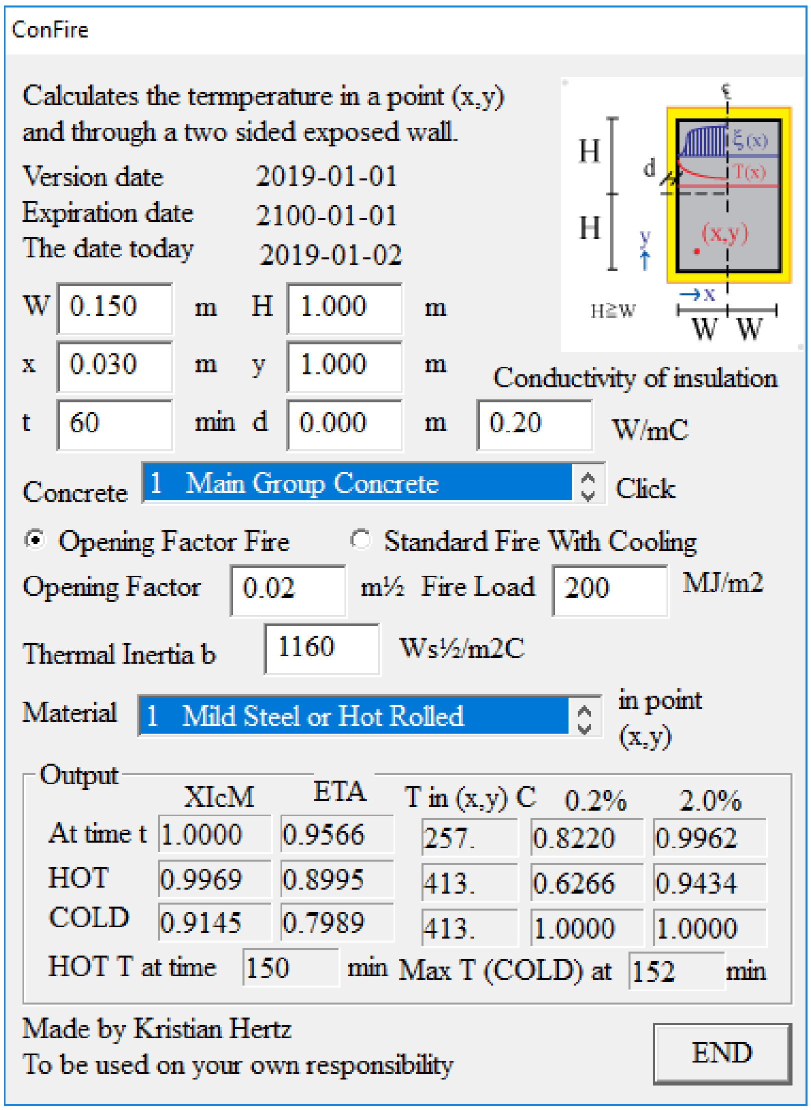
Users Guide for the program ConFire.exe

3. Edition

Kristian Hertz



Notice! It may take up to 30 seconds before the program starts.
You must click on a concrete in the box to choose it.
Do not press Enter after changing a value. This will stop the program.
Use always period " ." for decimals. For example 9.78 and not 9,78

Contents

Preface
The program ConFire designed to calculate temperatures and damages of the concrete in structures exposed to fully developed fires or standard fires.

This means that ConFire is applicable for a calculation of the load-bearing capacity of a reinforced concrete structure with any concrete and reinforcement at any time of any fire including standard fires and including insulated cross sections.
Design methods are provided in the textbook and design guide:

Hertz KD (2019) Design of Fire-resistant Concrete Structures.
ICE Publishing. Thomas Telford Ltd, London.

Responsibility
The user has the total responsibility for the application of the program and neither programmer nor distributing organisations can be held responsible for use or installation of the program.

What does the program do?

The program calculates the temperature in a point given by the coordinates (x,y) in a rectangular cross section of with 2W along the x-axis and 2H along the y-axis.
W must be smaller than H and x smaller than W and y smaller than H. If the section is large in the y-axis (a wall or a slab) H and y is assessed as 1.000 m. If the section is exposed to one side only, W is assessed as the section with (This is on the safe side for the temperature calculated, if the backside is not isolated). Likewise, the height is assessed as H if the top is not fire exposed. If x is entered negative, the temperatures are calculated in a concave corner for example on the reinforcement in the end of a slab over a wall. If d is entered larger than 0, the cross section is considered insulated by a material of thickness d and with a constant thermal conductivity, which must be entered.
The temperature in the point (x,y) is calculated at the time t of a fully developed fire given by the opening factor in $m^{½}$, the fire load in MJ/m^2 enclosing surface and the thermal inertia b in $Ws^{½}/m^2C$. Alternatively the temperature may be found for a standard fire of t minutes with a cooling phase. In addition, the maximum temperature (COLD) is found in the point. It is shown when this occurs within 10 hours. The HOT temperature is found at the time, when the maximum temperature occurs in a depth of 30 mm and the time when this takes place is found.
For these 3 temperatures the damage is found in the point (x,y) depending on the material in this point. It might be a reinforcing bar or -wire or it might be concrete. The material is chosen, and the reduction of the 0.2% strength is given and of the 2.0% strength. For concrete, these two are considered identical, but for steel large differences occur. You are only allowed to apply the 2.0% strength if you can document that the strain of the reinforcement is at least 2.0%.

Furthermore, the reduction is found pr cm through the cross section. This is done at the fixed time t. It is also done in the HOT condition, where the temperature is max in the depth 30 mm of a two sided exposed cross section of with 2W. Finally, it is done in the COLD condition, where the maximum temperatures have been reached throughout the cross section and where residual compressive strengths are applied.
In the HOT condition and at the fixed time, hot values are applied for the reductions. In points, where the maximum temperatures have been reached before the HOT-time or fixed time, these maximum temperatures are applied.
The reduction in the mid point ξ_{cM} is found, and the average values of the reductions are calculated, and the stress distribution factor η is found as the average value divided by ξ_{cM}.

Finally, data files with the ending .RES are written to the same folder, where the program is placed. These are ASCII files, and they may be opened for example with Notepad. Right click on a file. Click on Open with and Choose program on a list and press OK. Choose Notepad and mark Choose always the chosen program for this type of file.

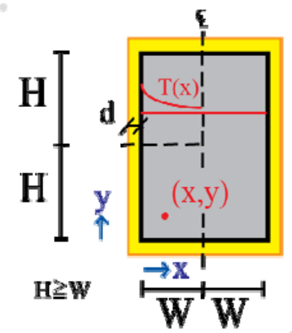
The additional data files contain:

CONTXY.RES The variation in time (minutes) of the temperature in the point (x,y)

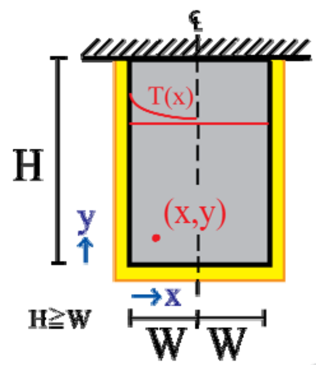
CONFIRE.RES The variation per cm across the half cross section W of the temperature and the reduction of the compressive strength at the fixed time t
in the HOT condition, where the temperature is max for x=30 mm
in the COLD condition due to maximum temperatures

The program has an expiration date. After this date, it must be renewed.

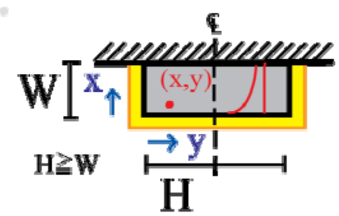
Geometrical data



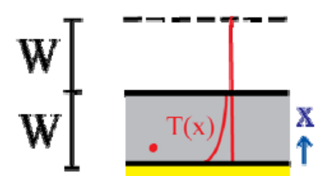
For a column exposed to fire at four sides, the smallest width is 2W and the height of the cross section is 2H. x is along W and y along H.



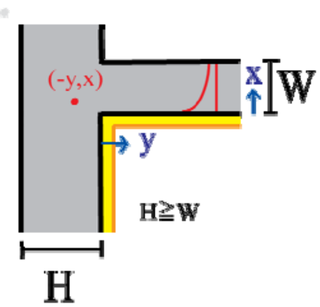
For a three-sided exposed beam where the height is larger than the half of the width, the height is H and the width is 2W. This is because the temperatures will be equal to those in a four-sided exposed cross section of the double height.



For a wide three-sided exposed beam, where the height is smaller than the half of the width, the height is W and x is along W, and the width is 2H and y is along H.



For a wall or a slab exposed to fire on one side the thickness is assessed as W. This implies that the backside or the top side is considered insulated, which may be slightly on the safe side. However, you seldom know how the backside or top can be changed during the lifetime of a building. For a slab is used H = 1 m and y = 1 m.



For a concave corner, you can approximately calculate a temperature for example in an anchorage zone by entering x or y as a negative value. Still x is along W and y along H, and H is the largest thickness of the slab or the wall.

Thermal inertia

$$b = \sqrt{\rho c_p \lambda} \quad \left[J/m^2 s^{1/2} K \right]$$

is assessed according to the average value of it at the surfaces.

If a surface has several layers the inner layer is usual most important. If large areas of concrete surface is insulated for example the slabs in a ceiling or walls in a compartment this should be taken into account. The following guide from (Hertz, 2006a) is given for assessment of b. Alternatively, equivalent values can be made of the opening factor in $m^{1/2}$ and the fire load in MJ/m^2 enclosed surface by multiplying both with the factor k_{eq}. (k_{eq} is from (Pettersson et al, 1976).

Type	description	k_{eq}	b $s^{1/2}/m^2K$
A	Standard Fire Compartment, Concrete, Brick, Light concrete	1.00	1160
B	Concrete	0.85	1365
C	Light aggregate concrete or areated concrete (500kg/m^3)	3.00	387
D	50% concrete + 50% light concrete	1.35	859
E	33% concrete + 50% light concrete + 17% light structure	1.65	773
F	20% concrete + 80% steel uninsulated	0.85	1365
G	20% concrete + 80% gypsum air gypsum(2*13+100+2*13 mm)	1.50	800
H	100 mm mineral wool with steel plate	3.00	387
I	Isolated concrete ceiling and light facade	2.07	560

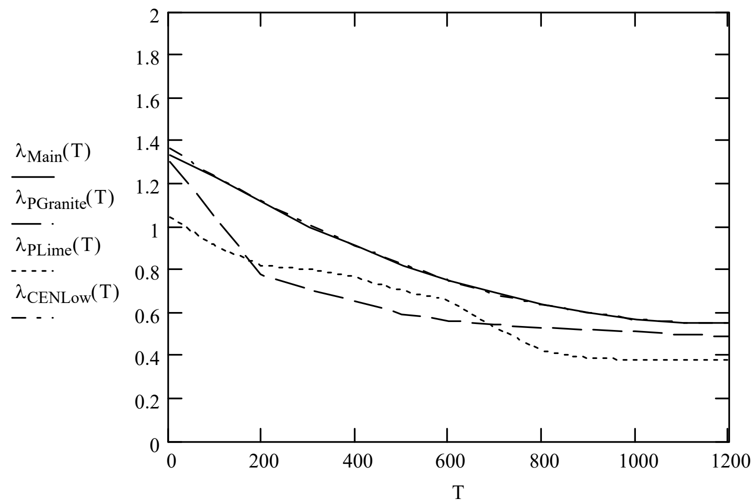
How does the program calculate?
The temperature distribution through a half double-sided exposed cross section is calculated by means of a finite difference method.
The calculation proceeds until the maximum temperatures are recorded in all lamellas or a maximum time of 10 hours = 600 minutes is reached. The temperatures are also recorded at the fixed time t and the temperature variation in time is recorded in the depth x. Furthermore, the maximum temperatures are recorded which have been obtained in each point through the width W until the time HOT where the temperature is maximum in the depth 30 mm from the surface.
The fire exposure is calculated by means of the author's expression from the Danish action code DS410 (DS, 1999):

$$T_g = 20 + \frac{150\ln\left(8\Gamma t + 1\right)}{1 + 0.04\left(\frac{t}{t_d}\right)^{3,5}} \quad \left[°C\right], \quad \text{where} \qquad \Gamma = \frac{\left(\frac{O}{b}\right)^2}{\left(\frac{0.04}{1160}\right)^2}, \quad t_d = 7.80*10^{-3}\frac{q}{O}\left[\min\right]$$

and b is the thermal inertia $b = \sqrt{\rho c_p \lambda} \quad \left[J/m^2 s^{½} K\right]$

Alternatively the standard fire is used. T_g= 20 + 150*ln(8t+1).
The total emissivity at the surface is assessed to be 0.7 and the convective contribution to the heat transfer at the surface 23 W/m^{2}C.
The same is calculated with respect to y and H, and two the set of results are combined by means of the recognized approximation (for example (Carslaw and Jaeger, 1959), which is also adopted by the Danish concrete code DS411 (DS1999b): T(x,y) = T(x) + T(y) – T(x)*T(y)/T(0) where the T is the temperature increase from the initial 20°C. Finally the maximum temperature and the HOT temperature is found in the point (x,y).
For a concave corner x or y is entered with a negative value, and the logical approximation will be T(x,y) = T(x)*T(y)/T(0) if T(0) was a constant surface temperature. However, T(0) is increasing before T(x) and T(y) increases, and in this period this approximation may be slightly on the unsafe side, where the corresponding approximation for the convex corners above is on the safe side.
The expression for concave corners is therefore modified in order to make it safer as T(x,y) = 4*T(x)*T(y)/((T(x)+T(0))*(T(y)+T(0)))

In the following chapters it is described, how the material properties are assessed.



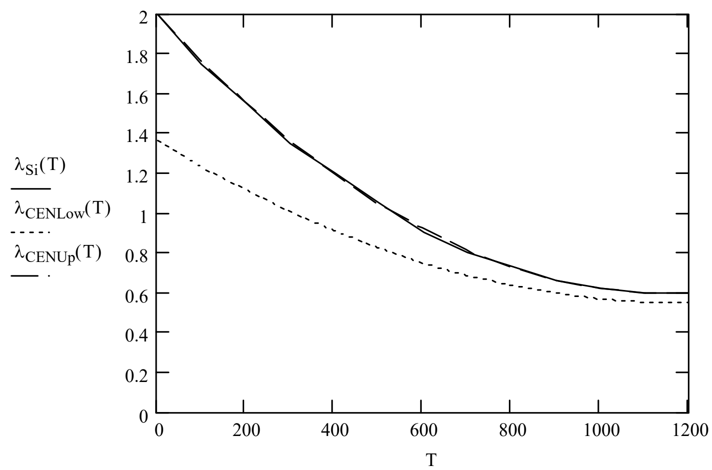
Conductiviy of Main Group Concrete curve ___ compared with measured curves for granite ---- and limestone .... and the lower limit curve -.-.-.-. from EN1992-1-2 (CEN,2006)

Conductivity

The conductivity of concrete varies considerably with the aggregates applied and with the temperature of the concrete. An analysis of a number of test series of these variations is given in (Hertz, 1981). In addition, values are provided by (Pettersson and Ödeen, 1978), (Anderberg and Pettersson, 1991).

The values for a typical Danish concrete is found in an advanced test series by (Østergaard, 1972), where the conductivity is calculated from temperature profiles measured in fire exposed slabs.
All of these measured variations have been considered as a basis for the choice of a common and slightly conservative curve for the main group concretes.

The choice is made identical to the lower limit curve from the CEN code (CEN,2006), and therefore it is in agreement with this. The main group comprise granite, limestone, Basalt, and sea- and land-gravel transported by the ice to Denmark from Scandinavian mountains.

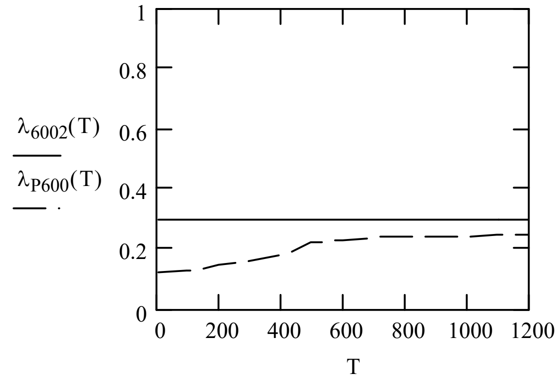


Conductivity for Siliceous concrete ____ and the upper ----- and lower limit .... curves from EN1992-1-2 (CEN,2006)

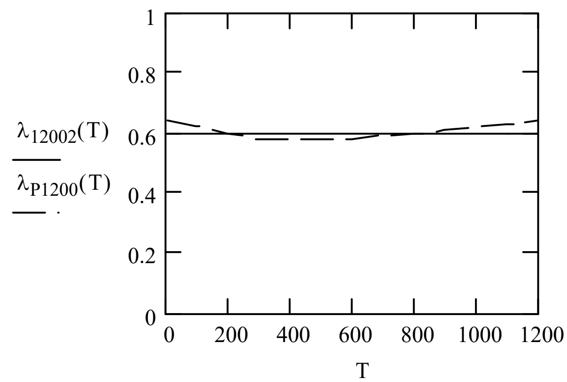
For Siliceous concrete, the upper limit curve from the CEN code is in a good agreement with the measured curves in the references mentioned, and it is therefore applied.

For light aggregate concrete the conductivity is more uniform in temperature, and as a simple approximation a constant value is chosen for it, which in the figure is compared with test results as found in (Pettersson and Ödeen, 1978) for the parameter.

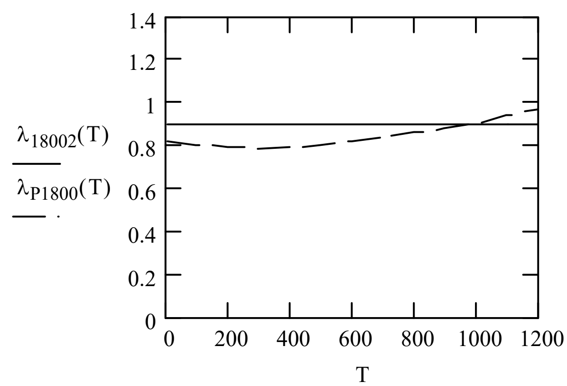
Variation for 600 kg/m^3



Variation for 1200 kg/m^3



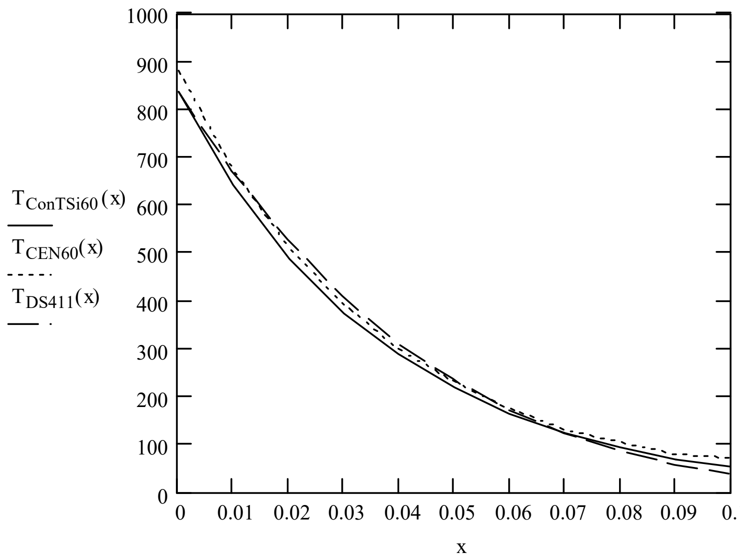
Variation for 1800 kg/m^3



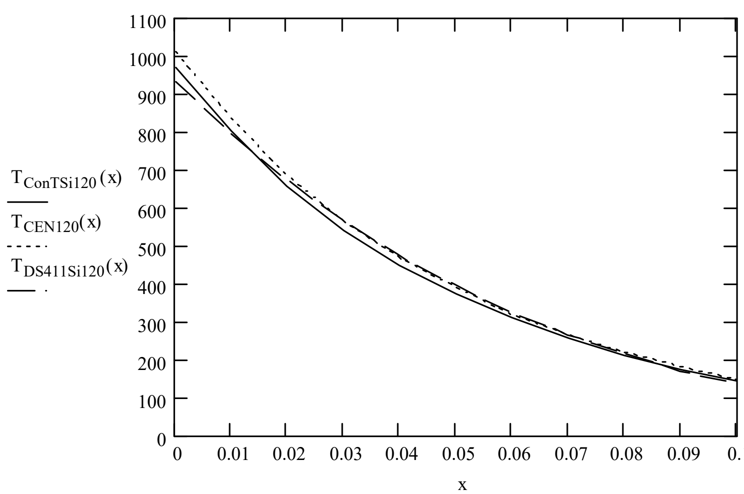
Heat Capacity
The specific heat capacity for dry main group concrete is according to (Hertz, 1981) between 1 and 1.1 kJ/kgºC, and slightly less 0.9 kJ/kgºC at 20ºC. According to (Wickström and Pålsson, 1999) it is 1.2 kJ/kgºC, and according to the Eurocode it ends at 1.1 kJ/kgºC above 400ºC, and starts at 0.9 kJ/kgºC at 20ºC.
The water in the concrete means, that the total heat capacity is larger at the beginning of a fire. The evaporation heat of the water means an increase of the total heat capacity by 5.65 kJ/kgºC at 100-120ºC according to (Wickström and Pålsson, 1999) for 5% Water, and 0.92kJ/kgºC at 100-115ºC and decreasing linearly until 200ºC for 3% water according to EN1992-1-2 (CEN, 2006). The very simple procedure by (Hertz, 1981) intended for a pocket size computer suggest to apply a constant value of 1.0 kJ/kgºC considering that the increased conductivity for which the water is responsible, transports the heat into the cross section necessary for its escape. Therefore, this simple method uses constant values for heat capacity as well as for conductivity.
In the present program, the conductivity varies and the heat capacity is increased. The increase according to (Wickström and Pålsson, 1999) is equal to 5.65*20 = 113 kJ/kg for 5% which is equal to 68,7 kJ/kg for 3 weight % water. The increase according to EN1992-1-2 (CEN, 2006) is 0.92*(15+85/2) = 52.9 kJ/kg for 3% water.
According to the physics (for example (Glent, 1970)), the evaporation heat of water at 100ºC is 2257 kJ/kg, from which you get 0.03*2257 = 67.7 kJ/kg for the evaporation heat of 3 weight percent moisture. For the heat capacity of the water you get 1.007 kJ/kgºC at 100ºC which means an increase of the heat capacity of the dry concrete by 0.02*1.007 = 0.03 kJ/kgºC from 20ºC to 120ºC equal to 3.0 kJ/kg in total.
From these considerations, the heat capacity of the dry concrete is assessed as **1.1 kJ/kgºC** and it is increased by (67.7+3.0)/100 – 0.2 = **0.51 kJ/kgºC** between 20º and 120º. The 0.2 is the difference between the constant 1.1 and the real value of 0.9 at these small temperatures for the concrete.

The same values of the specific heat capacity may apply for the different qualities of light aggregate concrete (For example (Pettersson and Ödeen, 1978)).

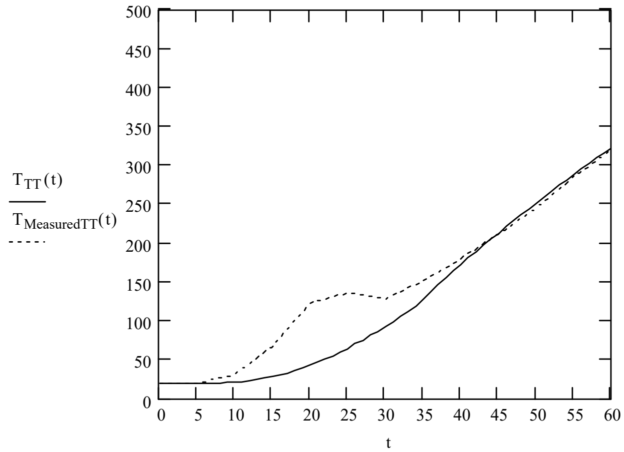
Comparisons with full-scale tests



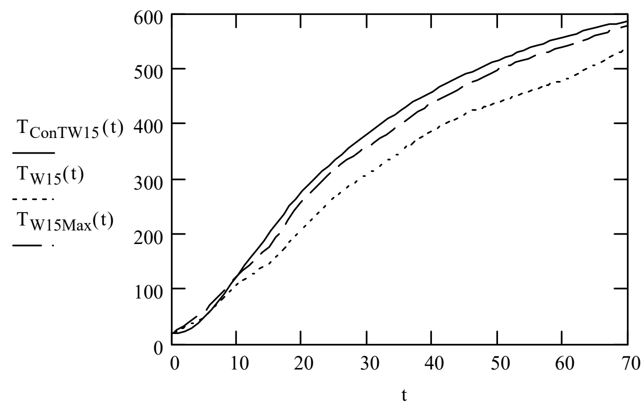
Comparation between ConTemp ___ and values from the Eurocode EN1992-1-2 (CEN, 2006)..... which is based on measurements and the simpified calculations from the Danish code DS411 (DS, 1999b) for temperatures in a slab of siliceous concrete after 60 minutes standard fire exposure. The thermal diffusivity in DS411is assessed as $520*10^{-9} m^2/s$.



Comparation between ConTemp ___ and values from the Eurocode EN1992-1-2 (CEN, 2006) ..... which is based on measurements and the simpified calculations from the Danish code DS411 (DS, 1999b) for temperatures in a slab of siliceous concrete after 120 minutes standard fire exposure. The thermal diffusivity in DS411 is assessed as $520*10^{-9} m^2/s$.



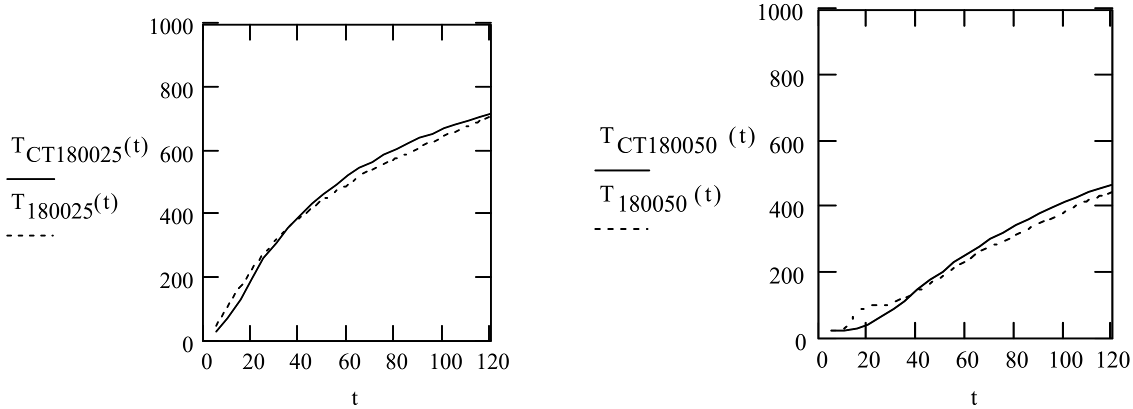
Comparison between measured .... and calculated ____ temperatures
at the prestressing reinforcement at the centre line of a 100 mm web of a
TT beam made of Main Group concrete.



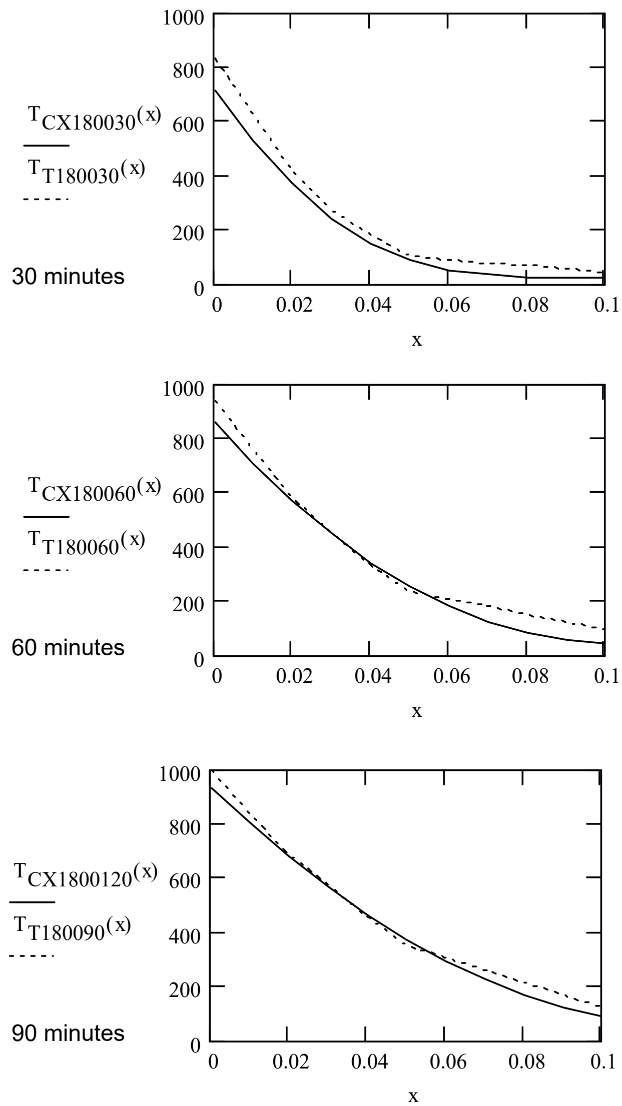
Comparison between measured .... and --- and calculated ____ temperatures
at the depth 15 mm of the reinforcement in a 1500 mm wall of Main Group concrete.
Notice the large difference between the temperatures at the two sets of thermocouples.
From (Andersen and Lauridsen, 1999).

The author has made a series of full-scale tests for the Danish industry as documentation for calculation procedures and data for standard fire exposed light aggregate concrete structures (Hertz, 2002). A number of temperature measurements are taken from these tests in order to document the present calculation procedure.

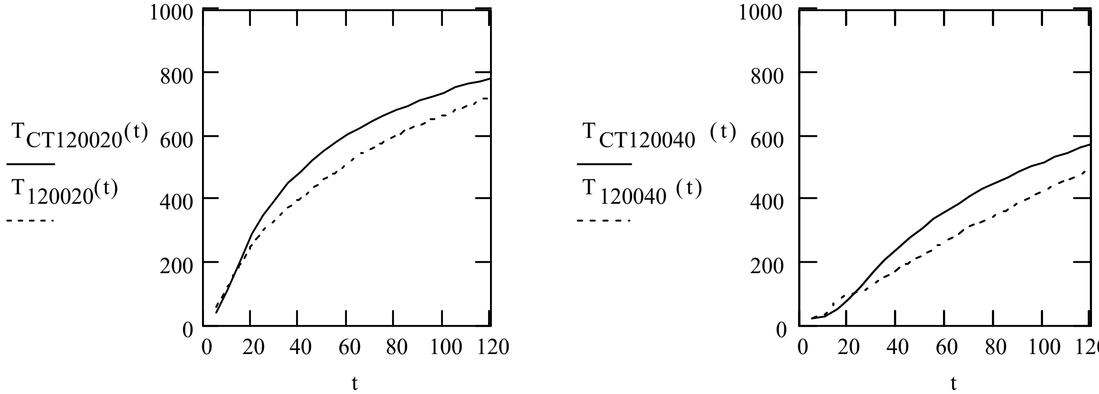
For Light aggregate concrete of density 1800, 1200 and 600 kg/m^3 the following agreements are found.



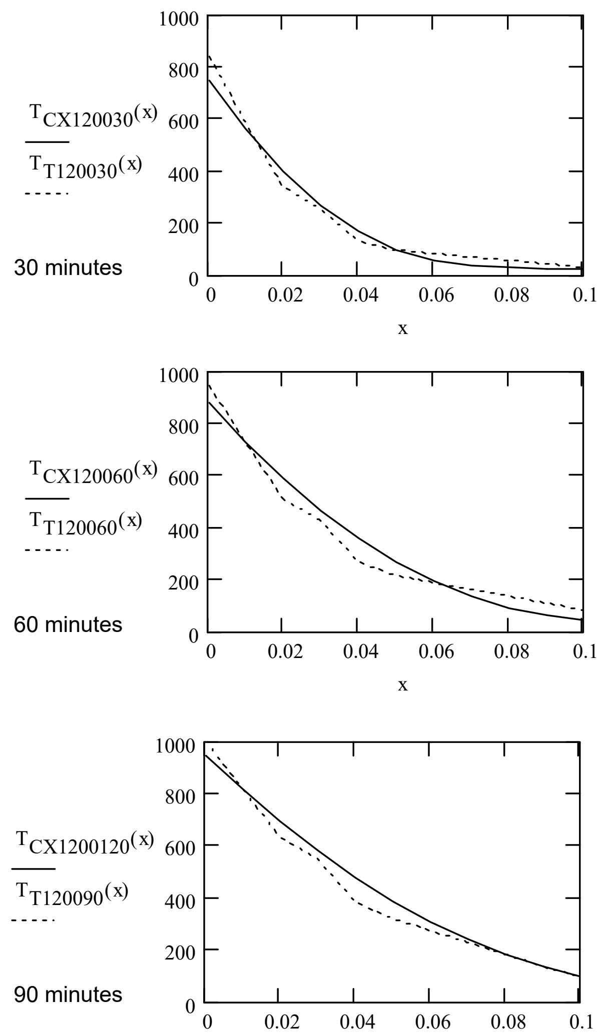
Comparison between ConTemp ___ and Full-Scale Tests ….. for the temperature variation in the depth 25 mm and 50 mm of a 100 mm wall of 1800 kg/m^3 Light Aggregate concrete exposed to standard fire.



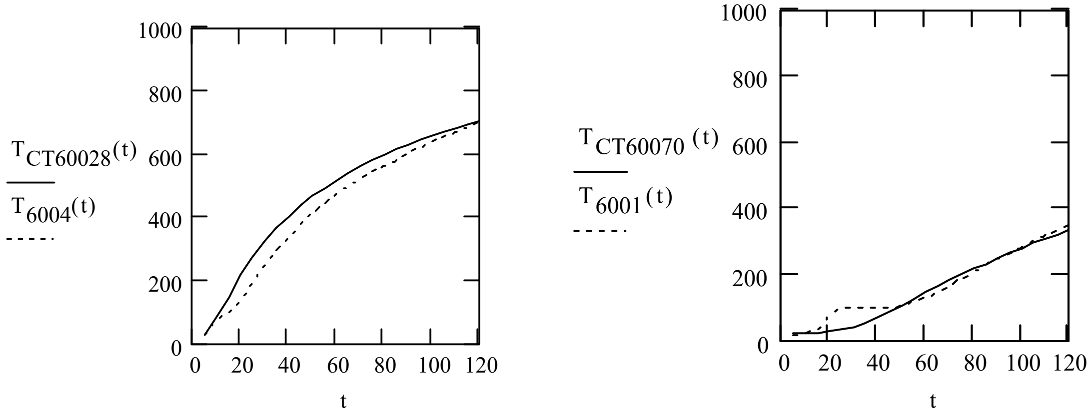
Temperature profiles for 1800 wall at 30, 60 and 90 minutes calculated ___ by ConTemp and measured at test ----.



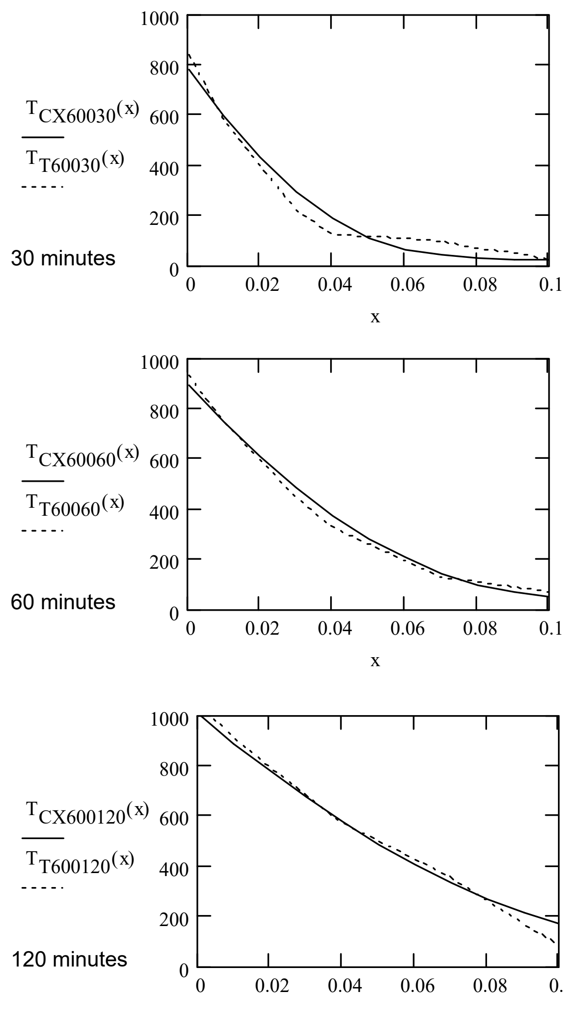
Comparison between ConTemp ___ and Full-Scale Tests ….. for the temperature variation in the depth 20 mm and 40 mm of a 100 mm wall of 1200 kg/m^3 Light Aggregate concrete exposed to standard fire.



Temperature profiles
for 1200 wall
at 30, 60 and 90 minutes
calculated ___ by ConTemp
and measured at test -----.



Comparison between ConTemp ___ and Full-Scale Tests ….. for the temperature variation in the depth 28 mm and 70 mm of a 100 mm wall of 600 kg/m^3 Light Aggregate concrete blocks exposed to standard fire.



Temperature profiles
for 600 wall
at 30, 60 and 120 minutes
calculated ___ by ConTemp
and measured at test -----.

Comparisons with FEM Calculations
An early program ConTemp is included as a part of the ConFire program. The maximum temperatures from ConTemp is compared with maximum temperatures calculated for fully developed fires by the finite element program TASEF-2 (Wickström, 1979) and (Pettersson and Ödeen, 1978) for a Main Group concrete. However, the values are calculated using a lower curve for the thermal conductivity like the one shown for granite concrete in the chapter on material properties.
A special version is therefore made of the ConTemp program with these values for the Main Group concrete, and the results of this program is called ConTemp Low. As you can se maximum temperatures from the two programs are in a fairly good agreement, except perhaps for the extreme fire of 0.12 $m^{½}$ 1200 MJ/m^2.

O=0.04 $m^{½}$, q = 400 MJ/m^2, W = 0.10 m = half with of the cross section.

x cm		2	4	6
TASEF-2		605	455	410
ConTemp	Low	602	437	373
ConTemp		621	484	434

O=0.02 $m^{½}$, q = 200 MJ/m^2, W = 0.08 m = half with of the cross section.

x cm		2	4	6
TASEF-2		495	425	410
ConTemp	Low	495	424	413
ConTemp		530	477	470

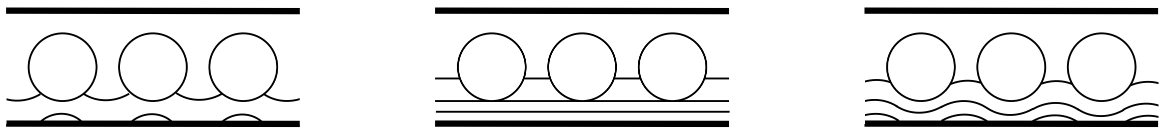
O=0.02 $m^{½}$, q = 200 MJ/m^2, W = 0.30 m = half with of the cross section.

x cm		2	4	6
TASEF-2		470	340	260
ConTemp	Low	464	326	238
ConTemp		483	356	273

O=0.12 $m^{½}$, q = 1200 MJ/m^2, W = 0.10 m = half with of the cross section.

x cm		2	4	6
TASEF-2		730	530	465
ConTemp	Low	813	583	487
ConTemp		823	629	555

In addition, the results of the ConTemp calculations show how the difference in conductivity influences the temperatures. If this is compared to the dispersion of the material properties obtained by different tests of the same group of concrete, you understand the need for using a conservative curve like the lower limit curve from EN1992-1-2 (CEN, 2006), which is used in ConTemp in order to make it generally applicable.
Another reason for the differences is, that the Swedish calculations presumes a water content of 5% by weight, where ConTemp presumes 3% by weight as may be expected for indoor structures.



Isotherms in principle in hollow core slabs exposed to standard fire

Approximation for hollow core slabs

When a hollow core slab is exposed to a fire, the holes are initially acting as a hindrance to the transport of heat into the cross section, because they are filled with air. The temperature therefore increases more in the bottom of a hollow core slab at the beginning of a fire than it does in the bottom of a massive slab, and the highest temperatures are found under the holes. This is the situation after 30 minutes of a standard fire as shown in principle by the isotherms on the figure above.

Later in the fire the temperature at the inside surface at the bottom of a hole increases, and the thermal radiation from this surface increases proportional to the temperature in K in the power of four. This means that the holes are transporting heat from the bottom to the upper zones of the slab in the later parts of a fire exposure. The bottom is therefore cooled more than the bottom of a massive slab. This is the situation at 90 minutes of a standard fire and later, and as shown the curvatures of the isotherms are now opposite the curvatures at 30 minutes. (Schiermacher and Poulsen, 1987) and (Meaouia, 2002).

In between the two times, at 60 minutes the isotherms will be almost straight lines.

If the task is to calculate temperatures in the bottom of a hollow core slab for example at the reinforcement after 60 minutes standard fire, you may just as well calculate this for a massive slab.

If the task is to calculate temperatures in the bottom zone after 60 minutes standard fire, it is seen to be on the safe side to calculate these temperatures for a massive slab. However, if the task is to calculate the temperatures later, you may risk that the temperatures exceed 500C in most of the flange under a hole. This occurs usually from 90 min Standard fire, and then the concrete is totally cut by cracks, and you cannot presume that the cross-section remains in place. Instead, you have to calculate the temperatures of the prestressing wires by means of a 3-sided exposed cross section, where the bottom flanges under the holes are fallen down.

If more precise temperatures for some reason should be applied, a finite element or a finite difference method may be used, but still concrete of temperatures above 500°C cannot be considered as remaining in place.

A comparison between a finite element calculation and Contemp is shown below Temperatures in the depth 30 mm of a 265 mm thick hollow core slab of siliceous concrete (Anderberg, 1992)

	60 min St	90 min St
FEM	380	500
ConTem	373	471

Strength reductions

The strength reductions are calculated by means of the same subroutine, which is applied for the program Damage. The reductions are found by means of the formula

$$\xi(T) = k + \frac{1-k}{1+\frac{T}{T_1}+\left(\frac{T}{T_2}\right)^2+\left(\frac{T}{T_8}\right)^8+\left(\frac{T}{T_{64}}\right)^{64}}$$

and the data presented and discussed for concrete and reinforcement in the papers (Hertz, 2004), (Hertz, 2005) and (Hertz,2006b).

	k	T_1	T_2	T_8	T_{64}
Hot rolled bars 0.2 % stress	0.00	6000	620	565	1100
Hot rolled bars 2.0 % stress	0.00	100000	100000	593	100000
Hot rolled bars 0.2 % residual stress	1.00	100000	100000	100000	100000
Hot rolled bars 2.0 % residual stress	1.00	100000	100000	100000	100000
Cold worked bars 0.2 % stress	0.00	100000	900	555	100000
Cold worked bars 2.0 % stress	0.00	100000	5000	560	100000
Cold worked bars 0.2 % residual stress	0.58	100000	5000	590	730
Cold worked bars 2.0 % residual stress	0.52	100000	1500	580	650
C-w prestressing steel 0.2 % stress	0.00	2000	360	430	100000
C-w prestressing steel 2.0 % stress	0.00	100000	490	450	100000
C-w prestressing steel 0.2 % residual stress	0.20	100000	750	550	650
C-w prestressing steel 2.0 % residual stress	0.20	100000	950	550	650
Quenched and Tempered 1500 MPa 0.2% stress	0.00	1100	100000	430	100000
Quenched and Tempered 1500 MPa 2.0% stress	0.00	3000	1400	450	100000
Quenched and Temp 1500 MPa 0.2% res stress	0.213	100000	10000	590	660
Quenched and Temp 1500 MPa 2.0% resstress	0.213	100000	10000	590	660
Quenched and Self-temp 550 MPa 0.2% stress	0.00	100000	1150	540	700
Quenched and Self-temp 550 MPa 2.0% stress	0.00	100000	100000	590	700
Quenched and Self-temp 550 MPa 0.2% res stress	0.418	100000	100000	700	900
Quenched and Self-temp 550 MPa 2.0% resstress	0.437	100000	100000	700	900
Siliceous concrete HOT	0.00	15000	800	570	100000
Siliceous concrete COLD	0.00	3500	600	480	680
Main group concrete HOT	0.00	100000	1080	690	1000
Main group concrete COLD	0.00	10000	780	490	100000
Light aggregate concrete HOT	0.00	100000	1100	800	940
Light aggregate concrete COLD	0.00	40000	650	830	930

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