CRAWL

Hygrothermal conditions in crawl-spaces

Version 2.0

September 2003

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1 Introduction

The PC-program **CRAWL** calculates the crawl-space temperature and relative humidity for the cases of outdoor and indoor air ventilation. The heat loss through the floor structure is also calculated. Both the heat loss variation during the year, including the peak effect, and the accumulated heat loss during the heating season are given.

2 Mathematical description

Figure 1 shows a building with the considered type of crawl-space foundation.

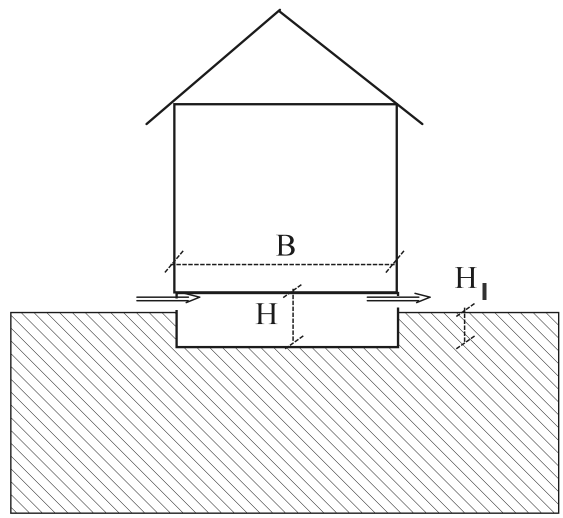

Figure 1: Buildings with a crawl-space foundation.

2.1 Heat and mass balances

Calculation methods for the crawl-space temperatures and heat flows are given in [1]. Both external and internal air ventilation of the crawl-space are considered. The crawl-space temperatures are obtained from energy-balances for the air, the ground surface and the floor. The total temperature process is divided into simpler processes. The steady-state and the periodic temperature components are dealt with in particular. The temperature component due to a pulse in the otdoor temperature is also dealt with.

The PC-program, described in this manual, calculates the crawl-space temperatures and the heat loss through the floor. A rectangular building with a foundation of the type crawl-space with constant insulation thickness at the ground and constant U-value of the floor and the crawl-space wall are considered. The air ventilation rate is assumed to be constant.

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 temperature in the building is constant T_i. The thickness of the thermal insulation at the ground surface (if any) is d_i (m), and the thermal conductivity is λ_i (W/mK).

A mass balance accounting for the vapour flow into the crawl-space due to the ventilation and the vapour diffusion to or from the ground gives the mean moisture content by volume v_c (g/m^3) in the crawl-space air. Diffusion from the house through the floor or from the crawl-space to the outdoor air through the walls is neglected.

The moisture content by volume v_{vent} (g/m^3) of the ventilation air is prescribed. For the outdoor air ventilated crawl-space we have:

$$v_{vent} = \phi_{out} \cdot v_s(T_{out}(t)) \tag{1}$$

Here, v_s (g/m^3) denotes the moisture content by volume at saturation, and ϕ_{out} (-) denotes the outdoor air relative humidity. For the indoor air ventilated crawl-space we have:

$$v_{vent} = \phi_{out} \cdot v_s(T_{out}(t)) + \Delta\, v_{indoor} \tag{2}$$

Here, $\Delta\, v_{indoor}$ (g/m^3), represents the moisture supply to the indoor air. This is an input parameter required by the program.

The relative humidity at the surface of the soil in the bottom of the crawl-space is assumed to be at a relative humidity of 100%. The PC-program uses the input data to calculate the mean temperature of the soil surface T_{ground} (°C). The humidity by volume in the soil v_{soil} (g/m^3) surface is then given by:

$$v_{soil} = v_s(T_{ground}) \tag{3}$$

The PC-program requires the total moisture resistance Z (s/m) between the surface of the soil and the crawl-space air. It should include surface resistances, and the moisture resistance of the thermal insulation and the vapour retarder, if there is one.

The sum of the flow of moisture into the crawl-space air must be equal to zero:

$$R_a \cdot (v_{vent} - v_c) + \frac{A}{Z} \cdot (v_{soil} - v_c) = 0 \tag{4}$$

This gives:

$$v_c = \frac{v_{vent} \cdot R_a + v_{soil} \cdot A/Z}{R_a + A/Z} \tag{5}$$

Here R_a (m$^3_{air}$/s) is the air flow rate of the ventilation, and A (m^2) is the horizontal area of the crawl-space.

The moisture supply $\Delta\, v_{ground}$ (g/m^3) to the crawl-space air, originating from the ground, will then be equal to:

$$\Delta\, v_{ground} = v_c - v_{vent} \tag{6}$$

2.2 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:

$$T_{out}(t) = T_0 + T_1 \cdot \sin(2\pi(t/t_p - \phi_1)) \tag{7}$$

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, (7), represents weekly mean temperature during the year. 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.

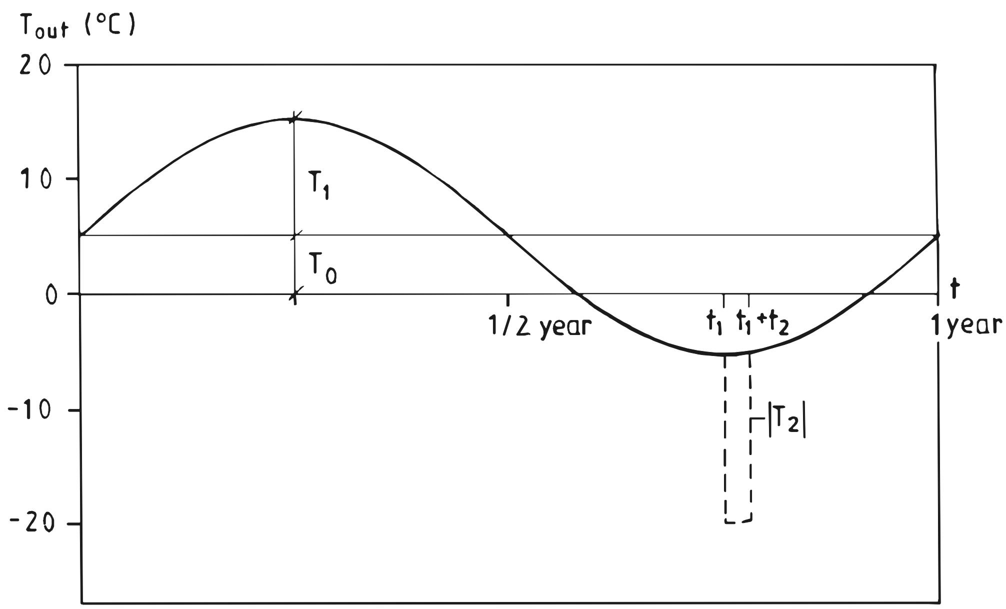

Figure 2: Representation of the outdoor temperature. The dashed curve represents the cold-spell for peak efekt calculatins.

3 Working with CRAWL

The following input data are required:

α_c	Convective heat transfer coefficient at the crawl-space surfaces (W/m^{2}K)
B	Width of building (m)
C	Volumetric heat capacity of the ground (MJ/m^{3}K)
Δv_{indoor}	Moisture supply to inddor air (indoor air ventilation) (g/m^3)
H	Height of the crawl-space (m)
H_1	Depth of soil layer outside the building, see Figure 1 (m)
L	Length of building (m)
λ	Thermal conductivity of the ground (W/mK)
n	Air exchange rate for the crawl-space, ($n = R_a/(A \cdot H)$), (1/h)
t_a	Start time for the heating season (days)
t_b	Stop time for the heating season (days)
t_2	Duration of temperature pulse (days)
T_2	Magnitude of temperature pulse (°C)
d_i	Ground insulation thickness (m)
λ_i	Thermal conductivity of the ground insulation (W/mK)
T_0	Annual average outdoor temperature (°C)
T_1	Amplitude of the seasonal outdoor temperature variation (°C)
T_i	Indoor temperature (°C)
U_f^1	U-value of the floor (W/m^{2}K)
U_w^1	U-value of the crawl-space wall (W/m^{2}K)
Z	Moisture resistance of the layers on top of the soil, (10^3·s/m)

The Input Data Window is shown in Figure 3.

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.

3.1 Restrictions on input data

There are the following restrictions on the input variables:

$$L, B, H, d_i, U_f^1, U_w^1, \lambda_i, \lambda, C, t_2, \alpha_c, n, T_0, T_1, T_2, t_a, t_b > 0$$

$$B \leq L$$

$$0 < H_1/B \leq 0.25$$

$$\left(\frac{d_i\lambda/\lambda_i}{B} \geq 0.05\right) \qquad \text{or} \qquad \left(0 \leq \frac{d_i\lambda/\lambda_i}{B} \leq 0.05 \quad \text{and} \quad H_1/B > 0.05\right)$$

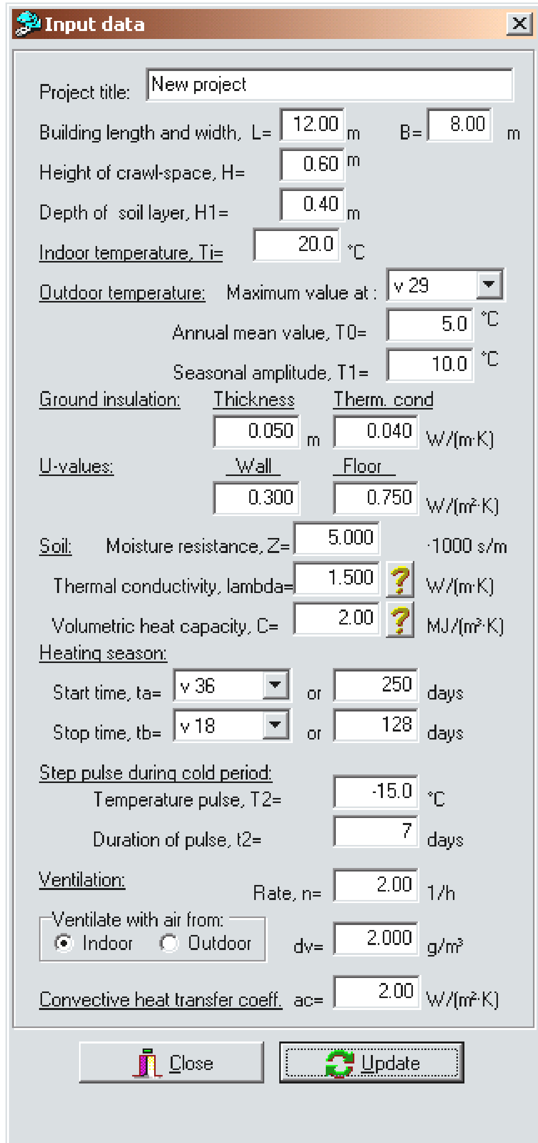

Figure 3: Menu for input of data.

3.2 Climate data

A set of 7 data files (*.RH), containing the weekly average outdoor relative humidities (given in percent) in different locations in Sweden, comes with the program. The data are taken from [2]. The files start with a string of information on the first line, giving the location. The second line contains the number of weekly mean values that will follow. This integer number is larger or equal to 2 and less or equal than 53. Relative humidities are given for the weeks between 0 and 52. Only integer numbers can be used, and the set of data must contain the week number 0 and 52. Linear interpolation between the given weeks are used in the program.

New files can of course be created for other locations, as long as the same format of the ASCII-files are used. The files must have the extension *.RH.

`KIRUNA.RH`	Weekly mean values of relative humidity in Kiruna, Sweden
`HARNOSND.RH`	Weekly mean values of relative humidity in Hörnösand, Sweden
`OSTERSND.RH`	Weekly mean values of relative humidity in Östersund, Sweden
`VASTERAS.RH`	Weekly mean values of relative humidity in Västerås, Sweden
`GOTEBORG.RH`	Weekly mean values of relative humidity in Göteborg, Sweden
`KALMAR.RH`	Weekly mean values of relative humidity in Kalmar, Sweden
`MALMO.RH`	Weekly mean values of relative humidity in Malmö, Sweden

The input data are tested so that they fall within acceptable limits.

3.3 Output data

The following output are produced:

T_{us}, T_{cs},T_{ds}	Steady-state temperature for the upper surface, the air and the lower horizontal surtface (C°).
T_{up}, T_{cp},T_{dp}	Amplitude of periodic temperature for the upper surface, the air and the lower horizontal surtface (C°).
T_{ut}, T_{ct},T_{dt}	Temperature at the end of the pulse for the upper surface, the air and the lower horizontal surtface (C°).
$\phi_u^p \cdot t_p$, $\phi_c^p \cdot t_p$, $\phi_d^p \cdot t_p$	Time lag for periodic temperature for the upper surface, the air and the lower horizontal surtface (days).
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.

The output data window is shown in Figure 4.

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

$$Q(t) = Q_s + Q_p(t) \tag{8}$$

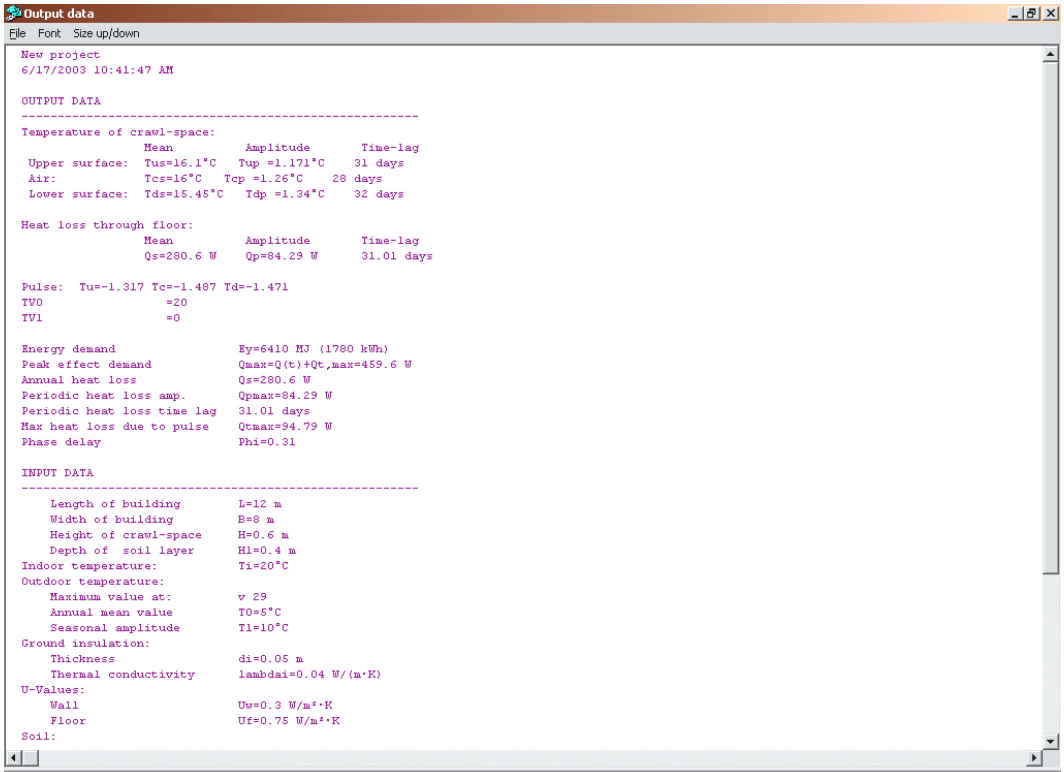

Figure 4: Menu for output of data.

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

$$E_y = \int_{t_a}^{t_b} Q(t)\, dt \tag{9}$$

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:

$$Q(t) = Q_s + Q_p(t) + Q_t(t_2) \tag{10}$$

The time lag for the crawl-space air temperature T_c^p is given by $\phi_c^p \cdot t_p$, were ϕ_c^p is the phase delay. With these output data the crawl-space temperature becomes:

$$T_c(t) = T_c^s + |T_c^p| \cdot \sin(2\pi(t/t_p - \phi_1 - \phi_c^p)) \tag{11}$$

Formulas for the upper and lower crawl-space temperatures are obtained from (2-3) by exchanging index c by u or d.

The heat loss through the floor becomes:

$$Q_{floor}(t) = Q_{floor}^s - |Q_{floor}^p| \cdot \sin(2\pi(t/t_p - \phi_1 - \phi_u^p)) \tag{12}$$

The graphical window is shown in Figure 5.

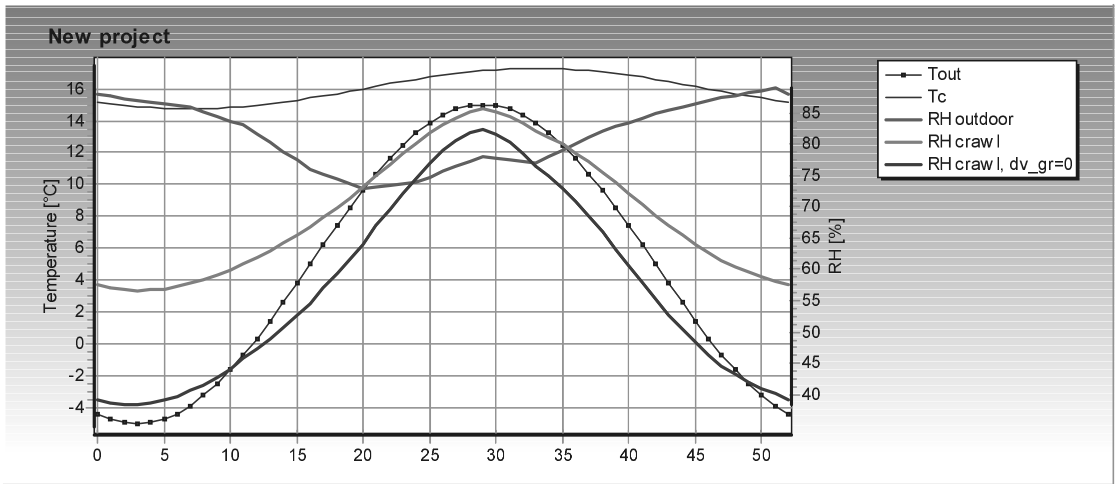

Figure 5: Menu showing a crawl-space temperature and relative humidity.

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

References

1. An analytical model for crawl-space temperatures and heat flows. Steady-state, periodic and step-response components. Carl-Eric Hagentoft, LTH/TVBH-3012, 1986, Dept. of Building Physics, Lund University..

2. Fukthandboken, tabell 4.2. L E Nevander, B Elmarsson, Svensk Byggtjänst, 1981.

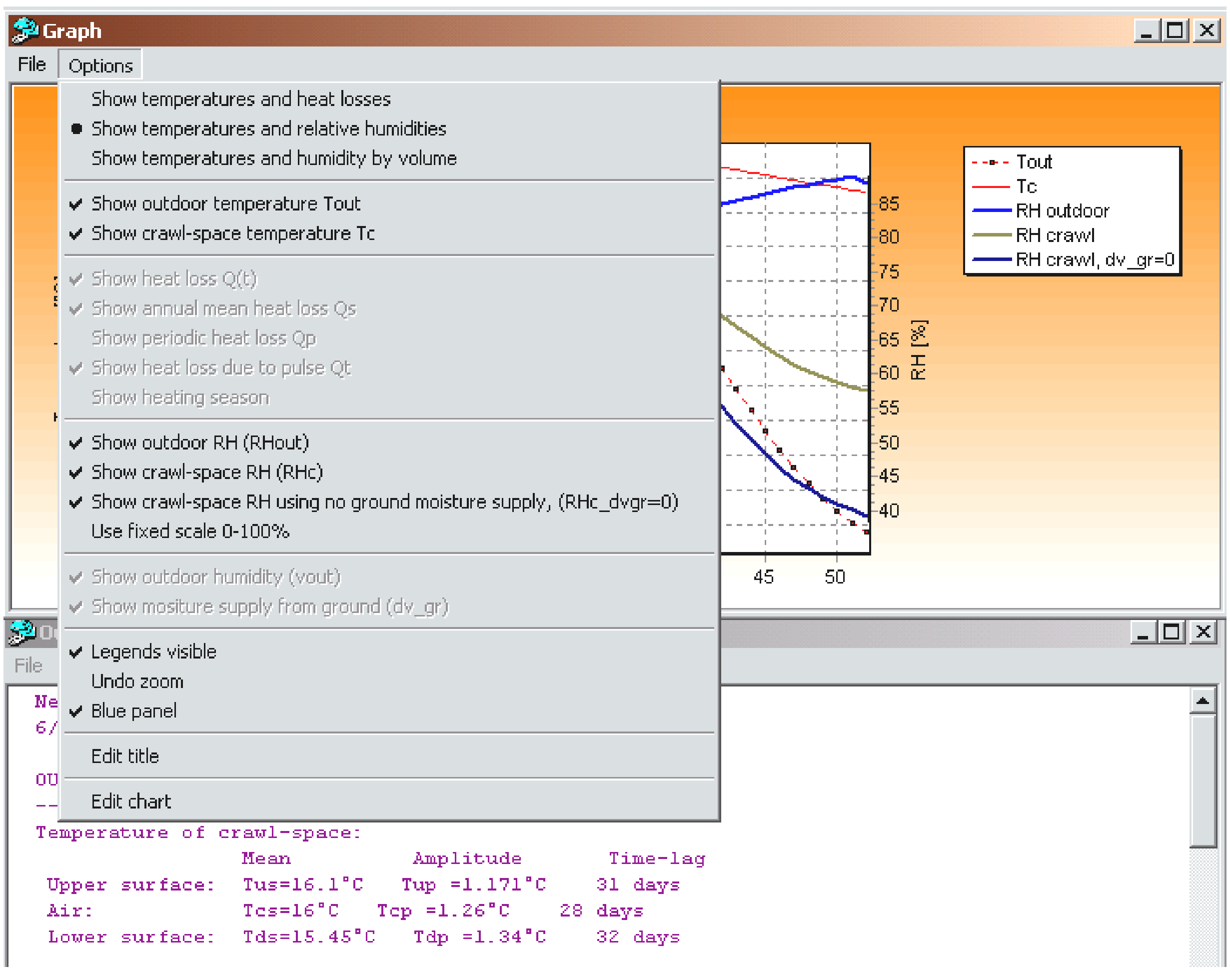

Figure 6: Sub-menu in the Graph window showing different options.

Appendix A. Changing the chart properties

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

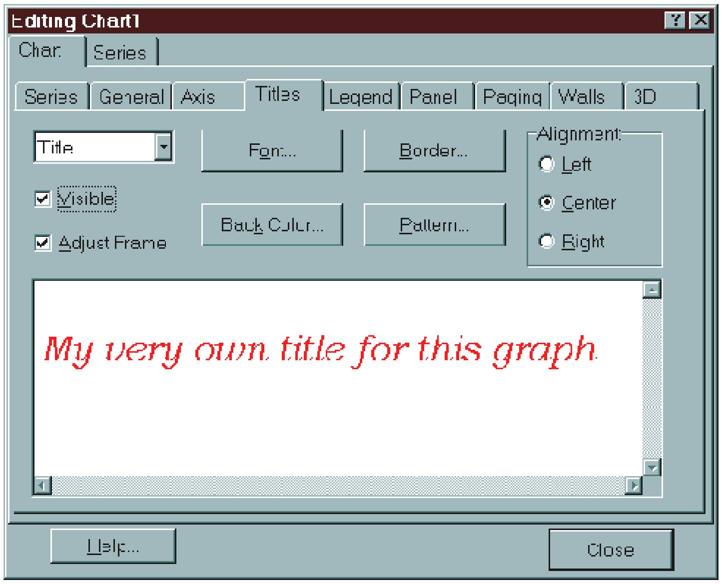

Figure A1: Chart settings may be changed in menu item Options/Edit chart.

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