



TECHNICAL NOTE #6

Thermal Resistance & Thermal Capacity

Clay Brick Masonry Walling



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Title

Thermal Resistance and Thermal Capacity of walls– the theory behind the concepts

Status

This Technical Note is provided as an information sheet for appending to the CBA web-site

Scope

The concepts are explained and the definitions of Thermal Resistance and Thermal Capacity, as well as the formulae for the calculation thereof, are provided.

Thermal Resistance & Thermal Capacity of Walls

The Theory behind the Concepts

Thermal Resistance

Building elements, particularly those in the shell of a structure give protection from the outside environment, and extreme conditions such as, heat and cold. The measures of how effectively the shell of a building maintains an equable temperature for the benefit of occupants is in part gauged via the thermal resistance of the shell. In mathematical terms the Thermal Resistance of an element is the inverse of its Thermal Transmittance.

The Thermal Resistance of a building element or the materials used provide for the flow of heat (always from a hot to cold temperature) to be impeded. This impedance is measured in terms of the total R-value for a building element, which equates to the sum of the component R-values of the various materials, including the inner and outer air surfaces and any air-spaces that make up the composite building element.

Calculation of Thermal Resistance (R) of a Wall

To calculate the Thermal Resistance (R-value) of a wall, the following equation is used :

$$R = \frac{1}{U} = \frac{1}{h_1} + \frac{1}{h_0} + \left(\frac{1}{a_1} + \frac{1}{a_2} + \dots + \frac{1}{a_n} \right) + \left(\frac{d_1}{k_1} + \frac{d_2}{k_2} + \dots + \frac{d_n}{k_n} \right) \text{ m}^2\text{KW}^{-1}$$

Where:

- R = total Thermal Resistance of the wall
- U = Thermal Capacity
- h_i = coefficient of heat transfer for inner surface of wall
- h_o = coefficient of heat transfer for outer surface of wall
- $a_1 \dots a_n$ = air-spaces coefficient of heat transfer
- $d_1 \dots d_n$ = thickness of each successive layer of materials
- $k_1 \dots k_n$ = thermal conductivity of n layers or different material of elements (W/mK)

Then if:

- d_1 = 0.114m for a single course of brick
- k_1 = 0.82 W/mK for brickwork

Then:

$$\frac{1}{20} + \frac{1}{9.4} + \frac{1}{6.2} + \frac{0.114}{0.82} + \frac{0.114}{0.82}$$

$$R = 0.60 \text{ m}^2\text{KW}$$

Calculation of Thermal Resistance (R) of a Wall, cont'd

The average Thermal Resistance of the shell is the weighted average of the various R-values of the building elements, or the inverse of the average U-value of the building shell.

Where:

$$U_n = 1/R_n$$

$$U_{\text{Average}} = \frac{A_1 \times U_1 + \dots + A_n / R_n}{\sum A}$$

$$R_{S q} = 1/U_{\text{Average}}$$

Thermal Capacitance (C)

As daily temperatures fluctuate externally and the building shell becomes exposed to solar radiation, and then outward radiation at nighttime, the surface temperature of an external wall will also fluctuate. In winter (heating) conditions, the heat of the day can usefully contribute to maintaining internal temperatures in the comfort zone, as some portion of the heat gain is passed through the wall, often with a lag in time, in which case this heat arrives at a useful time when the building is being heated. This serves to reduce the overall heating requirement if the building is occupied and heated at night. Similarly, in the hot season night time, walls can create a heat sink, which will absorb unwanted heat during the day.

In its simplest form the Thermal Capacitance is the product of the volume of an element multiplied by the density of the material times the specific heat of the material, being the amount of heat or energy necessary to change a unit mass of a substance by one degree K in temperature.

This physical property is known as the thermal capacitance (C)

Calculation of Thermal Capacity

The calculation of the heat-storing capacity of the structure as a whole is complicated by the position of any high mass element relative to any possible insulation, which may prevent that mass from accepting heat or giving it up to the internal environment when it is required for comfort.

It is convenient to express the heat-storing capacity of the shell in terms of the building shell area, i.e. external walls, as these are generally the major contributors to the total capacity, and are unlikely to be compromised by wall covering as may be the case for the floors of buildings.

$$C_s = \frac{V_1 \rho_1 c_1 + \dots + V_n \rho_n c_n}{\sum A} \text{ kJm}^{-2}$$

Where :

$V_1 \dots V_n$ = the volumes of various layers or components of structure (m^3)
 $\rho_1, \dots \rho_n$ = mass densities of various components (kg m^{-3})
 $C_1, \dots C_n$ = specific heats of various components ($\text{kJ}^\circ\text{C}^{-1} \text{ kg}^{-1}$)
 $\sum A$ = total area of shell (m^2)

$$C_s = \frac{(V_1 \rho_1 c_1 + \dots + V_n \rho_n c_n)}{(A_1 + \dots + A_n)}$$

Regulatory Requirements in South Africa

The Thermal Resistance of walls in many types of buildings in South Africa are required to be in excess of certain mandatory levels for purposes of the revised National Building Regulations and SANS 10400XA, which stipulate that :

- i) Non-masonry walls should have an R-value of no less than either 1.9 or 2.2 $\text{m}^2\text{K/W}$ depending on the geographic location of the structure.
- ii) Masonry walls will comply if they comprise of a double brick construction or through the wall 140mm hollow concrete block, which are plastered internally.
- iii) Other masonry walls should have an R-value which is greater than 0.35 $\text{m}^2\text{K/W}$.

In the SANS 204 Energy Efficiency in buildings standard, a performance requirement for walling is set out, which ensures a higher level of energy efficiency. It is recommended this be used as a basis for the rational design of walls.

In SANS 204 the heat storing ability of the structure is measured as the CR-value, which is described below.

CR-value

The rate of heat transfer through the element (or wall or layer within a wall) is determined by the Thermal Diffusivity, which is a combination of factors or variables that collectively contribute to a thermal time constant within this framework, namely the :

- Specific Heat (capacity) of the materials used (C)
- Size and volume of the element (V)
- Density (ρ), hence the mass of material
- Accessibility of this Thermal Capacitance, which is governed by the Thermal Resistances of the component layers (R) and
- External Surface Resistances (h), all contributing to a thermal time constant for the element.

These can be combined in the most basic form, as the product of the Thermal Transmittance and the Thermal Capacity of the shell of a structure, with a factor to translate the kilo-second units to hours.

$$CR_s = C_s * R_s * 0.2777$$