CELLAR

Heat losses to the ground from buildings

Version 2.0

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1 Introduction

1.1 Overview

The PC-program **CELLAR** calculates the heat loss to the ground rom a rectangular building with a foundation of the cellar type with constant insulation thickness at the floor and the wall. Both the heat loss variation during the year, including the peak effect, and the accumulated heat loss during the heating season are calculated. The results are based on heat conduction in a semi-infinite ground with homogeneous soil. The effect of moisture movements or changes in moisture content are not considered.

2 Mathematical description

Figure 1 shows a building with the considered type of foundation. It is thermally insulated towards the ground.

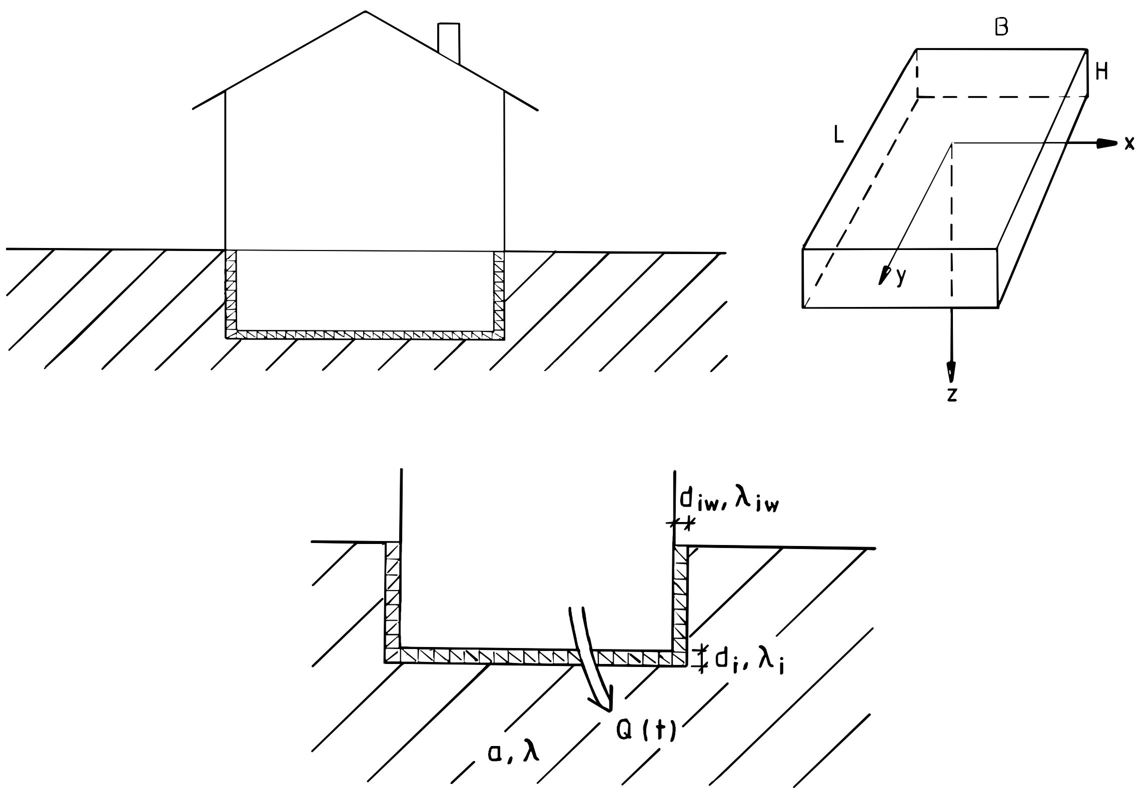

Figure 1: Buildings with foundation of the type cellar.

2.1 Governing equation

The ground is assumed to be homogeneous with constant thermal conductivity λ (W/mK) and volumetric heat capacity C ($= \rho c$) (J/m^{3}K). The governing equation for conductive heat flow in the ground is:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{\rho c}{\lambda} \frac{\partial T}{\partial t} \tag{1}$$

The solution of the equation is obtained from a combination of numerically results (FDM) and analytical solutions, see (Hagentoft, 1988).

2.2 Heat loss

The heat loss, $Q(t)$ (W), through the floor surface, S, becomes:

$$Q(t) = \iint_S -\lambda \frac{\partial T}{\partial n} \, dS \tag{2}$$

2.3 Boundary condition at the interior

The temperature in the building is constant T_i. The thickness of the thermal insulation at the floor is d_i (m), and the thermal conductivity is λ_i (W/mK). The boundary condition becomes:

$$\frac{T_i - T}{d_i/\lambda_i} = -\lambda \frac{\partial T}{\partial n} \tag{3}$$

Here, d_i/λ_i (m^2K/W) should be interpreted as the total thermal resistance between the interior and the soil.

2.4 Boundary condition at the exterior

The outdoor temperature may vary strongly during the day, and from day to day. However, variations with a short time period or duration can be neglected.

The following approximation of the outdoor temperature is used:

$$T_{out}(t) = T_0 + T_1 \cdot \sin(2\pi(t/t_p - \phi_1)) \tag{4}$$

Here, T_0 is the annual mean temperature, and T_1 is the seasonal amplitude of the temperature variation with the time period, t_p, of one year. The phase ϕ_1 is choosen in order to achive the maximum outdoor temperature at the right time of the year.

The sinusoidal temperature, (4), represents a mean temperature during the winter months. In order to calculate the peak effect we need to represent the outdoor temperature in greater detail, in particular during the coldest period. It should normally be sufficient to use a single suitably chosen pulse, which the duration time t_2. The magnitude of the pulse is T_2. The value of T_2 is negative for a cold spell. The maximum heat loss is obtained at the end of the pulse.

2.5 Heat loss during the heating season

The heat loss to the ground is denoted by $Q(t)$ (W).We get a steady-state (time-independent) component Q_s and a periodic one $Q_p(t)$:

$$Q(t) = Q_s + Q_p(t) \tag{5}$$

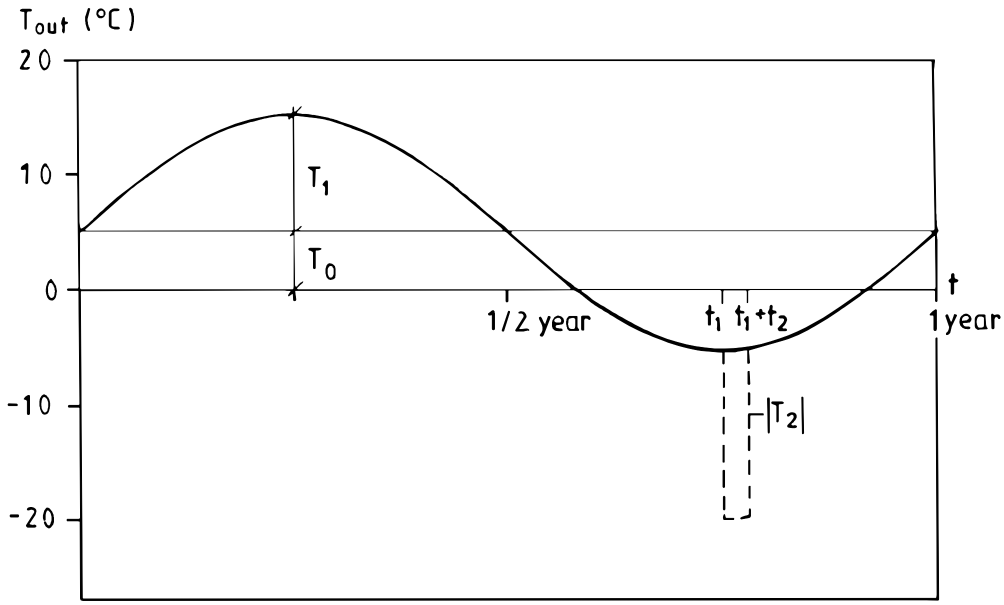

Figure 2: Representation of the outdoor temperature for the calculation of the energy demand (continuous curve) and the peak effect (continuous + dashed curve).

The accumulated heat loss over the heating season, starting at the time t_a of the year and ending at t_b, becomes:

$$E_y = \int_{t_a}^{t_b} Q(t)\, dt \qquad (6)$$

Let $Q_t(t)$ denote the extra heat loss due to a cold spell. The peak heat loss due to a superimposed cold spell becomes:

$$Q(t) = Q_s + Q_p(t) + Q_t(t_2) \qquad (7)$$

3 Working with CELLAR

3.1 Input data

The following input data are required by the PC-programs:

L	Length of building (m)
B	Width of building (m)
H	Depth to the floor of the cellar (m)
T_i	Indoor temperature (°C)
T_0	Annual mean outdoor temperature (°C)
T_1	Amplitude of the periodic outdoor temperature (°C)
λ_i	Thermal conductivity of the floor insulation (W/mK)
d_i	Insulation thickness of the floor (m)
λ_{iw}	Thermal conductivity of the wall insulation (W/mK)
d_{iw}	Insulation thickness of the wall (m)
λ	Thermal conductivity of the ground (W/mK)

C Volumetric heat capacity, ρc, of the ground (J/m^3K)
t_a Start time for the heating season, day of the year, (days)
t_b End time for the heating season, day of the year, (days)
T_2 Increase of outdoor temperature due to temperature pulse (°C)
t_2 Duration time for the pulse (days)

The input data window is shown in Figure 3.

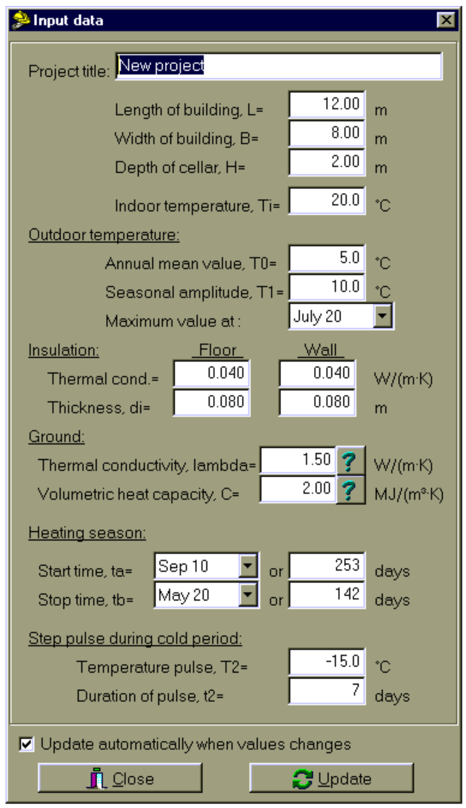

Figure 3: Menu for input of data.

There are the following restrictions on the input variables:

$$L, B, d_{iw}, \lambda_i, \lambda_{iw}, \lambda, C, t_2 > 0$$

$$B \leq L$$

$$0 < H/B \leq 0.25$$

$$\left(\frac{d_i\lambda/\lambda_i}{B} \geq 0.05\right) \quad \text{or} \quad \left(0 < \frac{d_i\lambda/\lambda_i}{B} \leq 0.05 \quad \text{and} \quad H/B > 0.05\right)$$

$$\frac{d_{iw}\lambda/\lambda_{iw}}{H} \geq 0.10$$

$$\sqrt{at_2}/H \leq 2$$

$$t_a < t_b$$

As an alternative, English units (Btu, ft, h, °F) can be used both for the input data and the output. Alternation between SI-units and English units can be made in the Options menu.
The input data are tested so that they fall within acceptable limits.

3.2 Output data

The following output are produced:

E_y	Accumulated heat loss over the heating season (J, kWh).
$Q(t)\|_{max}$	Peak effect during the winter (W).
Q_s	Annual mean heat loss (W).
$Q_p\|_{max}$	Amplitude of the periodic heat loss (W).
t_{lag}	Time lag, (days), for the periodic heat loss.
ϕ_p	The phase delay, (-), for the periodic heat loss.

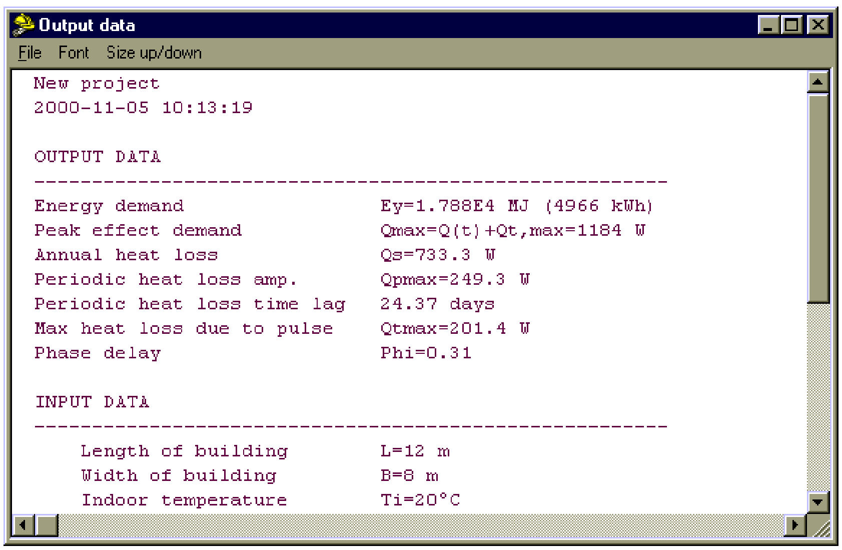

Figure 4: Menu for output of data.

The output data window is shown in Figure 4.

With these output data the heat loss (except for the pulse) becomes:

$$Q(t) = Q_s + Q_p|_{max} \cdot \sin(2\pi(t_{days}/365 - \phi - \phi_p)) \tag{8}$$

The graphical window is shown in Figure 5.
The chart shown in the Graph Window has several options, which is shown in Figure 6.

References

1. Heat loss to the ground from a building. Slab on the ground and cellar. Thesis, LTH/TVBH-1004, 1988. Dept. of Building Physics, Lund University.

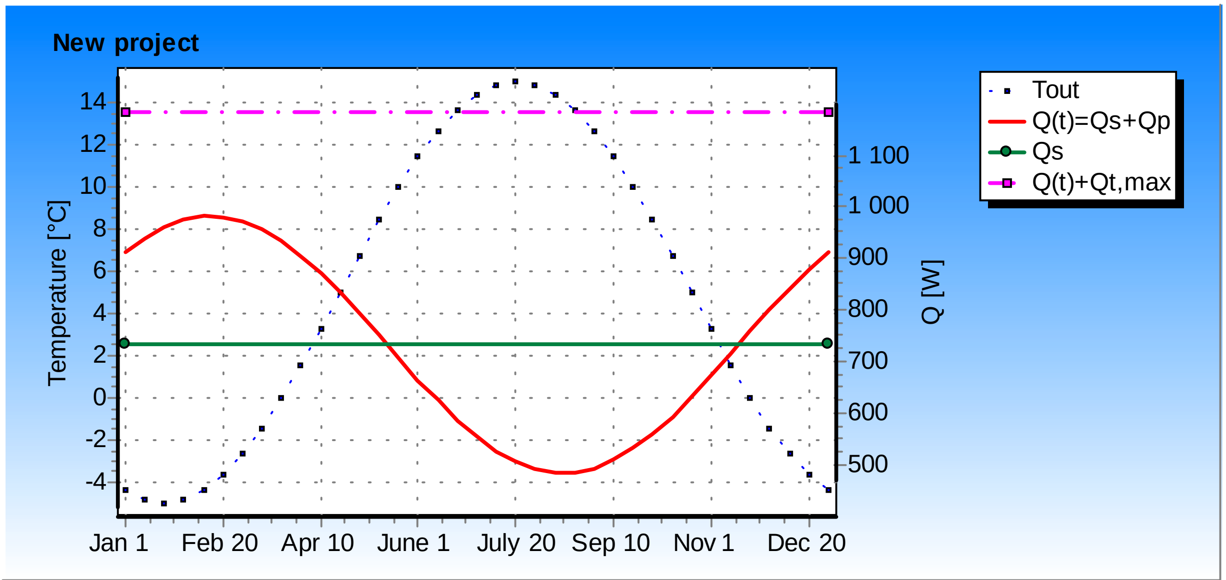

Figure 5: Heat losses to the ground.

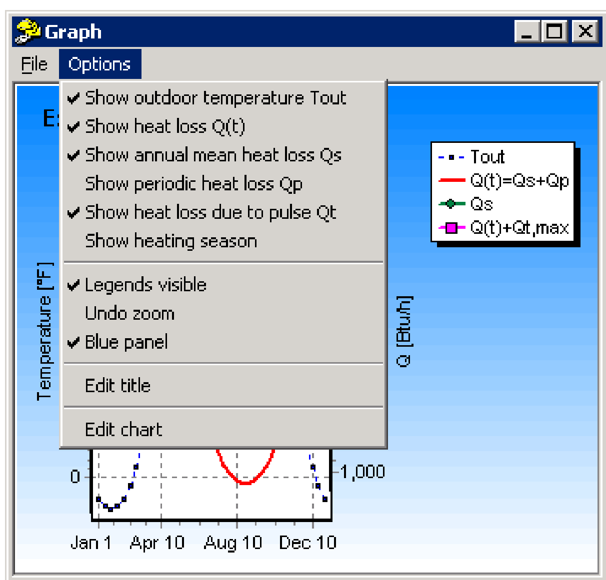

Figure 6: Sub-menu in the Graph window showing different options.

Appendix A. Changing the chart properties

The properties of a chart may be changed by the chart editor (Options/Edit chart), see Figure A1.

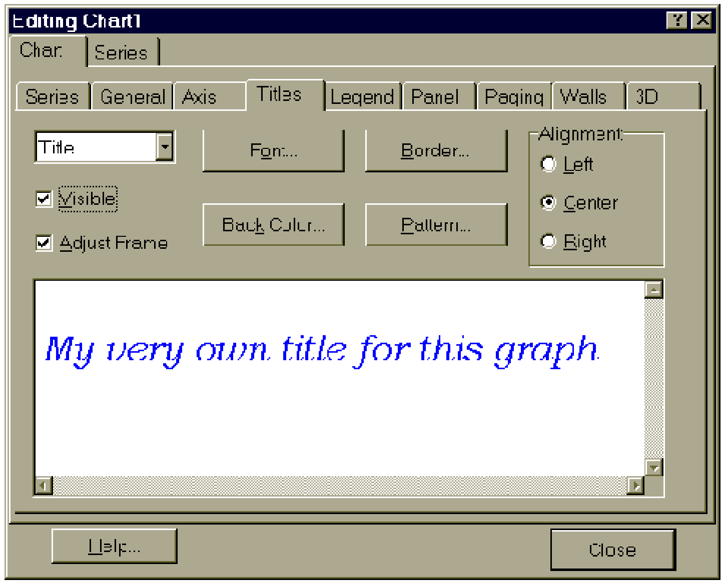

Figure A1: Chart settings may be changed in menu item Options/Edit chart.

There are two principal sections to the Chart editor, Chart parameters and the Series parameters, which are separated as two tabs of the Chart Editor. To get help on any topic in the Chart Editor, select the help button (question mark) at the top right hand side of the Editor window and drag it onto the Topic in question. Some of the chart display parameters is described below:

Chart pages

Series - Change of a series type to line, bar, area, point, etc
General - Chart rectangle dimensions, margins, zoom and scroll, print preview and export
Axis - All axes definitions. Some parameters depend upon the series associated with the axis.
Titles - Title and Footer
Legend - Legend display. Formatted displays work in conjunction with the chart serie
Panel - Chart Panel display properties. Colors, bevels, back images, color gradient and border.
Paging - Definition of number of points per chart page
Walls - Left, bottom and back wall size and color definitions
3D - 3D perspective options.

Series pages

Format - Contains Series type specific parameters
Point - Visible points, margins
General - Series value format, axis association
Marks - Series mark format, text, frame and back color and positioning