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Part 3: Actions on structures - Thermal actions on building

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Foreword

Rwanda Standards are prepared by Technical Committees and approved by Rwanda Standards Board (RSB) Board of Directors in accordance with the procedures of RSB, in compliance with Annex 3 of the WTO/TBT agreement on the preparation, adoption and application of standards.

The main task of technical committees is to prepare national standards. Final Draft Rwanda Standards adopted by Technical committees are ratified by members of RSB Board of Directors for publication and gazettment as Rwanda Standards.

DRS 114-3 was prepared by Technical Committee RSB/TC 09, *Civil Engineering and Building Materials.*

In the preparation of this standard, reference was made to the following standards:

1) BS EN 1991-1-5: 2003: Euro code 1: *Actions on structures — Part 1-5: General actions — Thermal actions*

2) BS EN 12524: 2000: *Building materials and products – Hygrothermal properties – Tabulated design values.*

The assistance derived from the above source is hereby acknowledged with thanks.

This second edition cancels and replaces the first edition (RS 114-3: 2020), of which has been technically revised.

DRS 114 consists of the following parts, under the general title *Structural Design —*

— *Part 1: Actions on structures — Densities, self-weight, imposed loads for buildings*

— *Part 2: Actions on structures — Wind actions*

— *Part 3: Thermal actions on Building*

Committee membership

The following organizations were represented on the Technical Committee on Civil Engineering and Building Materials(RSB/TC 09) in the preparation of this standard.

University of Rwanda – College of Science and Technology (UR-CST)

Institut d' Enseignement Supérieur (INES- Ruhengeri)

City of Kigali

Green Effect Engineering

Integrated Polytechnic Regional Centre –Kigali (IPRC)

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Introduction

Changes in temperatures may cause additional deformations and stresses and may, in some cases, significantly affect ultimate and serviceability limit states of structures. Fundamental principles and rules described in this standard provide basic tools for specifications of temperature changes and for the evaluation of thermal actions effects in buildings.

Deformations and consequent stresses induced by the thermal actions are dependent on the geometry of the element considered and the physical properties of the materials employed in its construction.

There are parameters correlated with the climate of the geographical location of the construction site and the consequent seasonal temperature variations. Other parameters are strictly linked to the conditions of the particular building in question are the presence of other nearby structures that act as solar radiation screens, the building orientation, its total mass (and consequent thermal inertia), the properties of its finishing (i.e. the degree of their solar energy absorption and thermal isolation) and the characteristics of the interior heating, air conditioning and ventilation.

Structural design — Part 3: actions on structures - thermal actions

1 Scope

1.1 This Draft Rwanda standard gives principles and rules for calculating thermal actions on buildings, and their structural elements.

1.2 This Part describes the changes in the temperature of structural elements. Characteristic values of thermal actions are presented for use in the design of structures which are exposed to daily and seasonal climatic changes.

1.3 This standard will be applied in accordance with Rwanda Building Control Regulations, specifically clauses regarding heating systems and comfort levels in buildings.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*

ISO 13370, *Thermal performance of buildings — Heat transfer via the ground — Calculation methods*

RS 112, *Basis of structural design*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

thermal actions

thermal actions on a structure or a structural element are those actions that arise from the changes of

temperature fields within a specified time interval

3.2

shade air temperature

temperature measured by thermometers placed in a white painted louvred wooden box known as a

"Stevenson screen"

3.3

maximum shade air temperature T_{max}

value of maximum shade air temperature with an annual probability of being exceeded of 0.02 (equivalent to a mean return period of 50 years), based on the maximum hourly values recorded

4 Symbols (and abbreviated terms)

For the purposes of this standard, the following symbols apply.

R thermal resistance of structural element

U conductance or thermal transmittance W/m^{2}K

R_{in} thermal resistance at the inner surface

R_{out} thermal resistance at the outer surface

R_{se} external surface resistance m^2.K/ W

R_{si} internal surface resistance m^2.K/ W

T_{max} maximum shade air temperature with an annual probability of being exceeded of 0.02 (equivalent to a mean return period of 50 years)

T_{min} minimum shade air temperature with an annual probability of being exceeded of 0.02 (equivalent to a mean return period of 50 years)

T_0 initial temperature when structural element is restrained

T_{in} air temperature of the inner environment

T_{out} temperature of the outer environment

Δ_{TU} uniform temperature component

Δ_{TE} non-linear part of the temperature difference component

Δ_T sum of linear temperature difference component and non-linear part of the temperature difference component

Δ_T**p** temperature difference between different parts of a structure given by the difference of average temperatures of these parts h height of the cross-section

p annual probability of maximum (minimum) shade air temperature being exceeded (equivalent to a mean return period of 1/p years)

α_T coefficient of linear expansion (1/°C)

λ thermal conductivity.

5 Classification of actions

5.1 Thermal actions shall be classified as variable and indirect actions

5.2 All values of thermal actions given in this Part are characteristic values unless it is stated otherwise.

5.3 Characteristic values of thermal actions as given in this part are values with an annual probability of being exceeded of 0.02, unless otherwise stated, e.g. for transient design situations.

6 Design situations

6.1 Thermal actions shall be determined for each relevant design situation identified in accordance with RS 112.

NOTE Structures not exposed to daily and seasonal climatic and operational temperature changes may not need to be considered for thermal actions.

6.2 The elements of load bearing structures shall be checked to ensure that thermal movement will not cause overstressing of the structure, either by the provision of movement joints or by including the effects in the design.

7 Representation of actions

7.1 Daily and seasonal changes in shade air temperature, solar radiation, etc., will result in variations of the temperature distribution within individual elements of a structure.

7.2 The magnitude of the thermal effects will be dependent on local climatic conditions, together with the orientation of the structure, its overall mass, finishes (e.g. cladding in buildings), and in the case of building structures, heating and ventilation regimes and thermal insulation.

7.3 The temperature distribution within an individual structural element may be split into the following four essential constituent components, as illustrated in Figure 1:

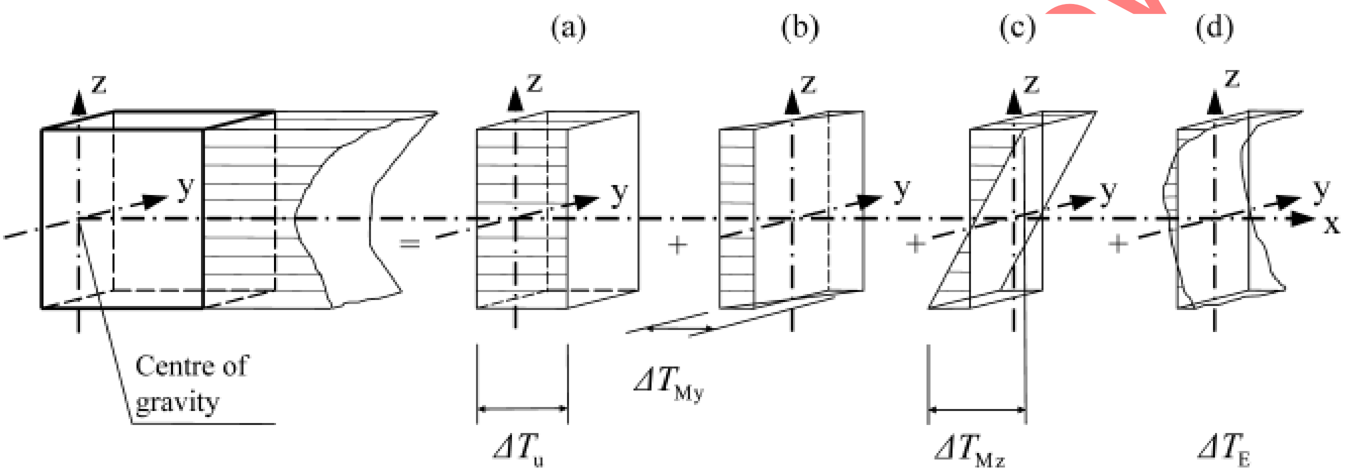
a) uniform temperature component, ΔT_u ;

b) linearly varying temperature difference component about the *z-z* axis, ΔT_{MY};

c) linearly varying temperature difference component about the *y-y* axis, ΔT_{MZ};

d) non-linear temperature difference component, ΔT_{E}. This results in a system of self-equilibrated stresses which produce no net load effect on the element.

7.4 The strains and therefore any resulting stresses are dependent on the geometry and boundary conditions of the element being considered and on the physical properties of the material used. When materials with different coefficients of linear expansion are used compositely the thermal effect shall be taken into account.



(a) Component of the uniform temperature; (b) and (c) components of the temperature linearly variable according to two axes contained in the plan of the section; (d) a residual component

Figure 1 — Diagrammatic representation of constituent components of a temperature profile

7.5 For the purpose of deriving thermal effects, the coefficient of linear expansion for a material shall be used.

NOTE The coefficients of linear expansion for a selection of commonly used materials are given in annex A.

8 Temperature changes in buildings

8.1 General

8.1.1 Thermal actions on buildings due to climatic and operational temperature changes shall be considered in the design of buildings where there is a possibility of the ultimate or serviceability limit states being exceeded due to thermal movement and/or stresses.

NOTE 1 Volume changes and/or stresses due to temperature changes may also be influenced by:

a) shading of adjacent buildings,

b) use of different materials with different thermal expansion coefficients and heat transfer,

c) use of different shapes of cross-section with different uniform temperature.

NOTE 2 Moisture and other environmental factors may also affect the volume changes of elements.

8.2 Determination of temperatures

8.2.1 Thermal actions on buildings due to climatic and operational temperature changes shall be determined in accordance with the principles and rules provided in this Section taking into account national or regional data and experience.

8.2.2 The climatic effects shall be determined by considering the variation of shade air temperature and solar radiation. Operational effects (due to heating, technological or industrial processes) shall be considered in accordance with the particular project.

8.2.3 In accordance with the temperature components given in Section 7, climatic and operational thermal actions on a structural element shall be specified using the following basic quantities:

a) uniform temperature component **ΔT_u** given by the difference between the average temperature T of an element and its initial temperature T_0.

b) linearly varying temperature component given by the difference ΔT_M between the temperatures on the outer and inner surfaces of a cross section, or on the surfaces of individual layers.

c) temperature difference ΔT_p of different parts of a structure given by the difference of average temperatures of these parts.

NOTE Values of ΔT_M and ΔT_p may be provided for the particular project.

8.2.4 In addition to ΔT_u, ΔT_M and ΔT_p, local effects of thermal actions shall be considered where relevant (e.g. at supports or fixings of structural and cladding elements). Adequate representation of thermal actions shall be defined taking into account the location of the building and structural detailing.

8.2.5 The uniform temperature component of a structural element ΔT_u is defined as:

$$\Delta T_u = T - T_0 \quad (1)$$

where,

T is an average temperature of a structural element due to climatic temperatures in winter or summer season and due to operational temperatures.

The quantities ΔT_u, ΔT_M, ΔT_p, and T shall be determined in accordance with the principles provided in 8.3 using regional data. When regional data are not available, the rules in 8.3 may be applied.

The first step is to determine the value of mean temperature T. It is calculated as the value of the mean winter or summer temperature of the structural element in question by adopting a specific profile that defines the temperature distribution throughout the element's thickness. If the internal (T_{in}) and external (T_{out}) conditions are sufficiently similar, a simplified procedure can be adopted, and the mean temperature may be determined as

$$T = \frac{T_{\text{out}} + T_{\text{in}}}{2} \tag{2}$$

8.3 Thermal conductivity

Conductivity (λ) of a material is its ability to conduct heat through its internal structure. Conductance (U) [W/m²K] on the other hand is an object property and depends on both its material and thickness. Thermal conductivity depends on temperature, density and moisture content of a material. Generally light materials are better insulators than heavy materials, because light materials often contain air enclosures. Heat energy can be transferred by conduction, convection or radiation.

8.3.1 Thermal insulation

Thermal insulation can refer to materials used to reduce the rate of heat transfer or the methods and processes used to reduce heat transfer. In thermal insulation calculations, this coefficient is used to calculate insulation material thickness needed to maintain inside-outside temperature difference depending on heating system and insulation area. Design thermal values for materials in general building application are given in Table 1.

Table 1 — Design thermal values for materials in general building application

Material group or application	Density ρ kg/m^3	Design thermal conductivity λ W/(m.K)
Asphalt	2100	0.70
Bitumen	1050	0.20
Concrete		
Light weight density	1800	1.15
Medium density	2000	1.35
	2200	1.65
High density	2400	2.00
Floor coverings		
Rubber	1200	0.17
Plastics	1700	0.25
felt	12	0.05
wool	20	0.06
cork	20	0.05
Tiles	2000	1.2
Carpet/textile flooring	200	0.06
Gase		
Air	1.23	0.025
Glass		
Soda lime	2500	1.00

Quartz	2200	1.40
Glass mosaic	2000	1.1.20
Water at 10ºC	1000	0.60
Water at 40ºC	990	0.63
Water at 80ºC	970	0.67
Metals		
Aluminium	2700	160
Bronze	8300- 8500	65
Brass	8300- 8500	120
Copper	8700-8900	380
Cast iron	7100-7250	50
Lead	11200-11400	35
Steel	7700-7800	50
Stainless steel	7900	17
Zinc	7100-7200	110
Masonry		
Brickwork	1700	0.73
Wood		
Hardwood	800	0.17
Softwood	550	0.14
Plywood	700	0.17
Hard-board	1000	0.3
Soft-board	300	0.08
Tiles (roofing)		
Clay	2000	1.0
Concrete	2100	1.5
Concrete blocks		
Light weight	600	1.63
Medium weight	1400	0.51
Heavy weight	2300	0.19
Wood- based panels		
Plywood	300	0.09
Synthetic		
Polyvinyl chloride (PVC)	1400	0.17

NOTE Materials are thermal insulators if their conductivity is less than 0.065 W/m.K

8.4 Thermal resistance

8.4.1 Thermal resistance of homogeneous layers

8.4.1.1 Design thermal values can be given as either design thermal conductivity or design thermal resistance. If thermal conductivity is given, obtain the thermal resistance value of the layer from

$$R = \frac{h}{\lambda} \qquad (8.3)$$

where

R is the thermal resistance of the layer and is expressed in m^2K/W

h is the thickness of the material layer in the component and is expressed in m

λ is the design thermal conductivity of the material and is expressed in W/mK

NOTE The thickness, *h*, can be different from the nominal thickness (e.g. when a compressible product is installed in a compressed state, *h* is less than the nominal thickness). If relevant, it is advisable that *h* also make appropriate allowance for thickness tolerances (e.g. when they are negative).

8.4.1.2 Thermal resistance values used in intermediate calculations shall be calculated to at least three decimal places.

8.4.1.3 This value is a measure of the capacity of a product to fight against heat loss. It depends on the thickness and thermal conductivity. The highest the R, the best performing the product.

8.4.2 Use the values in Table 2 for plane surfaces in the absence of specific information on the boundary conditions.

8.4.2.1 The values under "horizontal" apply to heat flow directions ± 30° from the horizontal plane.

Table 2 -- Conventional surface resistances

Surface resistance $m^2.K/W$	**Direction of heat flow**		
	Upwards	**Horizontally**	**Downwards**
R_{si}	0.10	0.13	0.17
R_{se}	0.04	0.04	0.04

NOTE 1 The values given are design values. For the purposes of declaration of the thermal transmittance of components and other cases where values independent of heat flow direction are required, or when the heat flow direction is liable to vary, it is advisable that the values for horizontal heat flow be used.

NOTE 2 The surface resistances apply to surfaces in contact with air. No surface resistance applies to surfaces in contact with another material.

8.4.2.2 The Heat flow, going through the wall depends on temperature difference between inside and outside and thermal resistance **R** of the wall. Each element constituting the wall has thermal properties: bricks or concrete, insulation, rendering, etc. Wall thermal resistance is the addition of thermal resistance of each component from interior coating to exterior rendering, and superficial resistances.

9 Temperature changes in industrial chimneys and tanks

9.1 General

9.1.1 Structures which are in contact with material with different temperatures shall be designed where relevant for the following conditions:

a) thermal actions from climatic effects due to the variation of shade air temperature and solar radiation,

b) temperature distribution for normal and abnormal process conditions,

c) effects arising from interaction between the structure and its contents during thermal changes (e.g. shrinkage of the structure against stiff solid contents or expansion of solid contents during heating or cooling).

9.1.2 The thermal stresses in the liner and in the windshield due to differences in temperature between the inner and outer surface of the respective walls shall be determined at the maximum flue gas temperature and the lowest outside temperature to be expected at site considering a statistical return period of 50 years.

9.1.3 For the purpose of verifying the thermal stability of building materials, the maximum outside temperature to be expected at site considering a statistical return period of 50 years has to be assumed.

9.1.4 When a chimney or chimney components are restrained from adopting a distorted shape in response to differential expansion, resulting stresses have to be taken into account. These stresses can be high, when a liner or a single unlined chimney carries flue gases from two or more sources at significant different temperatures or if a single side entry source introduces flue gases at very high temperatures.

9.1.5 The liner shall be capable of expanding in both vertical and horizontal directions without any adverse effect on windshield, support and liner. If a chimney has more than one liner, the individual liners shall be able to expand vertically and horizontally independently.

9.1.6 The influence of the deformations of the liner support on the movements of the liner has to be taken into consideration.

NOTE 1 Containment structures may be subjected to thermally induced changes in shape arising from heating/cooling effects of either the contents or their surrounding external environment.

9.2 Temperature components

9.2.1 Shade air temperature

9.2.1.1 Values of minimum and maximum shade air temperatures for the site location shall be obtained from national maps of isotherms.

9.2.2 Flue gas, heated liquids and heated materials temperature

Values of maximum and minimum flue gas, liquids and materials with different temperatures shall be specified for the particular project.

9.2.3 Element temperature

The derivation of values of element temperature will depend on the material configuration, orientation and location of the element and will be a function of the maximum and minimum shade air temperature, the external solar radiation, and the internal operating temperature.

9.3 Consideration of temperature components

9.3.1 Both the uniform temperature component of the temperature distribution (see Figure 1 (a)) and the linearly varying temperature difference component (see Figure 1 (b)) shall be considered for each layer.

9.3.2 The effect of solar radiation shall be considered in the design.

9.3.3 This effect may be approximated by a step temperature distribution round the structure's circumference.

9.3.4 The uniform temperature component and the linearly varying temperature difference component due to process temperature shall be considered for each layer.

9.4 Determination of temperature components

9.4.1 The uniform and linearly varying temperature components shall be determined taking into account climatic effects and operating conditions.

9.4.2 If specific information on how the element temperature can be correlated with the solar radiation and shade air temperature is available in order to provide values of element temperature, such information should be used to provide design values.

9.4.3 Values of the uniform temperature component from heated gas flow, liquids and heated materials shall be taken from the project specification.

9.4.4 The linearly varying temperature difference component in the wall or its layers shall be taken as arising from the difference between the minimum (or maximum) shade air temperature on the outer face and the value of the liquid or gas temperature on the inner face, taking into account insulation effects.

9.5 Values of temperature components (indicative values)

9.5.1 In the absence of any specific information on characteristic values of the element temperature, the following indicative values may be used.

NOTE These values may be checked against any available data to ensure that they are likely to be upper bound values, for the location and the type of element under consideration.

9.5.2 Values of the maximum and minimum uniform temperature component shall be taken as those of the maximum and minimum shade air temperature (see 8.2.1).

NOTE The recommended value for the linear temperature difference component is 15ºC.

Annex A
(normative)

Temperature profiles in buildings and other construction works

For the determination of action effects due to temperature components, Table A.1 gives values for the coefficient of linear expansion for a selection of commonly used materials.

Table A.1 — Coefficients of linear expansion

Material	αT ($x10^{-6}$/°C)
Aluminium, aluminium alloy	24
Stainless steel	16
Structural steel, wrought or cast iron	12 (see Note 4)
Concrete except as under	10
Concrete, lightweight aggregate	7
Masonry	6 - 10 (see Notes)
Glass	8.5
Timber, along grain	5
Timber, across grain	30 - 70 (see Notes)

NOTE 1 The values given shall be used for the derivation of thermal actions, unless other values can be verified by tests or more detailed studies.

NOTE 2 Values for masonry will vary depending on the type of brickwork; values for timber across the grain can vary considerably according to the type of timber.

NOTE3 For some materials such as masonry and timber other parameters (e.g. moisture content) also need to be considered.

NOTE 4 For composite structures the coefficient of linear expansion of the steel component may be taken as equal to $10x10^{-6}$/ºC to neglect restraining effects from different αT-values.

Annex B
(informative)

Temperature profiles in buildings and other construction works

B.1 Temperature profiles may be determined using the thermal transmission theory. In the case of a simple sandwich element (e.g. slab, wall) under the assumption that local thermal bridges do not exist; a temperature T(x) at a distance *x* from the inner surface of the cross section may be determined assuming steady thermal state as

$$T(x) = T_{\text{in}} - \frac{R(x)}{R_{\text{tot}}}(T_{\text{in}} - T_{\text{out}}) \quad \text{(B.1)}$$

where:

T_{in} is the air temperature of the inner environment

T_{out} is the temperature of the outer environment

R_{tot} is the total thermal resistance of the element including resistance of both surfaces

R(*x*)is the thermal resistance at the inner surface and of the element from the inner surface up to the point *x* (see Figure B

B.2 The resistance values $R_{tot,}$ and R(*x*) [m^2K/W] may be determined using the coefficient of heat transfer and coefficients of thermal conductivity given in ISO 6946:2007 and ISO 13370 (1998):

$$R_{\text{tot}} = R_{\text{in}} + \sum_i \frac{h_i}{\lambda_i} + R_{\text{out}} \quad \text{(B.2)}$$

where:

R_{in} is the thermal resistance at the inner surface [m^2K/W]

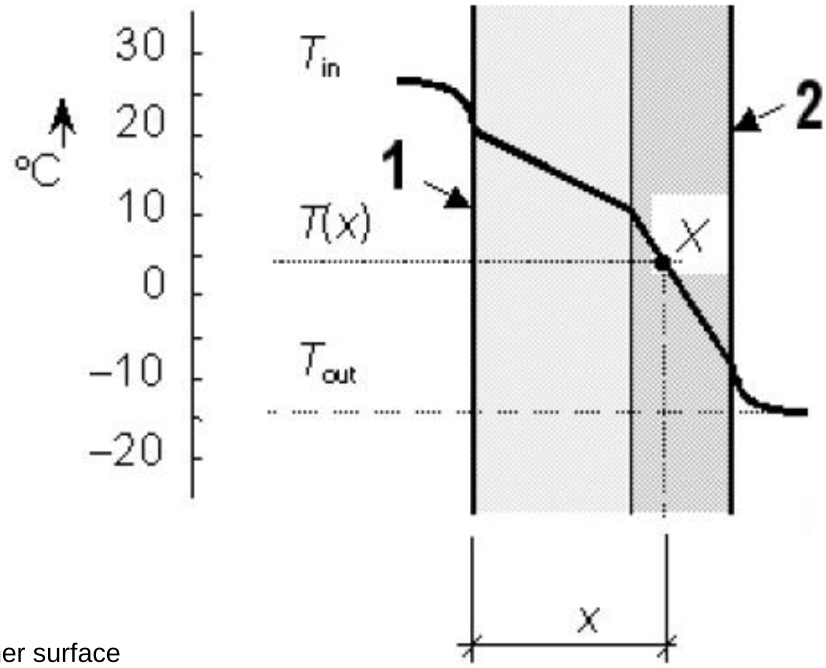
R_{out} is the thermal resistance at the outer surface [m^2K/W],

λ_i is the thermal conductivity and *h*i [m] is the thickness of the layer *i*, [W/(mK)]

$$R(x) = R_{\text{in}} + \sum_i \frac{h_i}{\lambda_i} \quad \text{(B.3)}$$

where layers (or part of a layer) from the inner surface up to point *x* (see Figure B.1) are considered only.

NOTE In buildings the, thermal resistance R_{in} = 0.10 to 0.17 [m^2K/W] (depending on the orientation of the heat flow), and R_{out} = 0.04 (for all orientations).



Key

1 Inner surface

2 Outer surface

Figure B.1 — Thermal profile of a two-layer element

Bibliography

[1] BS EN 1745: 2002 *Masonry and masonry products — Methods for determining design thermal values*

[2] BS EN 12939: 2001 *Thermal performance of building materials*

[3] ISO 10456 *Procedure for determining declared and design thermal values*

[4] www.meteorwanda.gov.rw - Monthly weather forecast]

- Information on meteo stations

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