KU LEUVEN

EG-Meeting
10/10/2022

Energy-efficient building construction and renovation, not a straightforward story

Hugo Hens
Professor Emeritus
Department of Civil Engineering
Section Building Physics and Sustainable Construction

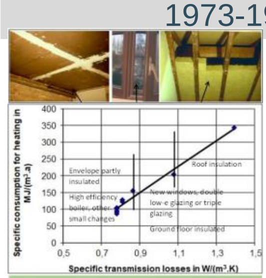
Content

- Introduction
- 1973-1992: no requirements
- Steps taken
  - 1992: insulation and ventilation decree
  - 1/1/2006: EPR introduced
  - Up to NZEB
- What with renovation?
- Predicted versus measured energy use for heating
- Carbon-neutrality?
- Conclusions

Introduction

To Remind
1973: 1th oil crisis
Car-free Sundays,
1976: start research on energy use in buildings, emphasis on economical aspects
1979: 2d oil crisis
Intensification of the named research
Years 1980
Energy prices dropping, research on energy use in buildings loosing impetus.
'Global warming' surging as new motivation

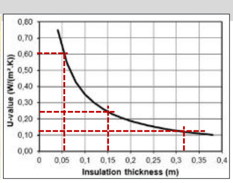
1973-1992: no requirements



Insulation and air-tightening roof
Before: U=2,5 W/(m².K)
After : U=0,3 W/(m².K)

Germany, the Netherlands:
Insulation requirements, advancing U-values for all envelope parts.
Not so in Flanders
Anyhow: from 1981 on, inhabited dwelling used as research object.

Interlude

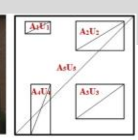


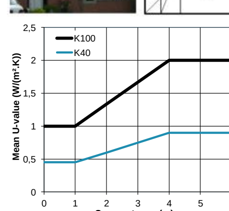
Thermal transmittance or U-value in W/(m².K)

$$U = \frac{1}{1/h_e + R + 1/h_i} \quad \text{with } R = \sum_{i=1}^{n} (d_i/\lambda_i)$$

in which:
R is the total thermal resistance in m².K/W
h_e, h_i the out- and inside surface film coefficient in W/(m².K)
d_i the thickness of each layer in m
λ_i the thermal conductivity of each layer in W/(m.K)

Interlude





Compactness C (m) =Protected volume divided by loss surface

Mean thermal transmittance in W/(m².K)

$U_m = U_i A_i / \Sigma A_t$

Level of thermal insulation

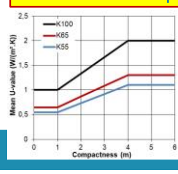
$C \le 1$	$K = 100 U_m$
$1 < C \le 4$	$K = \frac{100 U_m}{C/3 + 2/3}$
$4 < C$	$K = 50 U_m$

Steps taken: 1992, insulation and ventilation decree

Envelope assemblies	U_{max}(W/(m².K)) **R_{min} (m².K/W)** **1992**
Walls, roofs and windows	
Windows as a whole	3.5
The glazing	
Roofs and upper ceilings	0.6
Opaque walls	0.6/*1.0*
Curtain walls as a whole	3.5
Opaque walls below grade	/**1**
Floors	
Contacting the outside air	0.6
Above a non frost)free space	0.6
Above a frost-free space	0.9
On grade	1.2
Other	
Outside doors and gates	3.5
Party walls	1.0
Partition walls between apartments	1.0
Walls contacting cellars and crawlspaces outside the protected volume	/**1**

New residential buildings
18/9/1992: U_{max} for envelope parts
Level of thermal insulation K65,
after 18/9/1993: K55
Designed ventilation system
in social houses

Neither controls nor fines = widespread laxity



Steps taken: 1/1/2006 EPR introduced

Envelope assemblies Year→	U_{max}(W/(m².K)) **R_{min} (m².K/W)** 1992	2006
Walls, roofs and windows		
Windows as a whole	3.5	2.5
The glazing		1.6
Roofs and upper ceilings	0.6	0.4
Opaque walls	0.6/*1.0*	0.6
Curtain walls as a whole	3.5	2.9
The glazing		1.6
Opaque walls below grade	/**1**	/**1**
Floors		
Contacting the outside air	0.6	0.6
Above a non frost)free space	0.6	0.4 /**1**
Above a frost-free space	0.9	0.4 /**1**
On grade	1.2	0.4 /**1**
Other		
Outside doors and gates	3.5	2.9
Party walls	1.0	1.0
Partition walls between apartments	1.0	1.0
Walls contacting cellars and crawlspaces outside the protected volume	/**1**	/**1**

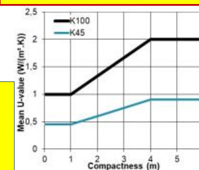
$E=100(E_{prim\ H,\ DHW,\ C}/E_{prim,\ ref})$

$E_{prim\ H,\ DHW,\ C}$ calculated annual primary energy used, MJ/a

$E_{prim,\ ref}=115A_{T,E}+70V_{EPW}+105Vent_{dedic,ref}$, MJ/a, the reference with $A_{T,E}$ loss surface, m², enclosing the protected volume V_{EPW}, m³, and $Vent_{dedic,ref}$ reference ventilation flow, m³/h

E-Level new reference
Requirements
U_{max} lowered
E100 , K45
Designed ventilation system

Control and Fines if not

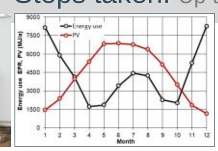


Steps taken: Up to NZEB

Envelope assemblies Year→	U_{max}(W/(m².K)) / **R_{min} (m².K/W)** 1992	2006	2010	2012	2014	2015	2016-..
Walls, roofs and windows							
Windows as a whole	3.5	2.5	2.5	2.2	1.8	1.8	1.5
The glazing		1.6	1.6	1.3	1.1	1.1	1.1
Roofs and upper ceilings	0.6	0.4	0.3	0.27	0.24	0.24	0.24
Opaque walls	0.6/*1.0*	0.6	0.4	0.32	0.24	0.24	0.24
Curtain walls as a whole	3.5	2.9	2.9	2.2	2.0	2.0	2.0
The glazing		1.6	1.6	1.3	1.1	1.1	1.1
Opaque walls below grade	/**1**	/**1**	/**1**	/**1.3**	0.4/**1.5**	0.4/**1.5**	0.24
Floors							
Contacting the outside air	0.6	0.6	0.6	0.35	0.3	0.3	0.24
Above a non frost)free space	0.6	0.4 /**1**	0.4 /**1**	0.35 /**1.3**	0.3 /**1.75**	0.3 /**1.75**	0.24
Above a frost-free space	0.9	0.4 /**1**	0.4 /**1**	0.35 /**1.3**	0.3 /**1.75**	0.3 /**1.75**	0.24
On grade	1.2	0.4 /**1**	0.4 /**1**	0.35 /**1.3**	0.3 /**1.75**	0.3 /**1.75**	0.24
Other							
Outside doors and gates	3.5	2.9	2.9	2.2	2.0	2.0	2.0
Party walls	1.0	1.0	1.0	1.0	1.0	0.6	0.6
Partition walls between apartments	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Walls contacting cellars and crawlspaces outside the protected volume	/**1**	/**1**	/**1**	/**1.2**	/**1.4**	/**1.4**	0.24

2010-2016
U_{max} stricter
+ additionally
2010
E80; K45
2012
E70, K40
2014
E60, K40, + renewables: solar boiler, PV, heat pumps
2016
E50 , K40, renewables

Steps taken: Up to NZEB



S-level

1. Number with units kWh/(m².a)

$$S-\text{level}=\frac{1}{3.6}\left(\frac{Q_{heat,env}+Q_{cool;env}}{A_{sphere,EPR}}\right)$$

$$A_{sphere,EPR}=4\pi\left(\frac{3V_{EPR}}{4\pi}\right)$$

Characterizes envelope and thermal inertia

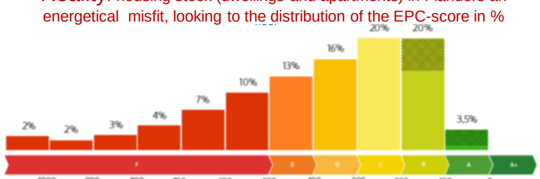
2. In $Q_{heat,env}$ and $Q_{cool,env}$ 3 terms (thermal insulation of the envelope, solar gains through the windows, air tightness of the envelope)
3. Active cooling the reference

2018
E40, S-level replacing K-Level, S32, renewables
2020
E35, S32, renewables
2021
E30, S28, renewables (heat pumps mandatory) ((n)ZEB?)

(n)ZEB not really zero energy
Often gas for heating during cold months,
PV-electricity during warm months

What with renovation?

Reality: housing stock (dwellings and apartments) in Flanders an energetical misfit, looking to the distribution of the EPC-score in %



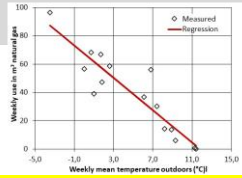
Evaluation tool: EPC-score, calc. energy use in kWh/(m².a)

A+	Less than 0 kWh/(m².a)
A	0 to 100 kWh/(m².a)
B	100 to 200 kWh/(m².a)
C	200 to 300 kWh/(m².a)
D	300 to 400 kWh/(m².a)
E	400 to 500 kWh/(m².a)
F	More than 500 kWh/(m².a)

Objective: carbon-neutrality in 2050
Needs buildings emitting few CO_2
What so ever required
Whole housing stock **EPC a** in 2050
Demands 3%/year renovation speed. Now 1%/year

What with renovation?

Problems
May demand extensive renovation
Means costs, many people cannot afford
Average habitation by owners 30 years
Renovation mostly when a residence changes owner, so, each 30 years
Landlords not motivated to renovate their rented housing stock
Etc.



What with renovation?

Example of a deep renovation

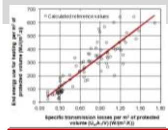
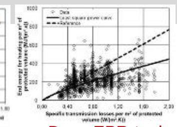
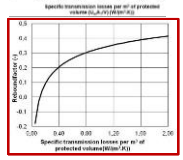
Outside walls	: 12 cm MW, 1 wall 21 cm MW
Low slope roof	: 20 cm PIR
Floor	: 10 cm sprayed PUR, cement screed above
Windows	: hard wood, low-e argon-filled DG / south sun reflecting
Air tightness	: n_{50}=3 h^{-1} (measured)
Heating	: Low temperature radiators, gas, condensing boiler
Hot water	: boiler-coupled
Ventilation	: extract, demand controlled

Result:
If new construction: K28, E54
Gas use : Calc.: 1710 m³/a, meas.: 970 m³/a

As retrofit: EPC a (<100 kWh/(m².a)
Calc.: 55 kWh/(m².a), meas.:31 kWh/(m².a)




Predicted versus measured energy use for heating

Does EPR-tool give trustworthy energy uses?
Not really!
Rebound, due to user habits, tempering use.
Calculated for and measured in 1050 units gives on average:
$E_{H,meas,a}=(1-a)E_{H,calc,a}$, a: rebound factor

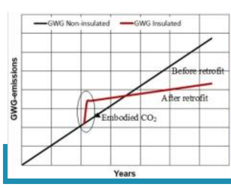
Why?
Day-night control, so not constantly18°C as assumed
Sleeping rooms hardly heated
Bathroom only heated when used

Carbon-neutrality?

Important, looking to global warming

Facts
Energy consumption by building use only one side of the story
Other: embodied energy

Same for carbon
Besides being emitted by building use, also embodied (material production, transport, building site activity)



Carbon-neutrality?




Best choices
For new construction, stepping to (n)ZEB
For new and existing, heat pumps mandatory, on condition electricity carbon-free
For new, move to timber based construction?

But
Some important performances of timber frame for inhabitants a problem

- Hardly thermal inertia, makes active cooling necessary
- Worse moisture tolerance than stony construction
- Fire safety more critical than for stony construction

Conclusions


- New residential construction clearly moving towards nZEB
- Existing residential premisses a true problem, **EPC a** in 2050 a necessity
- Happily, calculated energy use for heating according to EPR-method overestimating real use
- Embodied carbon important. Must force building industry, transport to and work at building sites to go for as much as doable to carbon-free energy use

Thanks for your attention