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An APPLIED NOMOGRAPH FOR THERMAL LOAD READINGS

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ABSTRACT

This study uses the thermal time constant to determine the thermal load of different building materials. A nomograph is developed to read the heating and the cooling loads at any latitude. The vertical axes and the zeros points are defined according to the thermal time constant of materials.
The study introduces a very easy manner for obtaining the thermal load in walls. It is applied for both lat. 30° 8' and lat. 51° 7' and is in a good agreement with the calculated results.

1.THE APPLICATION OF A NOMOGRAPH FOR LOAD READINGS

The applying of load on a nomogragh was carried on. It is done that to read the peak load/m^2 for the considered building materials, it is needed to know the wall thermal time constant t_c and the internal wall temperature which is calculated also by thermal time constant method [1]..

The followed steps are :

1- Calculate the cooling load for the two chosen oriented walls by the modefied t_c method [2] or by using ASHRAE [3] or by any other method [4]. The calculation was chosen to be by ASHRAE [3] method. The calculation is carried on for four different building materials which are :

a. Concrete of 10.5 cm thickness with 2 cm plaster on both sides (con.). It is classified in
group E in ASHRAE Table.

b. Concrete of 10.5 cm thickness + air gap 10 cm + insulation 6 cm + timber 5 mm + 2 cm plaster, on both sides (con.+a.g+in.). It is classified in group D in ASHRAE Table.

c. Sand brick of 25 cm thickness with 2 cm plaster on both sides (s.b). It is not classified in ASHRAE Table.

d. Lime stone of 40 cm thickness (l.s). It is not classified in ASHRAE Table.

The ASHRAE method [3] gives the cooling load calculation using the following equation :

$$Q_{L,t} = U_w A_w (CLTD)_{,t}$$

where CLTD is the cooling load temperature difference °C and given in ASHRAE [3] Tables, t is refered to the time in hours. The CLTD is obtained from ASHRAE Tables, by 19 °C, 27 °C at south and west of concrete - group E - respectively, at lat 32, and by 16 °C and 23 °C for (con.+ a.g.+in.) - group D- for the same previously described conditions.

The lat - month (LM) corrections according to ASHRAE [3] were - after interapolation - 1.8,0 for S and W at Lat 30 8 and 2.9,0.78 for S and W at Lat. 51 7. Applying the eqn. of CLTD by correction from ASHRAE [3] :

$$CLTD_{corr} = (CLTD+LM) *k + (T_{ei}-TR) + (T_o-T_{mean})$$

Where LM is the latitude - month correction [3] K is the colour adjustment factor which is given in[3] by 1 for dark, 0.83 for medium and 0.65 for light for the chosen concrete T_{ei} is the comfort temperature which is 25 °C, T_o the is average daily temperature and is given as : the maximum of the outdoor at the chosen month (July) 34.4 °C for Cairo, 25.5 °C for London. This $T_{o,max}$ is multiplied by the design outdoor correction which is 97.5%, then $T_{o,max,corr}$ for Cairo = 34.4 x 0.975 = 33.54 °C

$T_{o,max,corr}$ for 51 7 = 25.5 x 0.975 = 24.86 °C

T_{mean} is the mean sol - air temperature.

T_R is the indoor design temperature.

Where the daily range for Cairo at July was 11.1 °C, for lat 51° 7' was 13 °C (I.H.V.E) Guide[4]

Then T_{avg} (Cairo ,lat 30° 8') = 33.54-0.5 x (11.1) = 27.94 °C

T_{avg} (London,lat 51° 7') = 24.86-0 .5x (13) = 18.36 °C

Then T_{mean} for Cairo was 28.65 °C (July)

T_{mean} for lat. 51° 7' was 15 °C (July) (I.H.V.E) (5)

Then applying the eqn. for $CLTD_{corr}$

$CLTD_{corr}$ (Cairo,S) =(19-1.8) x 0.65 + (25.5-25) + (27.94 - 28.65)

$= 17.2 \times 0.65 + 0.5 - 0.7 = 11.18 - 0.2 = 10.98\ ^{o}C$

$CLTD_{corr}$ (Cairo,W)=(27+0) x 0.65 +0.5 - 0.7 =17.35 ^{o}C

For lat. 51° 7\ Tcomfort is chosen to be 19.5 °C as it varied between 18 °C to 22 °C at this region.

$CLTD_{corr}$(51° 7\,W) = (27+0.76) x 0.65 + (19.5 -19) - (18.3-19) = 17.8 °C

Then the cooling load Q_{wl}=A U $CLTD_{corr}$

Q_{wl},Assumed A=1m^2, U= 3.05 W/m^2 °C (concrete) then :

$Q_{wl,peak}$ (Cairo,S) = 1x 3.05 x10.98=33.5 W

$Q_{wl,peak}$ (Cairo,W)=1 x 3.05 x 17.35 =52.9 W

$Q_{wl,peak}$(51° 7\,S) = 1 x 3.05 x 14 = 42.7 W

$Q_{wl,peak}$ (51° 7\, W) = 1x 3.05 x 17.8 = 54.3 W

For group D (con + a.g. +in) :

$CLTD_{corr}$ (Cairo ,S) = (16-1.8) x 0.65 + 0.5 -0.7 =14.7 °C

$CLTD_{corr}$ (51° 7\,W) = (23 + 0.76) x 0.65 +(19.5-19) +18.3 -19)=15.2 °C

Assumed A=1m^2 U=0.16 W/m^2 °C (calculated) then:

$Q_{wl,peak}$(Cairo,S)=1 x 0.16 x 9 = 1.44 W

$Q_{wl,peak}$ (Cairo,W) = 1 x 0.16 x 14.75 = 2.36 W

$Q_{wl,peak}$(51° 7\, S) = 1 0.16 x 12.1 = 1.94 W

$Q_{wl,peak}$ (51° 7\, W) = 1 x 0.16 x 15.2 = 2.4 W

Fig.(1) shows the peak load for a wall of 6.6m^2 area of different thermal time constant at souith and west orientations in Cairo.

2- Draw the horizontal axis X-axis to represent the internal wall temperature and divided it equally and draw vertical lines from those divisions upward to the end of the paper So. they are similar to those of the pyschromateric chart and the pyschromatricchart can be used to represent the above division lines , and to read thermal load.

3- Draw the vertical axix Y-axis to represent the thermal load.

4- Draw another Y2-axison the right side to use it for the thermal time constant , t_c values determination, see Fig. (2).

5- Define the zero on the Y1-axis; it is known that the t_c decreases the internal wall temperature increases, so when t_c=0 internal wall temperature becomes equal the outside wall temperature i.e T_{wi} = T_{wo} , the cooling load increases , where as T_{wo} = $T_{sol\text{-}air}$ at t_c=0, the t_c increses, the T_{wi} decreases than T_{wo} or the $T_{sol\text{-}air}$ it can be taken T_{wi} as a ratio of the assumption of T_{wi} = T_{wo} at t_c= 0 i.e.

T_{wi} (for $t_c > 0$) = c(t_c) T_{wi} (for t_c=0)

It is shown from the obtained results that T_{wi} reaches 33.9 °C for south at t_c= 15.1 hours , and 39.9 °C for west at the same t_c.

Then $T_{wo,max}$ reaches 43.8°C , 57 °C for south and west respectively,
as t_c=0 $T_{sol\text{-}air} = T_{wi}$ then:
$C(t_c) = T_{wo}/T_{sol\text{-}air}(T_{wi}) = 1$, so we define this slop for t_c at Y1-X other slopes for $t_c > 0$ relative to the slop of t_c.

For south at t_c=15.1 hours:
$C(t_c) = T_{wi}$ (t_c=15.1, hours) /T_{wi} (t_c=0,hours)=33.7/43.8=0.77
For west $C(t_c)$ =39.9/57=0.7
It is calculated the $T_{wi,max}$ for London at 51° 7\

$T_{wi,max}$ =27.1 oC for south and be 31.8 oC for west.
It is seen from I.H.V.E.[4] Guide:
$T_{sol\text{-}air,max}$ = 49.2 °C for south, 56°C for west for dark colors at both.
$C(t_c)$ at lat 51° 7\(S) = 27.1/49.2=0.55
$C(t_c)$ at lat 51°7\ (W) = 31.8/56=0.56
Take the averege of the $T_{wi,max}$ and the $T_{wo,max}$ or the $T_{sol\text{-}air,max}$ for the four orientation as:

$T_{wi,max}$

N	E	S	W
33.7	37.7	33.7	39.8

$T_{wi,avg}$=36°C

$T_{sol\text{-}air,max}$

N	E	S	W
40.5	50.5	43.8	57

$T_{sol\text{-}air,avg}$=48°C

$C(t_c)_{avg}$ for Cairo lat 30° 8\ =36/48= 0.75

For lat 51° 7\

$T_{wi,max}$(investigated)

N	E	S	W
26.4	30.2	27.1	31.8

$T_{wi,avg}$ = 28.8°C

$T_{sol\text{-}air,max}$(I.H.V.E)

N	E	S	W
30.5	48.0	49.6	56

$T_{sol\text{-}air,avg}$=45.9°C

$C(t_c)_{avg}$ for (51° 7\) =28.8/45.9 =0.63

It is shown that the $C(t_c)_{avg}$ for concrete (t_c=15.1) for Cairo at lat (30° 8\ )=0.75, the comfort temperature for Cairo 25°C then, a line was drawn with slop 0.75 from T=25°C on the dry -bulb X-axis to the Y1 left axis (representing load), and that is zero on this Y1-axis.

6- Devide this scale , taking the internal temperature for S wall as example for Cairo which is 33.9°C on the X-axis (dry-bulb) temperature) and plotting from this line a parallel lineto the sloped Y1-axis; this parallel line intercepts the Y1-axis in points. Devide the distance between the load value and the zero equally distances to know the drawing scale and complete the visions of Y1- by the same scale.

7- Divide the parallel line to Y1-axis to read t_c values until 33 hours by taking another t_c and let it be for sand brick which its t_c=23 hours .

For sand brick (t_c=23 hours)

$T_{wi,max}$ °C(calculated)

N	E	S	W
32	35.2	33	37

$T_{wi,avg}$=34.3°C

$T_{wo,max}$ °C(calculated)

N	E	S	W
41	58.8	45.2	58.5

$T_{wo,avg}$=51.1°C

$C(t_c)_{avg}$ for Cairo for lat. 51° 7\ by multiplying $T_{wi,max}$ at 30° 8\ by 0.8 (by their values of the sol-air temperature as will be shown in another study) then:

$T_{wi,max}$ °C (lat. 51° 7\(sand brick))

N	E	S	W
25.6	28.2	26.4	29.6

$T_{wi,avg}$=27.5 °C , $T_{sol-air,avg}$=45.9°C (as shown previously in step 5)

$C(t_c)_{avg}$ at 51° 7\ (sand brick) = 27.5/45.9 = 0.6

For limestone in Cairo 30° 8\

$T_{wi,max}$ °C(calculated)

N	E	S	W
30.5	33.5	31.1	34.2

$T_{wi,avg}$ = 32.3 °C

$T_{wo,max}$ °C (calculated)

N	E	S	W
38.8	53.3	40.3	54.5

$T_{wo,avg}$=46.8 °C

$C(t_c)_{avg}$ for limestone (Cairo 30 8) =32.3/46.8 =0.69

Investigate $T_{wi,max}$ for 51° 7\ as before:

$T_{wi,max}$ °C

N	E	S	W
24.4	26.6	24.9	27.4

$T_{wi,avg}$ = 45.9 = 0.58

For (con. + a.g.+in.) in Cairo 30° 8\

$T_{wi,max}$ °C(calculated)

N	E	S	W
30.3	31.2	30.9	32.1

$T_{wi,avg}$ = 31.1 °C

$T_{wo,max}$ (calculated)

N	E	S	W
41	59	45.3	59.5

$T_{wo,avg}$ = 51.2 °C

$C(t_c)_{avg}$ = 31.1/51.2 = 0.61

For lat 51° 7\ (investigated)

$T_{wi,max}$

N	E	S	W
24.4	25	24.7	25.7

$T_{wi,avg}$ = 25°C

$C(t_c)_{avg}$ for (con.+a.g. +in) lat 51° 7\ = 25/45.9 = 0.54

Draw a line for sand brick with the slop of 0.67 from the zero on Y1-axis to the vertical line representing comfort temperature (25°C) and at this intercept with line of 25°C .Draw a line parallel to X-axis and intercept Y2-axis (or a parallel to it) to represent t_c=23 hours. Divide the distance between t_c=15.1 hours(concrete) and t_c=23 hours(sand brick) to identify the scale and divide the Y2-axis until t_c=33 hours ; because the behavior of materials for t_c=33 hours is different and they need another chart for load readings. Read the load for $T_{wi,max}$ and find the peak load and compare it by that calculated in Fig. (1).

8- Repeat the steps 7,8 on another paper for t_c's materials of t_c> 33 hours and take the limestone and the (con.+a.g.+ in) as a reference instead of the concrete and sand brick studied in the previous steps.

9- To draw the load for any materials at any internal temperature, define this internal temperature on the horizontal line representing t_c material value and draw a line from this internal temperature parallel to the line joining the zero and the 25 °C on this horizontal t_c line, and the intercept at the Y1-0 axis will be the value of peak cooling load at this temperature (as shown in Fig.(1) for this t_c materials).

10- Repeat the steps 5,6,7,8,9 for lat. 51° 7\ as shown in Fig.(3) but by changing the comfort temperature to be 19.5 °C instead of 25 °C for lat. 30° 8\.

11- The load can be identified for lat 51° 7\ from that drawn for 30° 8\ by putting a transparent drawn for lat 30° 8\ on the nomograph chart and standing the point of 25 °C on the nomograph chart and from the chosen internal temperature draw a line parallel to the chosen internal temperature ; draw a line parallel to the 0-25 (on the transparent) and allocate the load from the intercept with Y1-axis . It is worth noting that this is typical to that drawn for lat 51° 7\. This can be done for any latitude.

12- repeat the same steps 5 to 11 for the heating load and divide the scale under zero on the Y1- axis and read the heating load from it. For example in Cairo (30° 8\) at January and lat 51° 7° in January , also it is found:

$T_{wo,max}$

N E S W

22.5 28.5 41.6 38.6

T_{avg}=32.8 °C

For lat 51° 7\ in March

	$T_{sol-air,max}$		
N	E	S	W
8.4	12	16.1	12

$T_{sol-air,\ avg.}$=12.1 °C

Then $T_{wi,avg}$ for Cairo30° 8\ in January:

$T_{wi,avg}$ = $T_{wo,avg}$ January / $T_{wo,avg}$ July) x $T_{wi,avg}$ July

= 32.8 x 36 /48 (concrete) = 24.4 °C,

Then C(t)=24.4/32.8 = 0.73

So,it is nearly equal to $C(t)_{avg.}$ in July which is 0.75 (as shown previousely) in 5) So, one could utilite the same slop of July for January.

To get $T_{wi,avg}$ for lat 51° 7\, $T_{wi,max}$ can be calculated for every orientation as given in step 7 and then take the average to get the $T_{wi,avg}$ and get the ratio of $C(t)_{avg}$ for March It is about 0.64; it is nearly equal to that got for July which is 0.63. The ratio or the slop of line (0-19) which is used for July could be represented for March.

From the calculated data, it is noticed that the heating load for E ,W for two internal temperature 21°C , 22.8°C were 53 W, 37 W for $T_{comfort}$ 25.5°C.

for lat 51° 7 \ for $T_{comfort}$ =19.4 °C

Heating load at E = ($T_{comfort}$ lat 30° 8\/ $T_{comfort}$ lat 51° 7\) x load at lat. 30° 8\

= 25x 53/19.4 = 66.3 W and

at W=25 x 37 /19.4 = 45.2 W

It can be investigated the maximum internal wall temperature for lat. 51° 7\ at which the heating load is calculated lastly by:

$T_{wi,max}$ = $T_{sol-air,max}$(E) lat 51° 7\ x $T_{wi,max}$ (E) lat 30° 8\ / $T_{sol\ air,max}$ (E) lat 30° 8\

Then, at E $T_{wi,max}$ = 12 x 21/28.5 = 8.8 °C and

at W $T_{wi,max}$ =12 x 22.8 /38.6 = 7 °C

Then draw the lines to 0-25 and define the points of t_c on Y1-axis for the heating load values and divide the scale under zero and go on the previous handling steps.

2.CONCLUSION

A nomograph is developing to read the cooling and heating load for any latitude . This is done for light and heavy building materials , based on defined values of the thermal time constant of the materials. The thermal load at any latitude can be given by a reference nomograph for Cairo $30^{o}\ 8^{\backslash}$.

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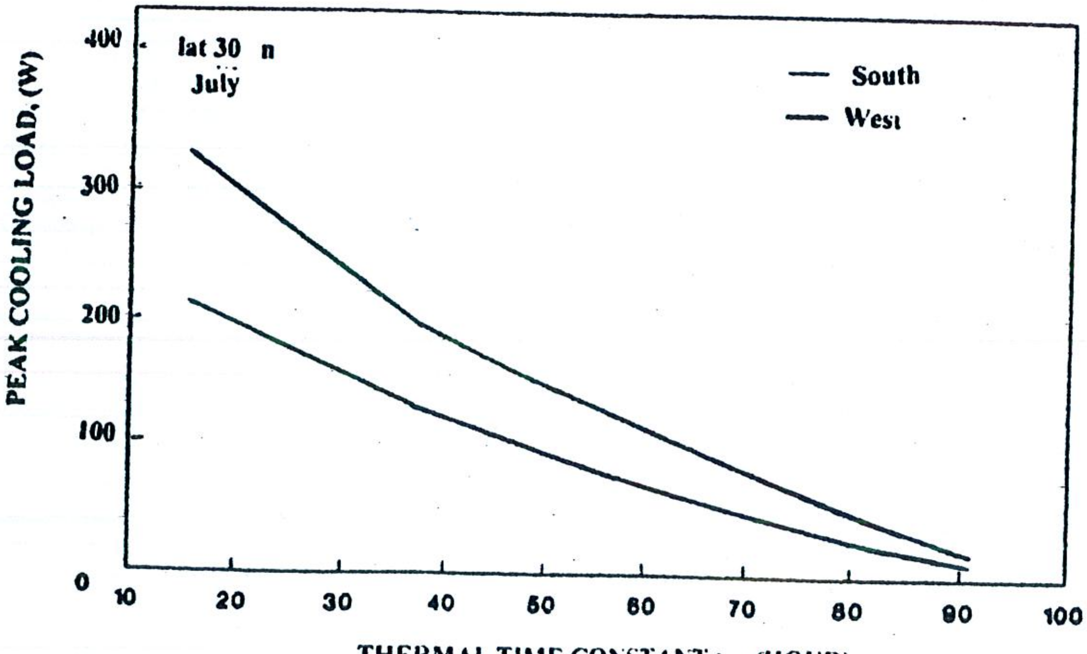

Fig. (1): Variation of the peak cooling load with the thermal time constant, t_{cw} for exposed area of 6.6 m^2 at south and west orientation

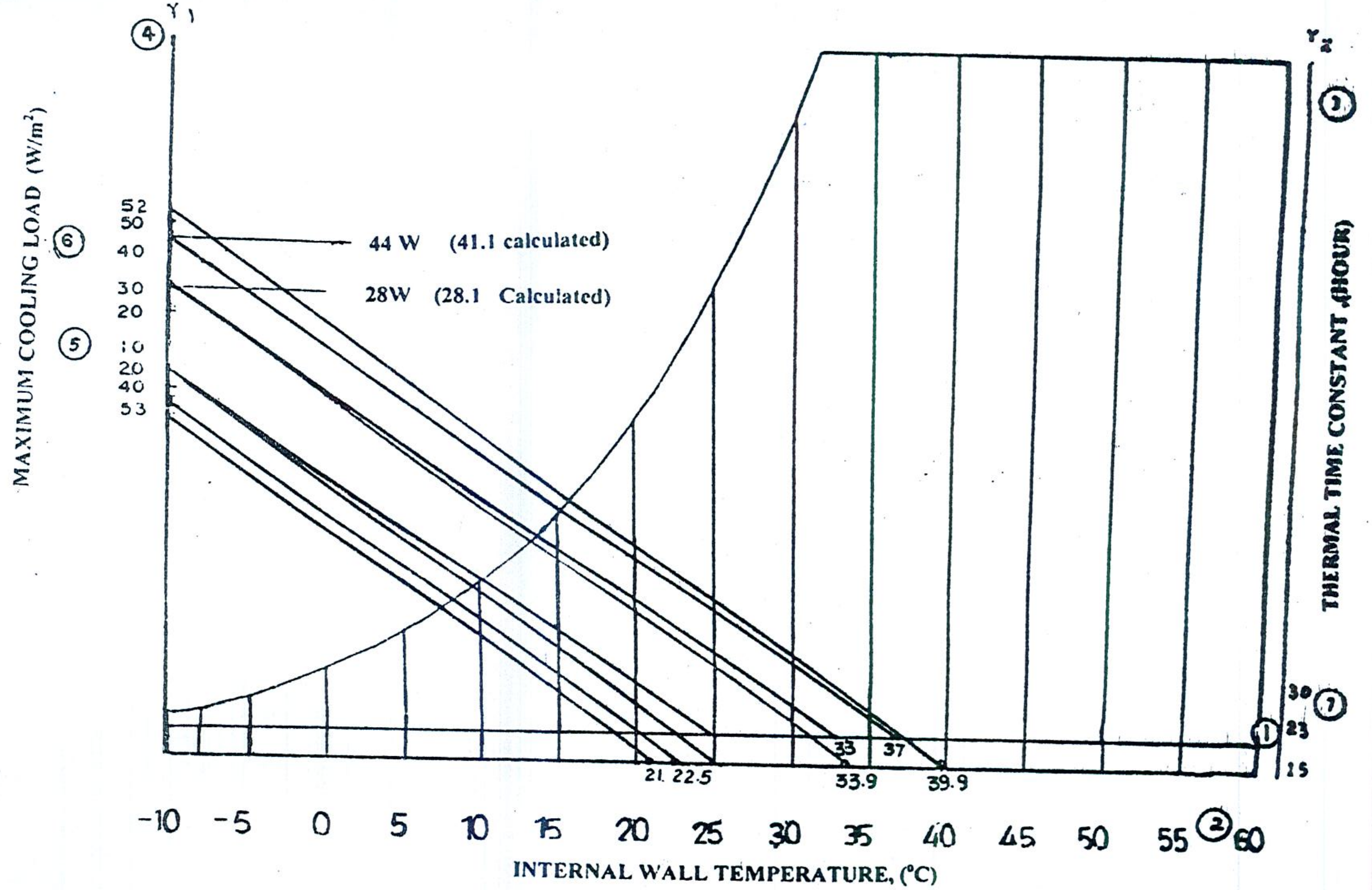

Fig. (2): The applying of the load on the nomograph chart for cairo Lat. 30o 8' for light materials of $t_c < 33$ hour.

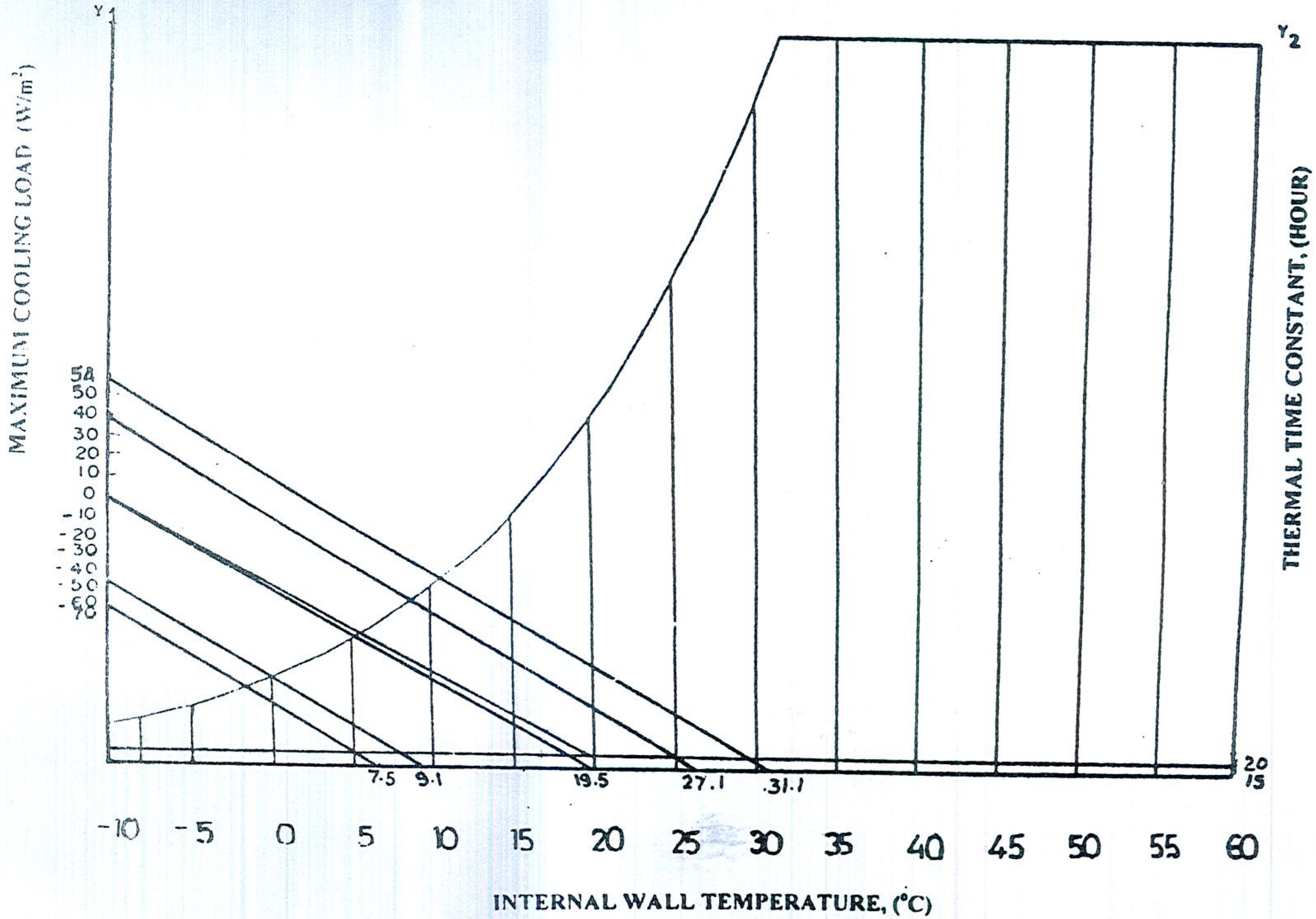

Fig. (3): The applying of the load on the nomograph chart for Lat. 51° 7' for light materials of $t_c < 33$ hour.