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Existing buildings

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Introduction

In general, building construction and building usage causes main environmental impacts, ranging from an intense resource consumption up to gaseous, liquid and solid waste production. As part of that burden, buildings have a large share in the annual energy consumption and the related greenhouse gas emissions of a country. If both have to be reduced, energy efficient construction should be a prime objective and measure. The techniques to realize less energy consumption in buildings without jeopardizing other user related performances are well known. To mention some: a highly insulated envelope, optimal integration of passive solar accounting for winter gains and summer comfort, the use of well insulating glass, heat recovery, a very efficient HVAC system, etc.

The build environment however is a very inert system, composed of units with a very long service life and subjected to a low substitution and retrofitting rates. New construction in many cases also adds units to the existing stock, a reality that does not enhance energy efficiency of the whole, on the contrary. Consequently, if energy conservation is really taken seriously in terms of 'energy consumption should decrease', then energy performance of the existing stock, in combination with the overall performance, must receive much more attention. Legal instruments should treat thermal retrofit as of prime priority. Hence, this is not what happens actually. New construction in many countries is more and more subjected to a tough energy performance legislation, while retrofit is treated as an adventitious activity that should not be complicated by additional energy legislation. Thermal performance demands does not go beyond some modest U-value requirements.

Data are important

In Flanders, household has a share of 218 PJ in the annual end use of 800 PJ (Verbruggen 1994, Verbruggen 1996)), i.e. about 27.3%, i.e. 990 GJ or 27 500 kWh per annum and per household (Flanders counts some 2 250 000 households). To put that number into perspective, we may compare it with the annual metabolism of a human being, 880 kWh. Each household in Flanders consequently absorbs the energy produced by 31 individuals. Included the tertiary sector, where energy consumption is mainly building related, buildings use attains 306 PJ/a, i.e.

38.2% of the total. For Germany, the distribution over the different sectors in 1992 looked as given in table 1 (GRE, 1996). Table 2 contains data for the US (DOE, 1997).

Table 1 Energy consumption for Germany, 1992

Consumption	PJ	%
Industry	2562	28
Traffic	2520	28
Households	**2394**	**26**
Tertiary sector	**1527**	**17**
Army	70	1

Table 2 Energy consumption in the US per sector in (%)

Consumption	%
Industry	32.6
Traffic	32.3
Building related	**33.7**

The three sets underline the importance of building related energy consumption. Although the size of the three countries and the climate differs substantially, the share in the annual consumption touches 40% of the total end use in all three. The share buildings have in greenhouse gas emissions is equally important. The residential sector in Flanders for example emits ±16 000 000 Ton CO_2 on an annual basis. This number includes electricity produced for lighting, appliances and heating (Hens et al., 1997). Figure 1 gives additional details on measured energy consumption in existing fuel heated buildings. The dots represent a sample of 1173 fossil fuel heated Laboratorium bouwfysica, 1997)

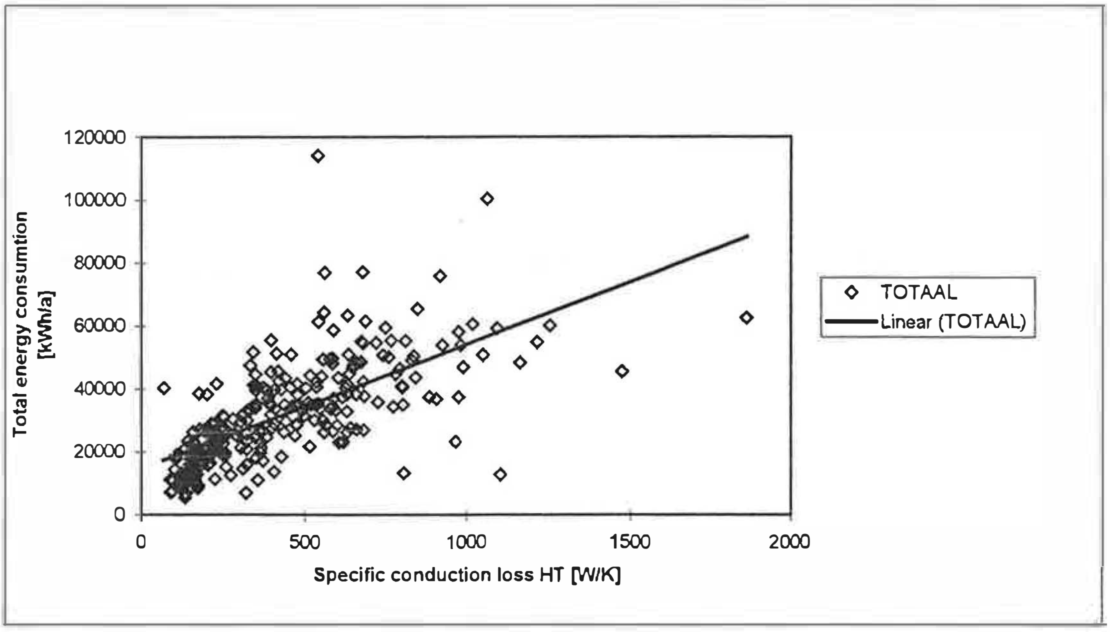

Figure 1 Total energy consumption as a function of the specific conduction loss

On the average the dwellings had a heated surface of 140 m² (range: 60-543 m²). The average level of thermal insulation was K98 for the fossil fuel cases (range: 41-180). The total annual end use for the fossil fuel dwellings decreases with the specific conduction loss (the product of the mean U-value of the enclosing surface (U_m) and that surface (A_T)). A least square approximation gave: $E_T = 19330 + 35U_mA_T$. Lower specific transmission losses may result from a smaller enclosing surface or a better thermal insulation (lower U_T).

An identical analysis on 75 electricity dwellings gave a heated surface of 240 m² (range: 56-543 m²), an average level of thermal insulation K46 (range: 30-181) and a total energy consumption: $E_T = 12508 + 22U_mA_T$.. Electrically heated houses clearly are better insulated than their fossil fuel counterparts. Apparently, electrical heating diminishes end use, even for identical specific conduction losses. Also on the average, - fossil fuel 32 456 kWh/a, electricity 20 750 kWh/a- electrical heating gives a lower number. As well better thermal insulation as rebound effects are responsible for those savings. The higher electricity prices in fact motivate the inhabitants to economize on thermal comfort.

Table 3 lists the annual consumption per m² of heated floor for the whole sample. If we compare the average of 180 kWh/(m².a)!with the fifteen IEA-SHC-Task 13 Solar low energy houses (IEA, 1995) of table 4, then, apparently, even 28 years after the first energy crisis, the reduction-potential for energy consumption in dwellings remains impressive.

Table 3 Average energy consumption in dwellings for Belgium (measured data for 1200 houses with an age between 2 and 85 years)

	Units	Average	Stdev.	Min.	Max.
Total consumption	**kWh/(m².a)**	180	68	66	488
Consumption for H en HW	**kWh/(m².a)**	149	71	66	428
Consumption for HH	**kWh/(m².a)**	28	14	8	74

H=heating, HW=hot tap water, HH=household, lighting, apparatus

Table 4 The fifteen IEA-SHC-Task 13 Solar low energy houses (Anon, 1995)

Country, house	**Floor surface** m²	**Heating** kWh/(m².a)	**Hot water, household** kWh/(m².a)
Austria, terrace house Lustenau	85.7	21	36
Belgium, terrace house La Pleiade, LLN	180	15	26
Canada, detached house Brampton	408	12	19
Canada, detached house Waterloo	208	25	31
Denmark, terrace houses Kolding	105/98	14/12	22/23
Finland, detached house Pietarsaari	166	13	14
Germany, two-family house Rottweil	175	18	32
Germany, terrace house Berlin	170	0	15
Japan, two-family house, Iwaki	150	13	25
The Netherlands, 42 flats Amstelveen	100	12	31
Norway, terrace houses Hamar	125	9	25
Sweden, detached house Röskär	50.4	17	57
Switserland, two-family house Gelterkirchen	182	28	29
USA, detached house Grand Canyon	125	10	37
USA, detached house Yosemite	150	23	32
Averages		**15.3**	**28.8**

Predicting energy consumption and CO_2-release

Modeling the building stock

The databases of the National Institute for Statistics contain overall information on the building stock (Anon, 1996). Each dwelling in fact is characterized by five variables. Age (before 1945, 1946 to 1970, 1971 to 1980, 1981 to 1990), type (terraced, double, individual, flat), total floor area (<45 m², 45 to 64 m², 65 to 104 m², 104 to 124 m², ≥125 m²), prime energy (oil, coal, gas, butane, electricity, others) and centrally heated or not.

With these variables we constructed a set of reference dwellings that substitute the whole housing stock. For that purpose, dwellings are assumed to be simple quadratic volumes. Up to 64 m² they exist as single floor constructions only. From 65 to 104, an equal distribution between 1 and 2 floors is adopted. Above 105 m², 1, 2 and 3 floors are considered. The quadratic volumes stand alone, are coupled two by two or form rows of terraced houses. Flats are grouped in medium rise blocs with 3 (20% of the total), 4 (30% of the total) or 5 stocks (50% of the total) and two flats per stock. In the software, each interval of floor area's is replaced by its average. Houses have 6% of their envelope glazed, flats 10%. Age is translated in U-factors and ventilation rates (table 5). Most houses constructed before 1945 have masonry massive walls with a thickness of 30 cm, single glass and neither roof nor floor insulation. From the second world war on, masonry cavity walls become the reference. After 1970 roof and cavity insulation and the use of double-glazing becomes common technology. In the eighties, floor insulation is added and more roof insulation applied. The U-values of table 5 are fair averages for the building technologies mentioned. The progressive decrease in average ventilation rate in the table is due to two elements: (1) the application of tighter windows and (2) the overall move to central heating after 1970. Energy vector and heating system define the heating system's efficiency.

For the period up to 1990 960 reference dwellings has been created that way. Each reference is characterized by a weighted average energy consumption, the weighting factors being the fraction of dwellings and flats per number of floors.

Table 5 Translating age into U-values and ventilation rates

	Facade U-value W/(m².K)	Roof U-value W/(m².K)	Floor U-value W/(m².K)	Glass and frames U-value W/(m².K)	Ventilation rate h^{-1}
before 1945	2.0	1.6	4	5.8/1.8	1.2
1946-1971	1.3	1.6	4	5.8/1.8	1.1
1971-1981	0.6	0.5	4	3.1/1.8	0.8
1981-1990	0.6	0.4	1.2	3.1/1.8	0.6

Energy consumption for the individual dwelling

Consumption is split in its main parts: heating, hot water and household. Cooling does not intervene. The climate in Belgium is too moderate for that, although a bad application of passive solar, resulting in glazed shrines without solar shading, and trendy behavior created some market for cooling applications. Heating is calculated using the following steady state single zone energy balance (Hens, 1997, Anon., 1999):

$$\left\{-\left(\Phi_{cond}+\Phi_{vent}\right)+\eta_{rec}\left[\left(\Phi_{sun}-\Phi_{long}\right)+\Phi_{free}\right]\right\}\Delta t+\eta E_{heat}=0\ (J) \tag{1}$$

with Φ_{cond} the conduction losses through the envelope, Φ_{vent} the ventilation losses, Φ_{sun}-Φ_{long} the solar gains corrected on long wave radiation, Φ_{free} the gains coupled to building use, η_{rec} the recuperation factor for the gains, E_{heat} the energy consumption by the heating system, η the system's efficiency and Δt the time step (here 1 month). The system's efficiency consists of two partial efficiencies: production and system. In the case local heating is applied, the system's efficiency is set equal to 0.645 for oil stoves, 0.63 for coal stoves, 0.69 for gas radiators, 0.65 for butane, 0.77 for electrical accumulators and 0.61 for wood stoves. Central heating is supposed to be hydronic only, with production efficiency coupled to age. For oil boilers for example, 0.82 with a loss coefficient of 0.05 and a mean supply temperature of 80°C is adopted for dwellings constructed before 1981. After 1981, high efficiency boilers become standard, production efficiency 0.86, loss coefficient 0.02 and mean supply temperature 65°C.

The model takes 15.7°C as the average inside temperature. That value was extracted from a detailed study on energy consumption in 52 dwellings distributed equally in relation to age and total floor area (Hens, 1993). A rebound effect is not considered. The TRY-year for Ukkel, Belgium, figures as the outside climate. The calculation proceeds on monthly basis. The sum of the positive monthly heating consumption E_{heat} gives the annual total.

The hot water heat demand per reference dwelling in W is set equal to:

$$\Phi_{HW}=\max\left[82, 0.815\left(A_{fl}-64\right)\right] \tag{2}$$

A_{fl} being the floor area in m². In the case of local heating, hot water production is a stand alone activity. With central heating, the boiler produces the hot water. The power demand for household per reference dwelling in W is calculated as:

$$\Phi_{HH}=201+0.725A_{fl1} \tag{3}$$

Both equations stem from a statistical analysis of measured data. Their transformation to consumption is straight forward. The equations (1), (2) and (3) together constitute the energy module within the software. The results are stored in a reference dwelling's matrix.

Simulating the reference year 1990

With the energy consumption per reference dwelling known, the calculation of the overall consumption for the residential sector in 1990 is straightforward. For each village, town and city, the number of dwellings per reference, listed in the NIS 1990 database, is multiplied with the related annual energy consumption for heating, hot water and household. In the case of individual heating, we assume electricity to be used for hot water. Household, included cooking, is electricity only. This of course is not correct as gas is a second favorite fuel for hot water and cooking. However, the NIS database does not give information on that. These simple rules, although somewhat fictitious, allow to add the totals per energy vector in an easy way. After, the results per location are totaled for each region in Belgium. Summing these totals results in the energy consumption for the country during the reference year 1990. The step to CO_2 emission demands a multiplication of the end use totals per vector with the associated CO_2 release in g/kWh, see Table 6..

Table 6 CO_2-release per kWh

Energy vector	**CO2 release g/kWh**
Coal	329
Fuel	264
Gas	192
Butane	264
Electricity (end use)	375
Other	329

Future evolutions

First, the transformations in the building stock have to be predicted. The dwelling demand primarily depends on the number of households. Two extreme cases for the evolution of that number have been implemented: (1) important increase with an annual growth of 1% in relation to the 1990 number, (2) marginal increase with an annual growth of 0.46% in relation to the 1990 number. The NIS further publishes annual data on new construction, demolition and retrofit. We used the data for 1991 to 1996 (Anon., 1996). The building industry also forecasts future needs on regular time intervals. This information, together with the housing policy of the regional governments, helped in shaping the dwelling offer in the near future.

Three different housing scenario's were considered: (1) restricted retrofit, unlimited expansion of the housing stock, i.e. business as usual, (2) explicit shift towards retrofit and reconstruction, restricted expansion of the housing stock, (3) demand guided retrofit and reconstruction, no expansion of the housing stock after 2010. The distribution of the energy vectors over the future building stock is distilled from the actual situation and a comparison with 1980. An increasing number of dwellings choose natural gas. Coal diminishes gradually, etc.

Four energy policy scenario's are included: (1) the actual legislation kept up (a level of thermal insulation K55 for new dwellings and threshold U-values in the case of retrofitting. K55 means that the average U-factor of the envelope (U_m) should equal 0.55 W/(m².K) for a compactness

(V/A_T) below 1 m, 1.1 W/(m².K) for a compactness above 4 m and $U_m=0.55[(V/A_T)/3+2/3]$ for a compactness V/A_T between 1 and 4 m), (2) K40 for new buildings (K40 means that the average U-factor of the envelope (U_m) should equal 0.4 W/(m².K) for a a compactness (V/A_T) below 1 m, 0.8 W/(m².K) for a compactness above 4 m and $U_m=0.4[(V/A_T)/3+2/3]$ for a compactness V/A_T between 1 and 4 m) and tougher U-factors for roofs, walls and windows in the case of a retrofit from 2001 on (0.5 W/(m².K) for walls, 0.2 W/(m².K) for roofs, 1.2 W/(m².K) for floors and 1.3 W/(m².K) for the glazing), (3) K40 for new dwellings and tougher U-factors for roofs, walls and windows in the case of a retrofit from 2001 on, a heating energy performance of 180 MJ/(m².a) for new dwellings from 2005 on (4) a heating energy performance of 180 MJ/(m².a) for new dwellings and tougher U-factors for roofs, walls and windows in the case of a retrofit from 2001 on. Each policy creates 240 additional reference dwellings with their specific energy consumption.

Multiplication, per region, of the annual number of new, retrofitted and demolished (reference) dwellings with the appropriate energy consumption gives the yearly change in consumption per vector. Addition to the totals per energy vector of the previous year results in a prognosis over the period considered. The step to CO_2-emission does not differ from the reference year (see Table 6).

Simulation results

Reference year

Table 7 gives the energy consumption and CO_2-emission for 1990. The calculations are based on the TRY-year for Ukkel, which is colder than 1990. CO_2-emissions therefore are also given for the proper 1990 climate

Table 7 Residential energy consumption in TJ/a and associated CO_2-emissions in MTons in Belgium, 1990 (TRY for Ukkel, specific climate for 1990, Vl=Flanders, W=Wallonia, B=Brussels)

	Dwellings	Oil	Coal	Gas	But/Pro	Electric.	Other	TOTAL
Energy consumption, TJ/a, TRY-year								
Vl	2 141 557	99 500	16 200	53 800	3 700	31 000	3 400	207 600
W	1 212 100	69 300	11 800	25 600	3 300	16 800	4 200	131 200
B	394 500	12 900	800	17 500	100	4 300	400	36 000
Belgium	3 748 200	181 700	28 800	96 900	7 200	52 131	8 000	374 800
CO2-emissions, MTon, TRY-year								
Vl		7.3	1.5	2.9	0.3	3.3	0.3	15.4
W		5 1	1.1	1.4	0.2	1.7	0.4	9.9
B		0.9	0.07	0.9	0.009	0.4	0.04	2.4
Belgium		13. 3	2.6	5.2	0.5	5.4	0.7	27.8
CO2-emissions, MTon, specific climate data for 1990								
Belgium		11	2.3	4.5	0.4	5.2	0.6	24.8

Even in a small country like Belgium residential energy consumption is impressive. CO_2-release in turn reaches 27 800 000 Tons per year, with oil as the major contributor, 47.5% of the total.

Next stands electricity, with 21%. Gas represents a more moderate 18% for 26% of the energy consumed. The deviation on the total introduced by the climate equals 12%, which is larger than the 7.5% decrease between 1990 and 2012, inscribed for Belgium in the Kyoto protocol. In case no climate correction will be applied and an equal share of the decrease between all energy consumers is imposed on a national level, 25.98 MTons of TRY-related CO_2 release in the residential sector should be the limit in 2012.

Table 7 was validated through a comparison with a top-down analysis for the Walloon region (Flamant, 1997). The difference was only 0.4% for the total consumption. Per vector, however, the variations were larger, with a maximum of 26.1% for 'other'.

The future

Table 8 gives the energy consumption and related CO_2-emissions in the residential sector for the years 2000, 2005, 2010 and 2015. In all six combinations of housing policy and increase in number of households, the positive impact of a better energy efficiency is obvious. A positive impact yet does not mean a decrease in consumption, see a high increase of the number of household, business as usual and a K55 or K40 energy efficiency legislation beyond 2000. In case the number of households follows the line of high increase and housing policy remains business as usual, then 25.98 Mtons CO_2-release in 2012 demands for a very strict energy performance legislation for new construction beyond 2000. The annual consumption per square meter of floor area for heating should not pass 180 MJ, and very though U-factors for roofs, floors, walls and windows (U=0.5 W/(m².K) for walls, 1.2 W/(m².K) for floors, 0.2 W/(m².K) for roofs and 1.3 W/(m².K) for glass) must be imposed in the case of retrofit. Things relax in case the number of households stabilize at a low increase. Then even a K55 legislation staying unchanged until 2015, suffices to reach the 25.98 Mtons target.

Table 8 Residential energy consumption and related CO_2-emissions for Belgium, prognosis for 2000, 2005, 2010 en 2015 as a function of housing policy (HP), housing demand (HH) and energy policy (EE-policy, the four scenario's listed) (TRY-year Ukkel)

HP.	HH	Energy consumption PJ															
		2000				2005				2010				2015			
EE-policy →		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	low	364	364	364	364	355	347	347	337	349	333	327	317	349	327	314	304
	high	376	376	376	376	381	372	372	362	387	370	364	355	398	375	364	354
2	low	360	360	360	360	347	336	336	324	332	312	302	391	327	297	277	268
	high	372	372	372	372	372	360	360	350	369	349	339	329	377	347	327	317
3	low	363	363	363	363	349	338	338	328	324	303	293	282	304	273	254	244
	high	375	375	375	375	368	357	357	347	343	322	312	301	323	292	273	263
HP.	HH	CO2-emissions MTon															
		2000				2005				2010				2015			
EE-policy →		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	low	27.0	27.0	27.0	27.0	26.2	25.6	25.6	24.7	25.8	24.6	24.1	23.3	25.7	24.1	23.2	22.4
	high	27.8	27.8	27.8	27.8	28.1	27.4	27.4	26.6	28.5	27.3	26.8	26.0	29.2	27.7	26.7	25.9
2	low	26.7	26.7	26.7	26.7	25.6	24.8	24.8	23.9	24.5	23.0	22.1	21.3	24.2	21.9	20.4	19.6
	high	27.6	27.6	27.6	27.6	27.3	26.7	26.7	25.8	27.2	25.7	25.0	24.1	27.7	25.6	24.1	23.2
3	low	26.9	26.9	26.9	26.9	25.8	24.9	24.9	24.1	24.0	22.3	21.6	20.7	22.4	20.2	18.8	17.9
	high	27.7	27.7	27.7	27.7	27.2	26.3	26.3	25.5	25.4	23.4	23.0	22.1	23.9	21.6	20.2	19.3

Switching from business as usual to more retrofit and reconstruction and a restricted expansion of the housing stock diminishe energy consumption and CO_2 release independent of the increase in the number of households. For a high demand, a K40 legislation for new constructions in combination with tougher U-factors for retrofit from 2001 on, realizes the 7% decrease in 2015. Combining a demand guided retrofit and reconstruction, no expansion of the housing stock beyond 2010, with the energy policy scenario 4 could even diminish CO_2-emissions in 2015 with 31 to 36%, compared to 1990. This scenario however imposes a heavy burden on a building industry, which is client and market oriented without much concern for societal consequences of its activity. She shows no overwhelming willingness to adopt tough energy efficiency requirements as a fear for a building cost increases and associated turn over decreases is much stronger than any concern for sustainable construction.

Obstacles that complicate energy efficient retrofit

Promoting energy efficient retrofit of the existing building stock is very important for lowering the national end use bill and related greenhouse gas emissions. Table 9 therefore reviews all parameters that impact energy consumption for heating in moderate and cool climates. Exterior climate and building use does not differ between new construction and retrofit. Building design, however, is marked by freedom in new and existence in retrofit. Compactness may be low. Orientation may be wrong. Both are difficult to change. Floor plan is easier to adapt. Also the glazed surface, thermal insulation and air-tightness could be more easily upgraded. Figure 2 shows that such upgrade is very efficient. However, several obstacles may complicate the decisions. To mention a few:

Famous architect	Forget any change to the facade and the windows. Thermal bridges may stay for ever. Only roofs and glass could get a better thermal performance.
Brick facades	Building control may forbid changing that aspect. This eliminates the most effective measure, exterior insulation, as a candidate for a thermal upgrade.
Mold risk	Exchanging existing windows with single glass for tighter ones with well insulated glass panels (see table 10) may increase dust deposit and mold risk on thermal bridges, that cannot be cured, considerably.
Costs	Some measures, although very energy efficient, that are very expensive may not pass a net present value analysis covering the sum of investment, maintenance and energy cost.
No interest in energy	As the energy bill is quite low compared to other annual costs (holiday, phone calling, taxation, etc.), not so many owners and tenants are motivated for an extreme energy efficiency. Some are even not willing to

	invest in energy efficiency measures	

Table 9 Parameters of influence on the energy demand and energy consumption for heating in a cool climate

GROUP	PARAMETER	INFLUENCE (other parameters equal)
DEMAND		
1. Exterior climate	**Temperature**	**Demand increases with lower outside temperatures**
	Solar irradiation	Demand decreases with increasing gains
	Wind	Demand increases with higher average wind velocities
	(Rain)	(Demand increases with higher rain intensities)
2. Building use	**Inside temperature**	**Demand increases with higher inside temperatures**
	Temperature control	Demand decreases when the principle 'heating only one present' is better applied
	Ventilation	**Demand increases together with ventilation**
	Free gains	Demand decreases with higher free gains
3. Building design	Compactness	Demand decreases when the compactness increases
	Floor plan	Demand decreases when the floor plan is correctly organised
	Type, area, orientation and slope of the glazed surfaces	Demand increases with a larger glass area. She decreases in case the glass has a higher solar transmissivity, in case more glass is oriented W-S-E and in case the glass slope is close to vertical
	Thermal insulation	**Demand decreases with a lower average U-factor of the envelope**
	Thermal capacity	Demand is hardly influenced by the thermal capacity of the building construction
	Air leakage	**Demand decreases with a lower air leakage of the envelope**
CONSUMPTION		
4. Heating system	Type of fuel	Defines the achievable efficiency.
	Efficiency (production, distribution, control, emission)	Consumption devreases with a higher overall efficiency (see building services)

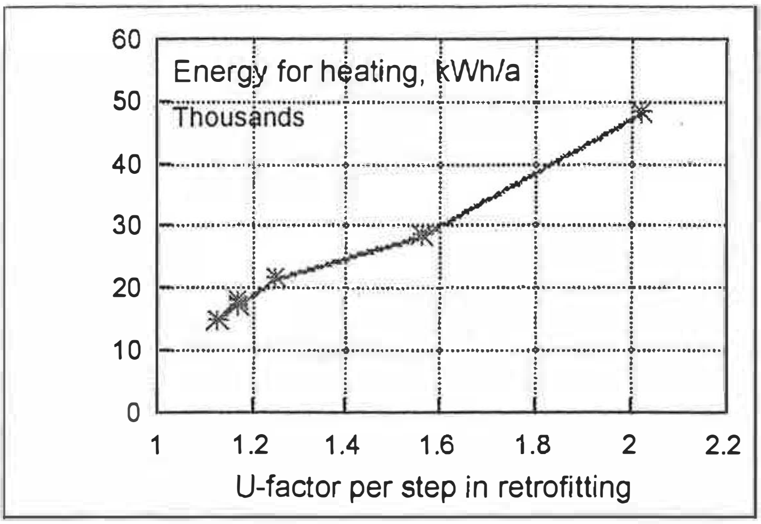

Figure 1 Energy retrofit of an existing building. Energy consumption for heating as a function of the average U-factor (Hens, 1993)

Table 10 Types of glazing

Type	**U-factor W/(m².K)**	**g** -	g_{visual} -
Single glass	5.9	0.81	0.90
Double glazing	3.0	0.72	0.80
Low e double glazing	1.8	0.63	0.70
Gas filled low-e double glazing (argon)	1.3	0.58	0.75
Gas filled low e double glazing (krypton)	1.1	0.58	0.75
Gas filled low e triple glazing (krypton)	0.7	0.50	0.65

Discussion

To be completed during the meeting.

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