4.1.4.1 The windows. Thermal performance

As mentioned before (under 2.2.1) the problems are big trying to find an optimal window construction. As shown in (21) it is very hard to calculate a proper U-value for a window during darkness. Of course, the problem will not be less trying to include the effect of the sun radiating through the window. Of course, it is totally out of the scope of this thesis trying to find the optimal window construction, but nevertheless I will try to find some intervalls, where the U-values for different window constructions usually are located.

4.1.4.1.1 The windows. Heat transferred during the hours of darkness

Heat is transferred by conduction, convection and radiation. All of these ways must be considered when calculating on windows in order to find a proper U-value. The heat transferred by conduction, through the glass and air, can be calculated in the same way as mentioned in previous chapters. However, the air gap between the panes makes it important to calculate the convection part as well. In (26 p 286 -) free convection in enclosed spaces is treated.

It has been found that free convection systems often can be represented by the use of three constants: The Nusselt number, the Grashof number and the Prandtl number.

The Nusselt number is calculated as:

$$Nu = h \cdot x / k$$

where h = the convection heat transfer coefficient
k = the thermal conductivity
x = some "distance parameter" from the warm wall (26 p 181)

The Grashof number represents a ratio of the buoyancy forces for the viscous forces and is calculated as:

$$Gr_x = \frac{g \cdot \beta (T_w - T_\infty) x^3}{\nu 2}$$

where
- g = Acceleration of gravity
- β = 1/T for ideal gases when T = the absolute temperature for the gas (here the air)
- T_w = Temperature at the wall
- T_∞ = Temperataure in the surrounding ("far away")
- x = The distance
- ν = the kinematic viscosity

The Prandtl number can be expressed as:

$$Pr = \frac{\nu}{\alpha} \quad \text{and } \alpha = \frac{k}{c \cdot \rho}$$

where ρ is the density and
c is the heat capacity of the gas

In (26 p 272) the following expression is mentioned:

$$Nu_f = C(Gr_f, Pr_f)^m$$

where f indicates that the properties of the air shall be evaluated at the film temperature, T_f:

$$T_f = \frac{T \; {-} T_w}{2}$$

$C(Gr_f, Pr_f)$ and m are constants that has to be evaluated from the geometry of the case.

For the special case with free convection in enclosed spaces

(26 p 287) mentions:

$$Gr_f = \frac{g \cdot \beta (T_1 - T_2) \delta^3}{2}$$

where T_1 and T_2 = the different wall temperatures

and δ = the gap between the walls (panes).

On the same page an expression for the Nusselt number is shown:

$$Nu_\delta = \frac{h \cdot \delta}{k}$$

(26 p 288) also mentions that the results sometimes are expressed in terms of an effective or apparent thermal conductivity defined by:

$$\frac{q}{A} = k_e \frac{T_1 - T_2}{\delta} \quad \text{and} \quad Nu_\delta = \frac{k_e}{k}$$

and a corresponding R-value would be :

$$\frac{\delta}{k_e}$$

It would therefore be possible to find out in what region a suitable U-value for windows would be. However, as mentioned above the heat transferred by radiation also has to be considered. On page 336 in (26) the following expression for radiation heat transfer between infinite parallel planes is mentioned:

$$q = \frac{\sigma \times A (T_1^4 - T_2^4)}{1/\varepsilon_1 + 1/\varepsilon_2 - 1}$$

where σ = Stefan Boltzmanns constant
A = The area
T_1, T_2 = The temperatures of the planes
$\varepsilon_1, \varepsilon_2$ = The emissivity for the planes

However, the gas (air) between the panes has to be taken into consideration, which emits and absorbs radiation depending on the wave-length of the radiation.

This brief survey of the problems encountered shows that heat transfer through windows is very complicated. In (21) an elaborate try has been made to actually calculate the U-values for windows.

The results from these calculations are for a 1 x 1 m window (21).

Windows of wood:

Two glazed (openable) 2.76 - 2.84 W/m^2 K
Three glazed (openable) 1.97 - 2.54 W/m^2 K

windows of aluminium::

Three glazed (openable) 2.61 - 2.72 W/m^2 K

For sealed glass units the values are approximately:

3.0 W/m^2 K for two glasses

2.25 W/m^2 K for three glasses

Unfortunately, the calculations have been made only for the bottom part of the window (height 0.1 m) and the author has not showed how the work has been made in detail, so it is hard to know the reliance of it, but, of course, the U-values above could be used for approximate calculations. However, the author also has measured the heat transferred through the windows. From the Appendix No 6.2.1 in (21) and the following tables it is shown that the U-values:

for 2 pane windows varies between 2.2 and 2.6
3 pane windows varies between 1.4 and 1.6
4 pane windows varies between 1.1 and 1.2 and
5 pane windows varies between 0.9 and 1.0 W/m^2 K.

In my numerical example I have used a U-value as high as 4.0 W/m^2 K for the existent windows, because thev are old and probably untight, so that cold air can ventilate through the air space and lower the degree of insulation.

For new windows I have chosen U-values as follows:

two glazed	2.4 W/m^2 K	
three glazed	1.5 W/m^2 K	(F26)
four glazed	1.2 W/m^2 K	
five glazed	1.0 W/m^2 K	

Other literature in this field e g (35 p 24) or (36 p 60) give slightly different values.

These U-values are valid during darkness.

4.1.4.1.2 The windows heat transfer and sun radiation during daytime

As is mentioned in (21 p 8) radiation from the sun pass through the window and will heat the inside air, furniture, etc in the room. The heat emitted from the room is transferred by another wavelength, which can not pass the glasses in the window as easv as the sun radiation. This is called the greenhouse effect (26 p 388).

Outside the earth the total radiation from the sun is about 1 400 W/m^2, (26 p 382), but because of the angle the sun meets the earth surface, reflection in the atmosphere, atmospheric pollution etc, this value is very much decreased. For Sweden the average total insulation is about 850 W/m^2 (altitude 55 deg, 26 p 390).

There have been several attempts to show how much sun that radiates through a window. Comparing this to how much heat that transfers the other direction makes it possible to calculate the so called effective U-value for a window. In (37 p 17) these are mentioned as:

Facade to	Two-panes	Three-panes	
North	2.8	1.95	$W/m^2\ ^oC$
East	1.3	0.4	$W/m^2\ ^oC$
South	-0.4	-1.3	$W/m^2\ ^oC$
Darkness	3.0	2.0	$W/m^2\ ^oC$

(38), (39) and (40) makes it possible to calculate the effective U-values for Malmö.

In Table V sun radiation tables for Malmö is described.

Table V Sun radiation transmitted through a one-pane window during one day in Malmö (56° N) the 15th of January (Wh/m^2). 90 deg inclination to the horizontal plane (40 p 19). C = clear days, HC = = half clear days, OC = overcast days.

	C	2 888		C	592		C	165
South	HC	1 788	East, west	HC	439	North	HC	188
	OC	440		OC	184		OC	137

Using the tables for how many days that are clear (= 3.1) and overcast (= 19.2) in Malmö (40 p 11) the sun transmitted will be for the south window:

$$(1/31)(2\ 888 \times 3.1 + 1\ 788 \times 8.7 + 440 \times 19.2) =$$
$$= 1\ 063\ Wh/m^2$$

In our case the house is equipped with two-pane windows and according to (40 p 10) there is a shading coefficient of 0.9 to be multiplied to the value.

The sun radiation transferred through the windows will thus be:

	Radiation in Wh/m^2
South	956
East/west	267
North	138

As mentioned above the existent windows have a darkness U-value = 4.0 W/m^2 ^oC. This means that the heat transferred the other direction is (see Table VI):

$$U_w \times \tau(T_i - T_o) = 4 \times 24(20 - -0.5) = 1\ 968\ Wh/m^2$$

where U_w = The U-value for the window during darkness
τ = The time (24-hours)
T_i = Inside temperature
T_o = Outside temperature (mean for January)

For the south direction 1 968 - 956 = 1 012 Wh/m^2 is transferred through the window (from the inside and out). An effective U-value that gives the same result will be for January: (The indices means w = window, e = effective, s = south)

$$U_{wes} \times 24 \times 20.5 = 1\ 012, \quad U_{wes} = 2.05\ W/m^2\ ^oC$$

In the following tables the values for the whole year are shown.

Table VI Sun radiated and heat transmitted through two-pane windows in Malmö. South direction Wh/m^2. Inclination = 90 deg

Month	Sun	Heat (Degree hours x x $U_{darkness}$	Difference (Sun - heat)
Jan	29 660	61 008	-31 348
Febr	44 425	56 140	-11 715
March	73 678	55 352	+18 326
April	75 288	40 320	+34 968
May	82 588	26 784	+55 804
June	76 281	14 400	+61 881
July	78 501	8 332	+70 169
Aug	79 812	9 820	+69 992
Sept	79 366	18 720	+60 646
Oct	61 565	33 032	+28 533
Nov	32 696	43 488	-10 792
Dec	21 221	53 568	-32 347
Sum	735 081	420 964	+314 717

From Table VI it is obvious that the window is a very good "sun collector". During the year approximately 314 kWh/m^2 more energy is transferred from the outside to the inside of the room. Only the four winter months, Nov, Dec, Jan, Febr, have a positive flow, i e from the inside to the outside. If it was possible to take care of all the sun radiated through the 1 m^2 window it would have the effective U-value:

$$-\frac{314\ 117}{105\ 241} = -\ 2.98\ \text{W/m}^2\ \text{K!}$$

where 105 241 = the number of degree hours in Malmö.

For the east, west direction, the values will be:

Table VII Sun radiated and heat transmitted through two-pane windows in Malmö east and west direction. Inclination = 90 deg

Month	Sum	Heat	Difference (Sun - heat)
Jan	8 268	61 008	-51 740
Febr	18 249	56 140	-37 891
March	41 860	55 352	-13 492
April	61 966	40 320	+21 546
May	87 584	26 784	+60 800
June	90 911	14 400	+76 511
July	89 068	8 332	+80 736
Aug	75 072	9 820	+65 252
Sept	53 105	18 720	+34 385
Oct	28 295	33 032	-4 737
Nov	10 749	43 488	-32 739
Dec	5 359	53 568	-48 209
Sum	570 486	420 964	+149 522

The effective U-value for the windows directed to the east and west is thus:

$$-\frac{149\ 522}{105\ 241} = -\ 1.42\ W/m^2\ K$$

Table VIII Sun radiated and heat transferred through two-pane windows in Malmö, north direction in Wh/m^2. Inclination 90 deg

Month	Sun	Heat	Difference
Jan	4 299	61 008	-56 709
Febr	9 050	56 140	-47 090
March	18 573	55 352	-36 779
April	28 815	40 320	-11 505
May	44 500	26 784	+17 716
June	53 482	14 400	+39 082
July	50 536	8 332	+42 204
Aug	36 149	9 820	+26 329
Sept	23 116	18 720	+4 396
Oct	13 536	33 032	-19 495
Nov	5 819	43 488	-37 669
Dec	3 543	53 568	-50 025
Sum	291 418	420 964	-129 546

Thus the effective U-value for the windows to the north will become:

$$129\ 546 : 105\ 241 = 1.23\ W/m^2\ K$$

However, these calculations of the effective U-values for the windows provide that there really is a need for all the sun radiated through the windows. In the summer this is of course not the fact. In almost all buildings the inside temperature becomes too high for convenience during the summer and this surplus heat is ventilated out from the building. Thus, the surplus heat is not worth anything but instead could be a cost for the landlord.

It is also obvious from this discussion that very bad insulated houses assimilate more of the heat radiated through the windows than a very thoroughly insulated building. In the later case there will be a heat surplus much faster. This also means that the effective U-values for the windows are dependent of the thermal insulation status in the rest of the house. A high status, i e good insulation, will give low effective U-values and a bad status make the effective U-values higher. It is therefore necessary to consider the energy balance for the whole building in order to to find the proper U-values for the windows. The calculated U-values can be corrected for this considering that no heat is needed during June, July and August. The corrected U-values for the windows thus become:

south:	- 112 075	:	105 241	=	- 1.06 W/m^2 ^oC
east/west:	+ 72 977	:	105 241	=	+ 0.69 W/m^2 ^oC
north:	+ 237 161	:	105 241	=	+ 2.25 W/m^2 ^oC

However, it might be more adequate to use a lower number of degree hours for this type of calculations. Using the same method in Table VI makes the U-values to:

south:	- 112 075	:	92 862	=	- 1.2 W/m^2 ^oC	
east/west:	72 977	:	92 862	=	0.8 W/m^2 ^oC	(F27)
north:	237 161	:	92 862	=	2.6 W/m^2 ^oC	

Using the fact that three-pane windows have another shading coefficient 0.8 (40 p 10), assuming that the coefficient decreases with 10 units (%) for each glass (40 p 8) and using the U-values for darkness described in (expression F26) the corresponding effective U-values for new windows will become:

	Number of glasses				
	2	3	4	5	
South	- 2.9	- 3-2	- 2.9	- 2.5	W/m2 K
East/west	- 0.9	- 1.5	- 1.4	- 1.2	W/m2 K
North	+ 0.9	+ 0.1	- 0.01	- 0.04	W/m2 K

Note: The best window (with the lowest U-values) is the three-pane window. This is so because the shading coefficient increases faster than the darkness U-value improves.

In Table IX the results from the calculations above have been gathered.

Table IX U-values for windows

	Dark-ness	North	East/west	South	
2 pane existing	4.0	+ 2.6	+ 0.8	- 1.2	W/m2 K
2 pane	2.4	+ 0.9	- 0.9	- 2.9	W/m2 K
3 pane	1.5	+ 0.1	- 1.5	- 3.2	W/m2 K
4 pane	1.2	- 0.01	- 1.4	- 2.9	W/m2 K
5 pane	1.0	- 0.04	- 1.2	- 2.5	W/m2 K

Of course, these values are very approximate and have to be handled with great care.

There are also many "human actions" that imply on the U-values for the windows. These are not at all considered here. (See e g 38.) The scope of this thesis is, as mentioned above, not to find an optimal window construction. However, it is necessary to have at least approximate values on the parameters implying on the LCC for the building.

Future research, in this special field of effective U-values for windows, will, of course, show other and more adequate methods to calculate heat transfer and sun radiation through windows.

4.1.4.2 The windows. Retrofit cost

The cost for bying new windows depends on the size and the number of panes in them. The cost for demolishing the old ones and fixing the new windows, however, can at least approximately, be considered as a constant and not dependent of the size, number of panes or other variables. In (31 Figure 16:27) the cost for exchanging one window, excluding the cost for purchasing the window, can be calculated to 1 100 SEK (1 077). From (41 and 42) the cost for the different type of windows can be fetched. The figures from the two manufacturers are depicted in Figure 19.

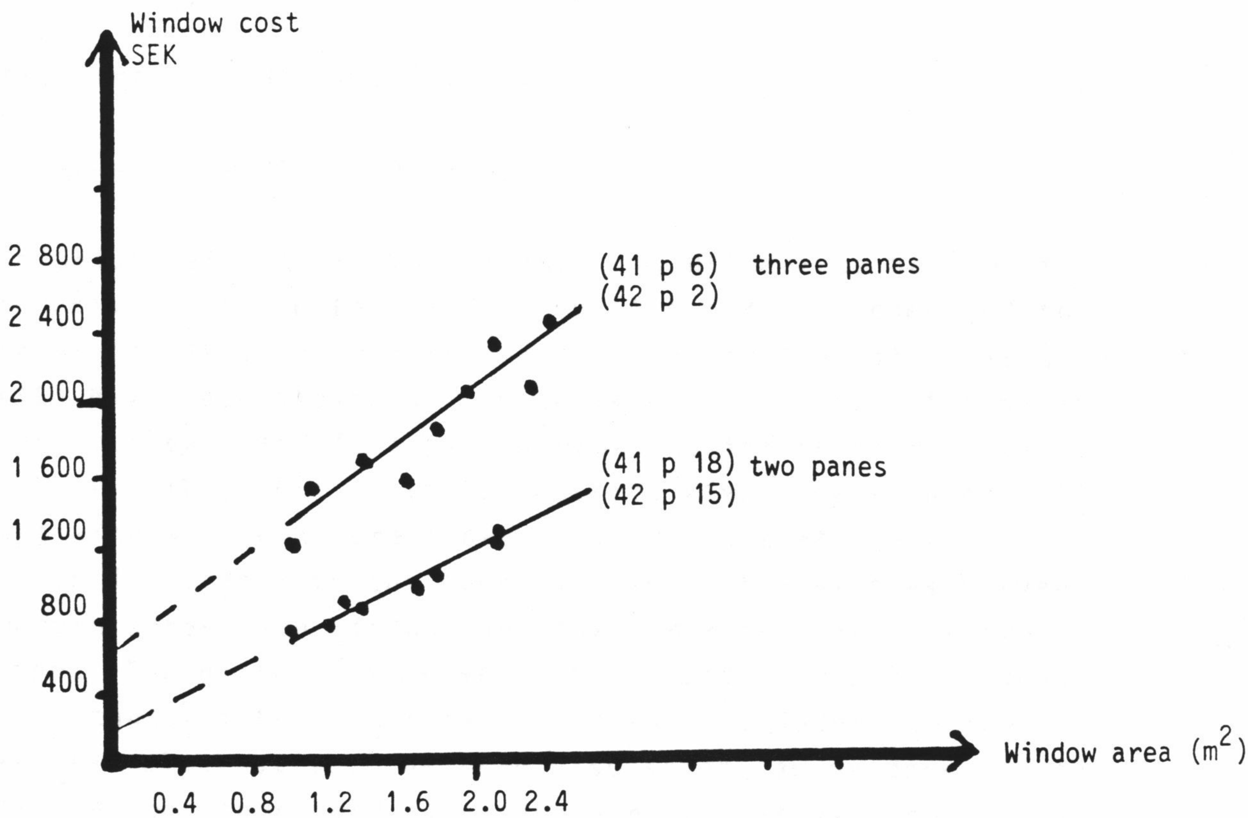

Figure 19. Purchasing cost for windows.

The window cost in Figure 19 excludes painting. Approximately 500 SEK has to be added to get white painted windows.

Expressions for two- and three-pane windows can be evaluated from the lines in Figure 19 as: (A_{wi} = Area of the windows).

two-pane: $200 + 500 \times A_{wi}$

including taxes 12.87 % and painting the expression will be:

$790 + 560 \times A_{wi}$

three-pane: $600 + 700 \times A_{wi}$

including taxes and painting:

$1\,250 + 790 \times A_{wi}$

Adding the cost for exchanging the window the retrofit cost will become:

two-pane: $1\,890 + 560 \times A_{wi}$

three-pane: $2\,350 + 790 \times A_{wi}$

Unfortunatelv, there is a rather big difference between the purchaseing price for windows in (41) and (42) compared to those in (31). One reason for this may be that the prices in (31) have been acquired from tenders on real retrofit projects. For four-pane and five-pane windows no information is available in (31), (41) or (42). Contacts viva voce with one of the window manufacturers has informed me that there is a great difference in the construction of the windows between modern three-pane windows and the older two-pane constructions. The difference between three- and four-pane windows will thus not be of the same size as calculated for the earlier alternative. The same discussion can be done for the lag between four- and five-pane windows. As mentioned above it is a more complicated construction that makes the difference between two-and tree-pane windows so big. This lag will thus probably be located in the constant part of the expression. The variable part of the cost differs mostly because of one more glass in the window. Assuming this for four- and five-pane windows and deminishing the lag between the constants to one half makes it possible to find the following approximate values for the window retrofit cost.

two-pane	$1\ 890 + 560 \times A_{wi}$	
three-pane	$2\ 350 + 790 \times A_{wi}$	(F28)
four-pane	$2\ 580 + 1\ 020 \times A_{wi}$	
five-pane	$2\ 910 + 1\ 240 \times A_{wi}$	

From chapter 4.1 (my numerical example) the remaining life of the windows is 10 years. New windows have a life-cycle that has been assumed to 20 years. This means that the inevitable LCC will be: (F28) and (F2)

$$(1\ 890 + 560 \times 1.7) \times 1.05^{-10} + (1\ 890 + 560 \times 1.7) \times$$
$$\times\ 1.05^{-30} = 1\ 744 + 657 = 2\ 402 \text{ SEK for each window}$$

An energy retrofit with three-pane windows the base year and subsequent 20 year-periods will make the retrofit cost to:

$$RC_{wi} = (2\ 350 + 790 \times 1.7) + (2\ 350 + 790 \times 1.7) \times$$
$$\times\ 1.05^{-20} + (2\ 350 + 790 \times 1.7) \times 1.05^{-40} = 1/2(2\ 350$$
$$+\ 790 \times 1.7) \times 1.05^{-50} = 3\ 693 + 1\ 392 + 524 - 161 =$$
$$= 5\ 447 \text{ SEK for each window}$$

Corresponding values for a four-pane window are 5 364 SEK and for a five-pane window 7 428 SEK.

Of course, it is possible to do an energy retrofit with new two-pane windows. This makes the retrofit cost to 4 192 SEK. (The old windows will be changed to new two-pane windows at the base year.)

4.1.4.3 The windows, energy cost LCC and optimization

In Table IX I have shown the calculated U-values for the different types of windows and direction to the compass.

The energy cost of the windows thus can be calculated as:

$$U_e \times e \times A \times D \times PV_{factor}$$

where U_e = efficient U-value
e = the energy price
A = the window area
D = the number of degree hours
PV_{factor} = the present value factor

This makes the energy cost for existing 2-pane windows to:

north:

$$2.6 \times 0.3 \times 1.7 \times 92\ 826 \times 10^{-3} \times \frac{1-1.05^{-10}}{0.05} +$$

$$+ 0.9 \times 0.3 \times 1.7 \times 92\ 826 \times 10^{-3} \times \frac{1-1.05^{-40}}{0.05} \times$$

$$\times 1.05^{-10} = 950 + 448 = 1\ 398 \text{ SEK}$$

east/west: $(950 : 2.6) \times 0.8 + (448 : 0.9) \times (- 0.9) =$
$= 156$ SEK

south: $(950 : 2.6) \times (- 1.2 + 448 : 0.9)) \times (- 2.9) =$
$= - 1\ 882$ SEK

2-pane new:	north	=	785 SEK
	east/west	=	- 785 SEK
	south	=	- 2 529 SEK
3-pane new:	north	=	87 SEK
	east/west	=	- 1 308 SEK
	south	=	- 2 791 SEK
4-pane new:	north	=	- 9 SEK
	east/west	=	- 1 221 SEK
	south	=	- 2 529 SEK

5-pane new: north = - 35 SEK
east/west = - 1 046 SEK
south = - 2 180 SEK

Now looking at the retrofit cost in the previous chapter it is possible to calculate the total LCC for the different windows. This is done in Table X.

Table X Life-cycle costs for one window in SEK

Type	North	East/west	South
Existing 2 panes	3 800	2 246	520
New 2 panes	4 977	3 407	1 663
3 panes	5 534	4 139	2 656
4 panes	6 355	5 143	3 835
5 panes	7 393	6 382	5 248

After this it is only to select the lowest solution i e the existing 2-pane alternative. In all the directions of the compass the most profitable solution is to leave the windows as they are and after 10 years, when the change is inevitable, replace the existent windows with new ones. From Table X it is also obvious that also the new two-pane alternative is cheaper than the three-pane ditto.

Note! Because of the rather small amounts of money that differs between the alternatives, the fact that the more complicated windows have lower darkness U-values can change the order between the LCC when including the power demand for the building. Such considerations are made further down in the thesis.

4.1.4.4 The combination of the attic floor, the external wall, the floor and the windows. Optimization

The model of my building (F25) has now to be augmented by the window expressions, multiplied with the actual number of windows in the house. Note! There are totally 24 windows to the east and west, 30 to the north and 30 to the south. The retrofit cost and the energy cost are held apart for comparative reasons. The model can be expressed as:

minimize:

$$Y_1(125\ 000 + 300\ 000 \times t_{af} + \frac{18\ 438.5}{0.04+0.8 \times t_{af}}) + Y_2 \times$$

$$\times\ 460\ 962 + Y_3(333\ 867 + 387\ 100 \times t_{ew} +$$

$$+ \frac{20\ 137.5}{0.0475+1.05 \times t_{ew}}) + Y_4 \times 583\ 190 + Y_5(X_1(477\ 865 +$$

$$+ 250\ 000 \times t_{fl}) + X_2(620\ 000 + 553\ 000 \times t_{fl}) +$$

$$+ \frac{15\ 335}{0.0475+0.56 \times t_{fl}}) + Y_6 \times 413\ 950 + Y_7(125\ 760 +$$

$$+ 23\ 550) + Y_8(100\ 608 - 18\ 840) + Y_9(125\ 760 -$$

$$-\ 75\ 870) + Y_{10}(163\ 410 + 2\ 610) + Y_{11}(130\ 728 -$$

$$-\ 31\ 392) + Y_{12}(163\ 410 - 83\ 730) + Y_{13}(190\ 920 - 279) +$$

$$+ Y_{14}(152\ 736 - 29\ 304) + Y_{15}(190\ 920 - 75\ 870) +$$

$$+ Y_{16}(222\ 840 - 1\ 050) + Y_{17}(178\ 272 - 25\ 104) +$$

$$+ Y_{18}(222\ 840 - 65\ 400) + Y_{19}(72\ 060 + 41\ 940) +$$

$$+ Y_{20}(57\ 648 - 3\ 744) + Y_{21}(72\ 060 - 56\ 460)$$

Subject to: $t_{af} > 0$, $t_{ew} > 0$, $t_{fl} > 0$

Y_{1-21} and $X_{1,2}$ = 1 or 0 integers

$Y_1 + Y_2 = 1$, $Y_3 + Y_4 = 1$

$X_1 + X_2 = 1$

$Y_7 + Y_8 + Y_9 + ...+ Y_{20} + Y_{21} = 3$

$Y_7 + Y_{10} + Y_{13} + Y_{16} + Y_{19} = 1$

$Y_8 + Y_{11} + Y_{14} + Y_{17} + Y_{20} = 1$

$Y_9 + Y_{12} + Y_{15} + Y_{18} + Y_{21} = 1$

If $Y_2 = 1$ then $t_{af} = 0$
If $Y_4 = 1$ then $t_{ew} = 0$ and
If $Y_6 = 1$ then $t_{fl} = 0$ (F29)

The variables Y_7 to Y_{21} decides the window construction. The constraint expressions makes it necessary to have windows and tells the model that not only south windows can be chosen. Solving the model adds $Y_{19} = Y_{20} = Y_{21} = 1$ and $Y_7 = Y_8 = ... = Y_{18} = 0$ to the earlier solution shown under (F25). The minimized object function value will become:

$$LCC* = 1\ 179\ 972 + 114\ 000 + 53\ 904 + 15\ 600 =$$
$$= 1\ 363\ 476 \text{ SEK}$$

I have now developed an energy-retrofit cost model for the simplified climatic shield of a building. One more energy consuming part in the house is the ventilation equipment. In the next chapter I will deal with this.

4.1.5.1 Ventilation equipment. Thermal performance

The building in my case has a so called natural ventilation equipment (58 p 22.1 -). This means that it is only the fact that warm air is lighter than cold air, that makes the equipment work. No fans or such things are involved in the process that has been dealt with in the chapter concerning natural convection. When the warm air flows out through the ventilaltion channels cold air is passing into the building from leaks in the doors and windows etc. This cold air has to be heated or otherwise the temperature in the room would get lower than suggested. One of the inconveniences with the system is that it works good only during the winter time. In the summer the buoyancy forces are too small (or negative) to encertain a proper function of the system (86 p 5). During good thermal conditions a ventilation flow of about 1 total change of the air per hour can be maintained. In my case I have chosen 0.8 renewals/hour, which means that the ventilation flow out of the building, with the net dwelling area of 2 000 m^2 and the height of each apartment = 2.4 m, will be:

$$VF = 2.4 \times 2\ 000 \times 0.8 = 3\ 840\ m^3/h$$

The air has to be heated from the outside temperature to the room temperature. The amount of heat necessary for this depends on the so called heat capacity for the air, which is about 1.005 kJ/kg ^oC for air at atmospheric pressure. The density for the air is about 1.18 kg/m , so the heat that is lost can be calculated as (26 p 3 and 542):

$$3\ 840 \times 1.18 \times 1.005 = 4\ 554\ kJ/^oC\ h$$

If the worst temperature conditions are estimated (LUT 1) the outside temperature is -16 ^oC. The energy that has to be used to heat the air is thus: