specimens of known thermal resistance. For flanking loss calibration, the calibration specimens should cover the same thickness and thermal resistance range as the specimens to be measured and the temperature range of intended use.

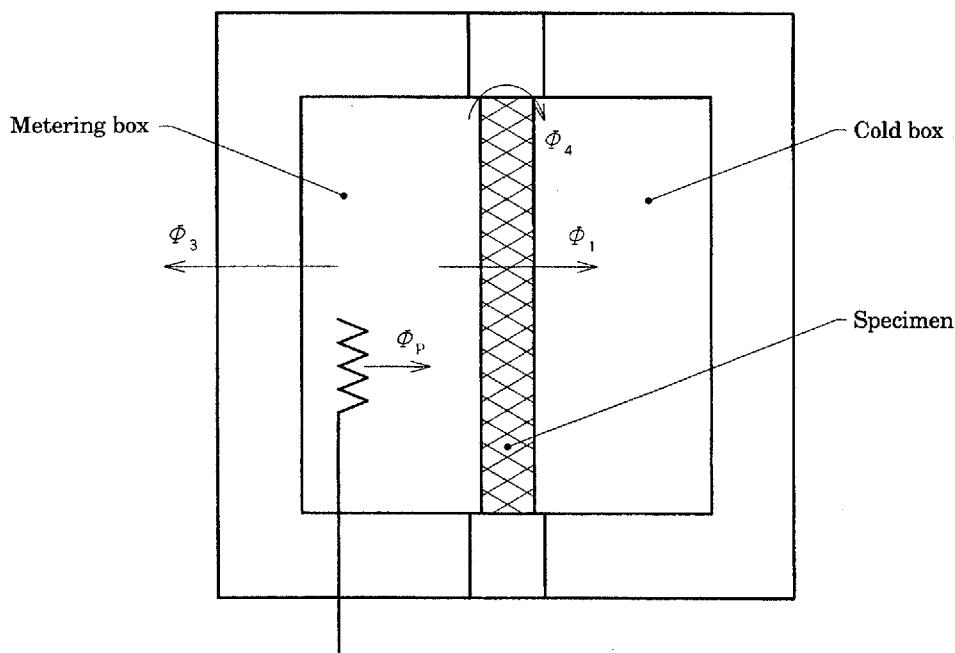


Figure 2 Calibrated hot box

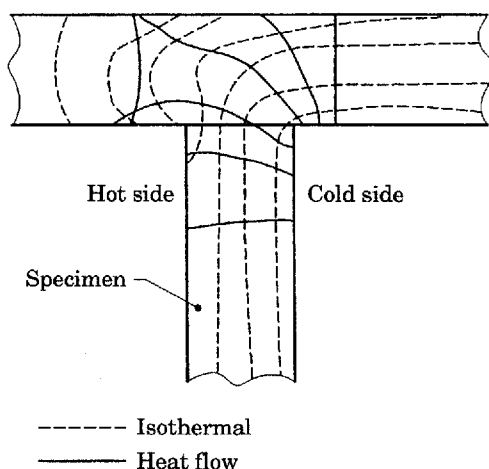


Figure 3 Heat flow path in specimen and frame

6 Limitations and sources of errors The operation of the apparatus, to a certain desired accuracy, is limited by a number of factors related to equipment design, calibration and operation and specimen properties, e.g. thickness, thermal resistance and homogeneity.

6.1 Limitations and errors due to apparatus

6.1.1 Limitations in imbalance resolution in a guarded hot box In practice, even with homogeneous specimens, local surface coefficients of heat transfer are not uniform, especially close to the borders of the metering box. As a consequence, neither the specimen surface-temperature nor the air temperature are uniform close to the periphery of the metering box both inside and outside. This has two consequences:

- a) It can be impossible to reduce to zero at the same time both the lateral heat flow, Φ_2 , through the specimen, and the heat flow, Φ_3 , through the metering box walls;
- b) The temperature nonuniformity close to the metering box, on the specimen surface, and in the air, respectively, define the corresponding best imbalance resolution.

The apparatus shall be designed and operated in such a way as to obtain optimum heat flow balance as indicated in a) above, i.e. apparatus geometry and guard air space and air flow speed so that Φ_3 does not exceed 10 % of Φ_p .

Inhomogeneities in the specimen will enhance nonuniformities in local surface coefficients and in specimen surface-temperatures. Heat flow imbalance through the metering box wall and in the specimen shall be evaluated, and when necessary corrected for. For this purpose the metering box walls shall be equipped to serve as a heat flowmeter. Additionally, a thermopile across the metering area periphery can be mounted on the specimen surfaces. In routine testing, imbalance detection can be simplified by calibration and calculation.

6.1.2 Size of metered area The metering area is defined:

- a) **for a guarded hot box**, as the centre-nose to centre-nose when the specimen is thicker or equal to the nose width, or if the specimen is thinner than the nose width, as the inner periphery of the nose;
- b) **for a calibrated hot box**, as the inner periphery of the metering box.

The size of the metered area determines the maximum thickness of the specimen. The ratios of the metering area side to the specimen thickness and of the guard width to the specimen thickness are governed by principles similar to those for the guarded hot box.

The size of the specimen can also limit possibilities for a representative section of the construction to be tested and thus allow errors and difficulties in interpretation of the result.

Measurement errors in testing to the hot box methods are in part proportional to the length of the perimeter of the metering area. The relative influence of this diminishes as metering area is increased. In the guarded hot box, the minimum size of the metered area is 3 times specimen thickness or 1 m × 1 m, whichever is the greater.

For the calibrated hot box, minimum specimen size is 1.5 m × 1.5 m.

NOTE: When the size of the specimen is smaller than 1.5 m × 1.5 m, the measurement may be performed in accordance with Annex 1.

6.1.3 Minimum power input Power input per unit area to the metering box shall be not less than the value given in the following formula.

$$(T_{si} - T_{se})/R_u$$

6.1.4 Maximum power input Maximum power input is limited by required temperature uniformity and surface coefficients. Large heat flowrates imply large air mass flow across the specimen surface if a high degree of air temperature uniformity

is to be maintained; this will affect the heat transfer mechanism of the surface. In the case of the guarded hot box decreasing the specimen resistance, this imposes stricter requirements on the equivalence of convective and radiative heat transfer in the metering and guard box to obtain a given accuracy.

6.2 Limitations and errors due to specimen

6.2.1 Specimen thickness and thermal resistance For a given apparatus design, specimen thickness can be limited for reasons depending upon specimen properties and boundary conditions, an upper limit for the thickness is due to edge losses, Φ_5 , or flanking losses, Φ_4 , which, although decreasing with increasing specimen thickness, can become significant in comparison to Φ_1 and degrade measurement accuracy.

6.2.2 Specimen inhomogeneity Most test specimens representative of building and industrial components will generally be inhomogeneous. Inhomogeneities in the test specimen will affect the pattern of the density of heat flowrate in such a manner that it is neither one-dimensional nor uniform. Also variations of the thickness throughout the specimen can cause significant local modifications of the pattern of the density of heat flowrate. The effects of these are nonuniformities in temperatures and local transfer coefficients making the following more difficult or even impossible:

- a) the definition of a mean surface temperature;
- b) the detection of imbalance in the guarded hot box apparatus;
- c) the definition of the metering area;
- d) the error analysis of test results for a given inhomogeneous specimen.

Specific examples include:

- e) facings having a high thermal conductivity. These form easy paths for imbalance heat flow rate, Φ_2 , and flanking heat losses, Φ_4 . It can help to cut the facing along the metering box periphery. When homogeneous layers are perpendicular to heat flow, heat resistance of the specimen can be obtained by measuring thermal conductivity of each layer in accordance with JIS A 1412-1 or JIS A 1412-2;
- f) horizontal and vertical structural members like studs. Their effect is in most cases symmetrical;
- g) sections of the specimen made of different materials. The temperature differences through the materials are not the same. A heat flow exists close to the interface of the different materials. When this interface is not far from the metering box periphery, this implies a temperature nonuniformity that affects both imbalance detection and the ambiguity in the definition of the metering area;
- h) cavities within the specimen. Natural convection can create an unknown imbalance heat flow rate, Φ_2 .

It is not possible to provide immediate solutions to all types of problems. The operator is advised to be fully aware of the effects of anomalies.

Calculations of the importance and effects if inhomogeneities are of great help to predict the thermal performance of the test specimen. If significant differences exist between predicted and measured specimen performance which cannot be explained, as a minimum requirement, where such divergences exist, a careful inspection of the specimen should be performed to identify any difference between actual and specified sizes, dimensions, materials, etc. Any irregularities from the original specification shall be reported.

6.2.3 Moisture content in specimen Moisture transfer during the test may have a significant effect on test results. It is not possible to specify a standard pre-test conditioning. As a minimum requirement, the method of conditioning shall be reported. For most specimens, it is normally impossible, without derating measurement accuracy to an unacceptable level, to reduce temperature differences so much that moisture transfer is so slow that steady-state mass transfer can be assumed during measurement time. It should also be realized that not only moisture transfer through the specimen, but also moisture redistribution in the specimen and phase change, will affect the results.

6.2.4 Temperature correlation Specimen thermal resistances or thermal transmittances are often a function of temperature differences across the specimen itself. Care shall then be taken in reporting and interpreting measurement results.

7 Apparatus Figures 1 and 2 show typical arrangements of the test specimen and major elements of the apparatus. Figures 4 and 5 show alternative arrangements. Other arrangements, accomplishing the same purpose, may be used. The apparatus design and construction should be made compatible with the expected types of specimen to be tested and expected testing conditions.

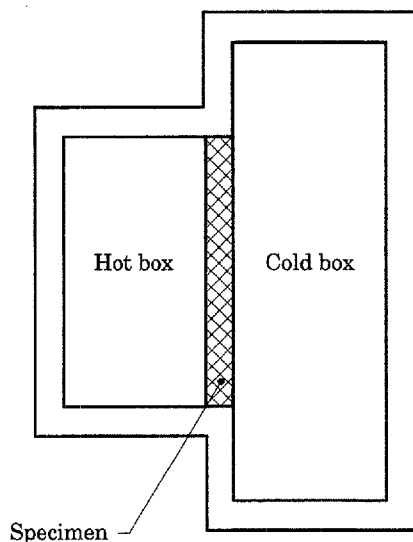


Figure 4

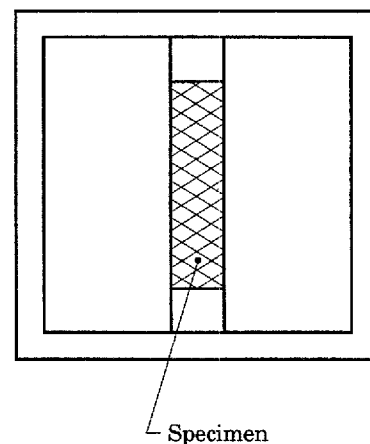


Figure 5

7.1 Design requirements The size of the apparatus shall be commensurate with the intended use, taking the following points into consideration.

- a) The metered area shall be big enough to provide a representative test area. For modular components the metered area should preferably span exactly an integral number of modules.
- b) The ratio of metered area to perimeter of the metered area influences accuracy in both types of boxes because one-dimensional heat flow cannot be maintained at the perimeter of the metered area. These error heat flows at the perimeter of the metered area will increase with decreasing metered area.
- c) Imbalance heat flow, Φ_2 , in the guarded hot box is due to nonuniformities both in surface coefficients and air temperatures close to the periphery of the metered area.
- d) An amount of heat enters the specimen through the nose of the metering box in the guarded hot box. Deviation from one-dimensional heat flow is caused by the finite thickness of the nose seal.
- e) Both edge insulation and edge boundary conditions affect peripheral losses, Φ_5 , for the guarded hot box and flanking losses, Φ_4 , for the calibrated hot box.
- f) All these problems are made more complex by nonhomogeneities in the specimen close to the perimeter of the metered area.
- g) In general, the size of the metering box determines the minimum size of other elements of the apparatus. The depth of the metering box should not be greater than that strictly necessary to maintain desired boundary conditions (desired boundary layer thickness, etc.) and to accommodate its equipment.
- h) The emittance of surfaces which have radiative exchange with the specimen surfaces can be either high or low. High emissivity (0.8 or greater) will in most cases be typical of actual use of building and industrial components.
- i) The low emissivity environment requires a greater convective component, such as higher velocities, to achieve conventional surface coefficients. This produces a substantial change in the distribution of the surface coefficient which can give better temperature uniformity, but this situation can produce an artificial thermal behaviour substantially different from actual use. In particular, it is unsuitable for specimens with permeable surfaces.

7.2 Metering box

7.2.1 Box wall construction The insulation of the box wall shall be chosen considering the intended range of specimen resistance and temperature difference so that an error in the evaluation of the metering box losses does not affect the determination of the specimen heat flow by more than 0.5 %. Box walls shall be thermally uniform to aid in achieving uniform temperatures inside the box and to aid in determining the heat flow through the walls using a thermopile or other type of heat flow sensor.

In addition, it shall be recalled that hot spots, such as heaters, fans, etc., can affect the uniformity of the temperatures inside the box, owing to their local radiative exchanges with the box walls.