The Concrete Centre

Dynamic Thermal Properties Calculator

essential materials
sustainable solutions

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1 Introduction

This guidance note describes The Concrete Centre's *Dynamic Thermal Property Calculator* tool (developed for TCC by Arup). The tool is an Excel spreadsheet that calculates parameters relating to the dynamic thermal storage of construction elements. Two groups of parameters are calculated: 1) *thermal admittance, Y*, and related quantities, as specified in EN ISO 13786:2007 and 2) surface heat capacities, κ (or 'Cm'), as specified in EN ISO 13790:2004, which are used in the SAP(2009 draft) and iSBEM calculation tools supporting Part L of the Building Regulations.

The specific parameters calculated are:

Thermal admittance parameters:

- **Thermal admittance, *Y*** [W/m²K]. This is the amount of energy leaving the internal surface of the element into the room per unit degree of temperature swing. This is under theoretical conditions where the internal environmental temperature undergoes periodic oscillation and the external environmental temperature is constant.
- **Time lead for thermal admittance** [hours]. This is the time difference between the timing of the peak heat flow at the internal surface and timing of the peak internal temperature.
- **Decrement factor** [dimensionless]. This is the ratio of the peak heat flow out of the external surface of the element per unit degree of external temperature swing to the steady state heat flow through the element per unit degree of temperature difference between the internal and external environmental temperatures.
- **Decrement delay** [in hours]. This is the time lag between the timing of the internal temperature peak and the peak heat flow out of the external surface.
- **Surface factor** [dimensionless]. This is the ratio of the swing in heat flow from the internal surface of the element to the swing in heat flow received at the internal surface of the element (such as solar gain from a sun patch).
- **Time lag for the surface factor** [in hours]. This is the time lag between the timing of the peak heat flow entering the surface and peak heat flow leaving the surface into the room.
- **Areal heat capacity** [kJ/m²K]. This is the amount of energy stored in the element over the first half period of the heat flow swing per unit area of element per unit degree of temperature swing. The same amount of heat is released in the following half period.
- **U-value** [W/m²K]. This is the steady state heat flow through the element per unit degree of temperature difference between the internal and external environmental temperatures per unit area. Note that this quantity may differ from other U-values quoted as it does not take account of thermal bridging and is sensitive to the values of surface thermal resistances used.

Surface heat capacities

- κ [kJ/m²K]. This is the volumetric heat capacity of the 'thermally active' part of the construction *up to* a maximum thickness of 100mm.
- κ_{30} [kJ/m²K]. This is the equivalent of κ but for a maximum thickness of 30mm

2 User guide

The spreadsheet contains three sheets: 'Input', 'Full Results' and 'Reference Data'. **Error! Reference source not found.** shows a screen shot of the 'Input' sheet. On this sheet the user specifies the construction build up and can alter (optional) the time period, the interior and exterior heat transfer coefficients and the location of the element (external or internal). The user can also enter project details. Further details on data entry are given below.

On the ‘Input’ sheet some key output results are also shown for convenience. These are admittance, decrement factor, decrement delay and κ value (note that decrement factor and decrement delay are not calculated for internal elements). A graph showing the amplitude and phase of the swings in internal and external heat flows and internal temperature is also displayed.

The ‘Full results’ sheet contains the full set of calculated parameters, listed in Section 1 together with a summary of the construction build up and other assumptions on which the calculation is based.

The ‘Reference Data’ sheet contains a list of thermal properties of common construction materials, taken from CISBE Guide A.

The following instructions explain how to use the spreadsheet.

1) Fill in the calculation settings.
    a. Enter the period of oscillation of the internal environmental temperature.
    b. Enter the internal surface resistance for the element. (Refer to Table 1 for typical values).
    c. Enter the external surface resistance.
    d. Select whether the element is an external element (i.e. separating a conditioned space from the outside) or an internal element (i.e. separating two conditioned spaces).
2) Fill in the Element construction.
    a. Select the layer type for each layer before entering any other details for the layer. Select “Solid Layer” if the layer is a layer of building material. Select “Cavity – Unlined” if the layer is a cavity without a foil lining. Select “Cavity – Foil-lined” if the layer is a cavity with a low emissivity foil lining. If these automatically calculated cavity resistances are not appropriate, select the “ Cavity – User defined thermal resistance”.
    b. Once the layer types have been selected, the parameters required for each layer will be highlighted. All of the highlighted fields must receive entries for the calculation to be carried out.
    c. Enter a layer name to identify each layer.
    d. Enter the thickness of each layer.
    e. Enter the density, specific heat capacity and thermal conductivity of each solid layer. Values of these properties for common materials are provided in the “Reference data” sheet. These may be copied and pasted into the input fields.
    f. Enter the thermal resistance of each cavity with a user defined thermal resistance.

    The layers do not need to be in consecutive rows in the Element Construction table. Empty rows will be ignored by the calculation. Once all the required parameters for a layer have been entered, the layer may be copied and pasted into other locations within the Element Construction table. To delete a layer, delete the layer type for the layer.
3) Click the calculate button to calculate the result for the element. The results will be presented in three formats.
    a. Key. This shows the most commonly used results.
    b. Heat flow plot. The plot shows a unit periodic swing in the internal environmental temperature. The plot also shows the surface heat flows into the internal surface and out of the external surface resulting from the plotted swing in internal temperature and a constant external temperature. This is a graphical interpretation of the admittance and the decrement factor, respectively.

c. Full Results sheet. View this by clicking on the tab at the bottom of the window. This shows all the input parameters that have been used in the calculation and the thermal resistance used in the calculation for each cavity layer. The Full Results sheet also gives a full list of the dynamic thermal properties calculated.

If any error messages are produced whilst using the calculator, follow the instructions to check the input parameters are valid. The programme checks that the user inputs are adequate to perform the calculation. There are no restrictions, however, on whether the input values are realistic. If the error message persists when there seems to be no problem with the entered data, open an empty version of the calculator and re-enter the data.

2.1 Software requirements

The tool was developed on the 2003 Service Pack 3 version of Excel and has also been tested on Excel 2000.

3 Theory

3.1 Admittance parameters (ISO 13786)

Thermal admittance is a framework to quantify how a construction element responds to periodic (sinusoidal) cycles in temperature and heat gain. This framework is described fully in EN ISO 13786:2007. The admittance framework also provides the basis for the CIBSE 'Simple Dynamic Model' for calculating cooling loads and summertime space temperatures (CIBSE (2005) Guide A: Environmental design).

The admittance framework calculates parameters describing the dynamic thermal properties of construction build ups composed of homogeneous, planar elements, from the thermal properties (thermal conductivity, specific heat capacity and density) of the material layers and cavities that make up the construction.

The two principal admittance parameters are admittance and decrement factor. These describe the response of the construction element to a periodic (sinusoidal) thermal 'forcing' consisting of a heat flow into the surface from the room (by radiative and conductive heat transfer processes). The admittance describes the rate of heat flow into the interior surface of the element and decrement describes the rate of heat flow from the exterior surface of the element. In both calculations it is assumed that the room air temperature is varying and the outside air temperature is constant (similar concepts can be defined reversing these assumptions). Each parameter describes the amplitude of the response and also has an associated time lead or lag between the timing of the response and of the forcing. The time period for the thermal forcing is usually taken to be 24-hours, but any time period can be used and the tool enables the time period to be used to be specified by the user.

Although admittance is sometimes taken to be a measure of thermal storage, this is not strictly true, since *Y* only describes the heat flow into the surface, whereas it is the difference between the heat flow into the interior surface of the element and that leaving the exterior surface that relates to the heat storage achieved. To calculate the effective thermal storage, therefore, requires both *Y* and decrement factor to be used and the associated time delays. This is done in the calculation of the 'areal heat capacity' which describes the effective heat storage achieved over one half cycle.

The third parameter calculated is the surface factor. This is not included in ISO 13786 but is used in the CIBSE simple dynamic model. It relates to the ability of a surface element to absorb incident radiative heat gain, e.g. from a sun patch on the surface. This parameter also has an amplitude and a time lag.

The theoretical scenarios forming the basis of these three parameters are shown schematically in Figure 1.

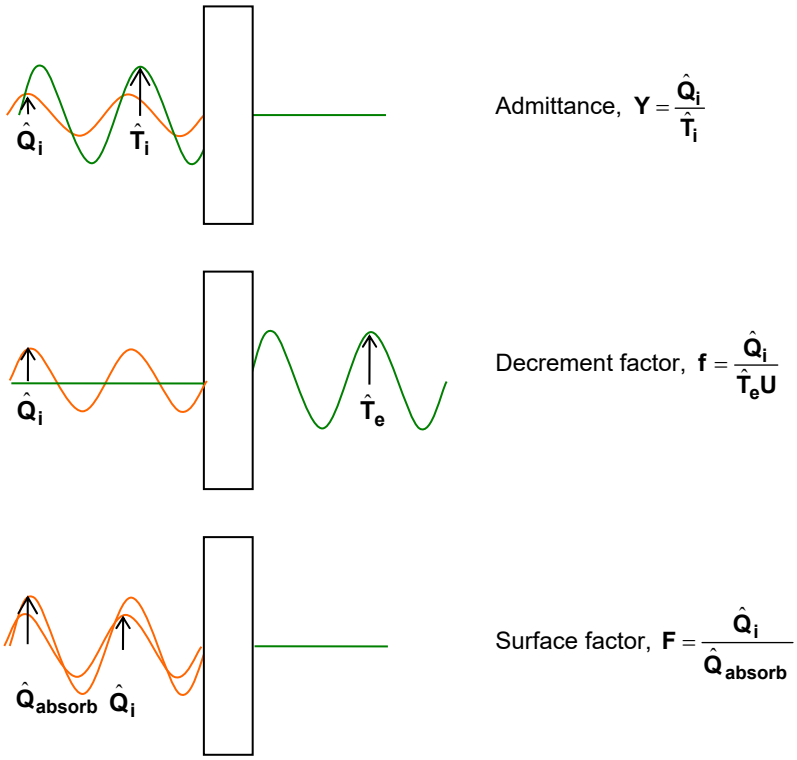

Figure 1: Schematic of the scenarios under which the dynamic thermal characteristics are calculated. $\hat{Q}_i$ is the swing in heat leaving the internal surface of the element into the room, $\hat{T}_i$ is the swing in internal environmental temperature, $\hat{T}_e$ is the swing in external environmental temperature, U is the U-value of the element and $\hat{Q}_{absorb}$ is the heat absorbed by the surface (heat flows are shown in orange and temperatures in green).

To calculate the admittance parameters, the tool follows the methodology set out in *ISO 13786:2007 – Thermal performance of building components – Dynamic thermal characteristics – Calculation methods*. Two important features of the calculation requiring clarification are the values used for the surface heat transfer coefficients and the thermal resistance of any internal cavities in the construction.

3.1.1 Surface heat transfer coefficients

The surface heat transfer coefficients used in the default calculation are those for horizontal heat transfer. This is obviously appropriate for a vertical wall. For a horizontal slab, typically the direction of heat transfer alternates between upwards and downwards over the diurnal cycle. It is therefore appropriate to use these intermediate values for the surface heat transfer coefficient. In cases where the heat transfer is either always upwards or always downwards the user may alter the surface heat transfer coefficients to the conventional surface resistances given in *BS EN ISO 6946:2007 – Building components and building elements – Thermal resistance and thermal transmittance – Calculation method* and shown in Table 1.

Surface Resistance m^2K/W	Direction of Heat Flow		
	Upwards	Horizontal	Downwards
R_{si}	0.10	0.13	0.17
R_{se}	0.04	0.04	0.04

Table 1: Conventional heat transfer coefficients given in ISO 6946.

3.1.2 Cavity thermal resistance

In situations where the construction build up has cavities the thermal resistance of these cavities needs to specified or calculated. The tool allows the user to either input a cavity thermal resistance based on an 'offline' calculation or can calculate the thermal resistance from a specification of cavity thickness.

The calculated values based on thickness are taken from the tabulated values given in the CIBSE Guide A (2005). Two types of cavity can be specified: unlined or foil-lined (low-e). To improve the interpolation of intermediate values between these tabulate values the methodology set out in *BS EN ISO 6946* was used. To use this methodology to reproduce the values given in the CIBSE Guide A required a number of assumptions to be made, in line with the standard. For a foil lined cavity, the convective heat transfer coefficient could not be less than 1.39 W/m^2K as the cavity got wider; the black-body radiative coefficient was 5.7 W/m^2K; the emissivity of the foil-lined surface was 0.16; and the emissivity of the unlined surface was 0.9. The direction of heat transfer through the cavity is assumed to be horizontal for the same reasons as the heat transfer from the internal and external surfaces is assumed to be horizontal. If this is not appropriate the user may set the thermal resistance of the cavity by selecting the "Cavity - user defined thermal resistance" layer type.

3.2 Internal heat capacities, κ and κ_{30} (ISO 13790)

The tool calculates two 'surface heat capacities', κ and κ_{30}. These quantities are not directly related to the admittance framework but to a simpler framework for calculating thedynamic thermal response of building elements used in ISO 13790:2004 *Thermal performance of buildings – Calculation of energy use for space heating* .[1] These quantities relate simply to the volumetric heat capacity of different parts of the construction element. The way in which they are calculated is described below.

κ is used in SAP (2009, draft) and the iSBEM calculation tools supporting Part L of the Building Regulations. It is calculated (in units of kJ/K per m² of surface area) from:

$$\kappa = 10^{-6} \sum_i \rho_i c_i d_i$$

where:

ρ_i is the density of layer *i* in the construction (kg/m³)

c_i is the specific heat capacity of layer *i* (J/kg K)

d_i is the thickness of layer *i* (mm).

[1] Note that ISO 13790 uses the notation χ rather than κ and in iSBEM κ was formerly referred to as "C_m".

The summation is done over all layers in the element, starting at the inside surface and stopping at whichever of these conditions occurs first (which may mean part way through the layer)

- half way through the construction
- an insulating layer
- a maximum thickness of 100mm

An insulating layer is defined here as an element having a thermal conductivity of less than 0.08 W/mK. This threshold is taken from the *User Guide to iSBEM version 3.3.b* (Note: ISO 13790 and SAP(2009) do not specifically define a criteria for an insulating layer). In the case of cavities, an effective thermal conductivity for the layer is calculated by dividing the cavity thickness by the cavity thermal resistance.

The surface heat capacity, κ_{30}, is calculated in a similar way to κ but the maximum thickness for the summation is 30mm. This quantity is used in ISO 13790 to model thermal storage effects where heating is intermittent. It is not used in SAP or iSBEM.

Note: κ is a relatively simplistic way of characterising the thermal mass of a construction element as, in addition to the assumptions made regarding the 'thermally active' layer thickness, it does not take account of the effect of thermal conductivity in determining the timescale for heat to enter and leave the element. The areal heat capacity defined in ISO 13786 provides a more accurate measure of the effective heat capacity of a construction element.

4 References and Further Information

Environmental Design – CIBSE Guide A Chartered *Institute of Building Services Engineers* 2006

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