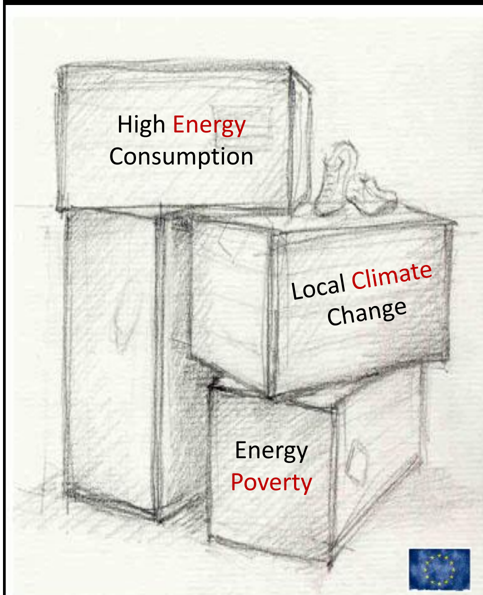
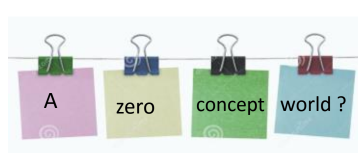
Energy Consumption in the European Built Environment
The Role of Cooling

M. Santamouris



The major problems of the built environment in Europe



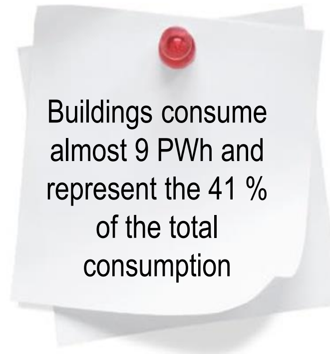
The total European building stock is close to 24 billion m^2 and almost 75 % of them are residential buildings with an average floor space close to 87 m^2 per dwelling while the rest is tertiary buildings.

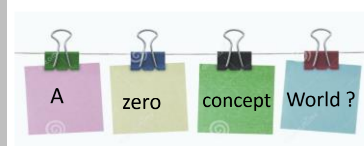
Almost 27 % of the total energy consumption in Europe is spent by residential buildings, while the rest, 14 % is consumed by the tertiary sector.

The average building energy consumption in the European Union countries , varies between 320 kWh/m^2/y in Finland and 150 kWh/m^2/y in Bulgaria and Spain, with a mean value close to 220 kWh/m^2/y.

Large differences in energy consumption exist between residential and tertiary buildings.

Dwellings consume on average almost 200 kWh/m^2/y while the mean consumption of the non residential buildings is close to 295 kWh/m2/y.





The energy consumption of the tertiary sector has a constant increase during the last 30 years. The increase rate is 1,1 % for the years 2010-2020.

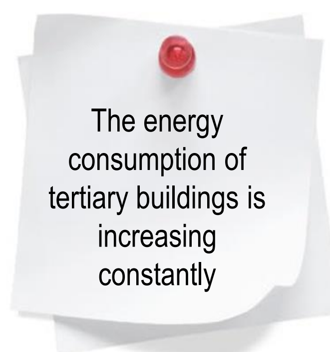
Increase of the energy demand is because of the evolution of the services sector that increased by 1,3 % per year.

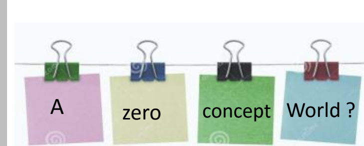
Services will be responsible for the 93 % of the additional energy to be consumed by tertiary buildings between 2000-2030.

Trade and office buildings are the largest energy consumers accounting each for about the 26 % of the global consumption of the tertiary buildings.

Space heating seems to be the end use presenting the higher energy consumption.

Energy spent for heating presents a constant decrease over time as a result of the important energy conservation measures applied in tertiary buildings.



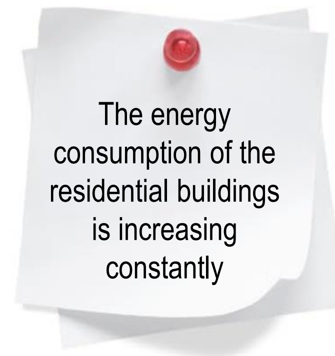


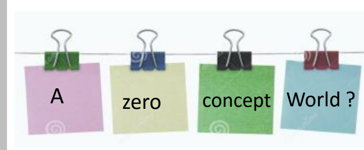
Despite the strict legislative framework, and the significant improvement of the energy efficiency, (1,4 % per year), the energy consumption of the residential buildings increased by 14 % between 1990 and 2012.

The electricity use increased by 60 % because of the very rapid penetration of electronic appliances and devices.

The final energy consumption in the residential sector in EU-27 was 307,321 ktoe in 2010, while the corresponding consumption for the year 1990, was 273,384 ktoe.

Increase of the energy consumption is attributed to various economic, social, political and technical reasons and mainly to the increase of the number of households and the increase of the occupied space per person





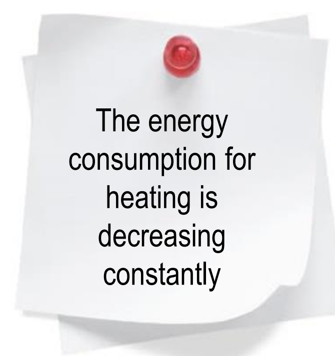
Although the total energy consumption of buildings has increased, the specific consumption for heating purposes has decreased to about 15 % during the period 1997-2009.

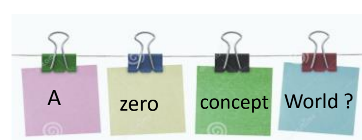
This may be attributed to the considerable lower consumption of the new dwellings built after 1997, representing almost 20 % of the total dwelling stock in 2009.

New dwellings consume almost 30-60 % less thermal energy than houses built before 1990,

Dwellings built in 2009 in Germany, present almost 58 % less energy consumption than those built in 1990.

The corresponding energy reductions in Sweden, Denmark, Slovakia and the Netherlands are 55 %, 53 %, 52 % and 50 %.

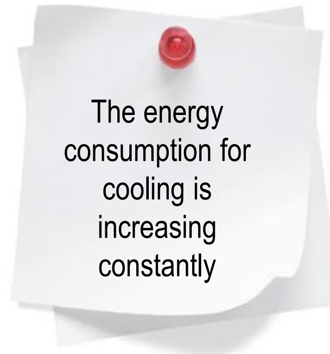


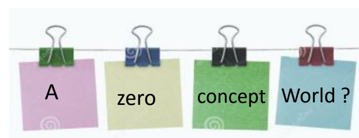


Space heating is the most energy consuming end use representing 71% of the total consumption of households, followed by water heating with 12%, cooking with 4% and lighting, air conditioning and other appliances with 15%,

Energy consumption for cooling is increasing rapidly in most of the Southern European countries. The highest cooling energy consumption is presented in Cyprus, where dwellings are spending about 670 kWh per year, followed by Malta with 540 kWh/year.

Very high increasing rates are observed in most of the southern European Countries because of the very rapid penetration of air conditioners. In particular, between 2005 and 2009 the energy consumption for cooling has increased almost by 100 % in Bulgaria, and by 30% in Spain and Italy,





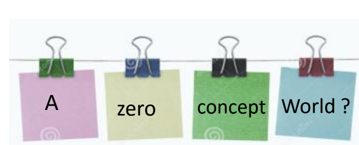
Energy consumption in the building sector is subject to significant economic, environmental and social factors and perturbations.

Past and present experience demonstrate that it is an extremely sensitive sector presenting a high variability in economic and environmental variations.

Financial problems oblige part of the population to consume less energy and satisfy partly their needs.

It is characteristic that during the financial crisis of 2007-2012 the energy consumption of the residential buildings has decreased by 4 %, while in countries with a deeper economic problem like Portugal, Slovakia and Ireland the decrease was 16 %, 22 % and 22 % respectively.

It is characteristic that because of the serious economic recession in Greece, the consumption of heating oil was reduced by 68,7 % in just one year,



The Cooling energy consumption is increasing because of the following reasons :

a) Increase of the living standards

b) Non appropriate quality of the building stock

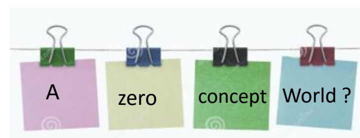
c) Global and Local Climate Change

d) Rapid Penetration of Electric and Electronic Appliances

e) Lack of Awareness on Alternative Cooling Technologies

f) Low peak electricity Prices for everyone

Why Energy Consumption for Cooling is increasing ?

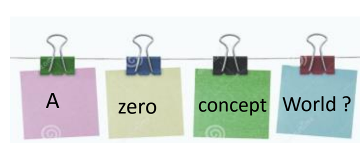


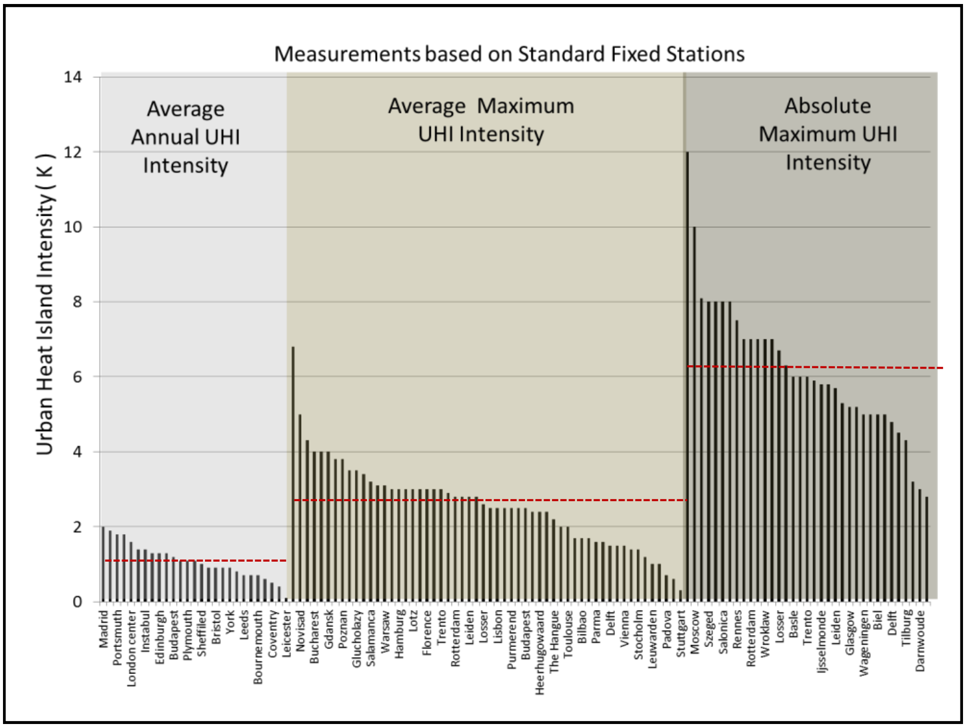
Climate change is a major issue for Europe. Increase of the ambient temperature and higher frequency of heat waves have an important impact on the energy and environmental quality of the built environment and increase the vulnerability of the local population.

Given that 74 % of the European population live in urban zones, urban climatic conditions and local urban climate change affect a very significant part of the European population and have a serious impact on the global energy and environmental quality of the built environment.

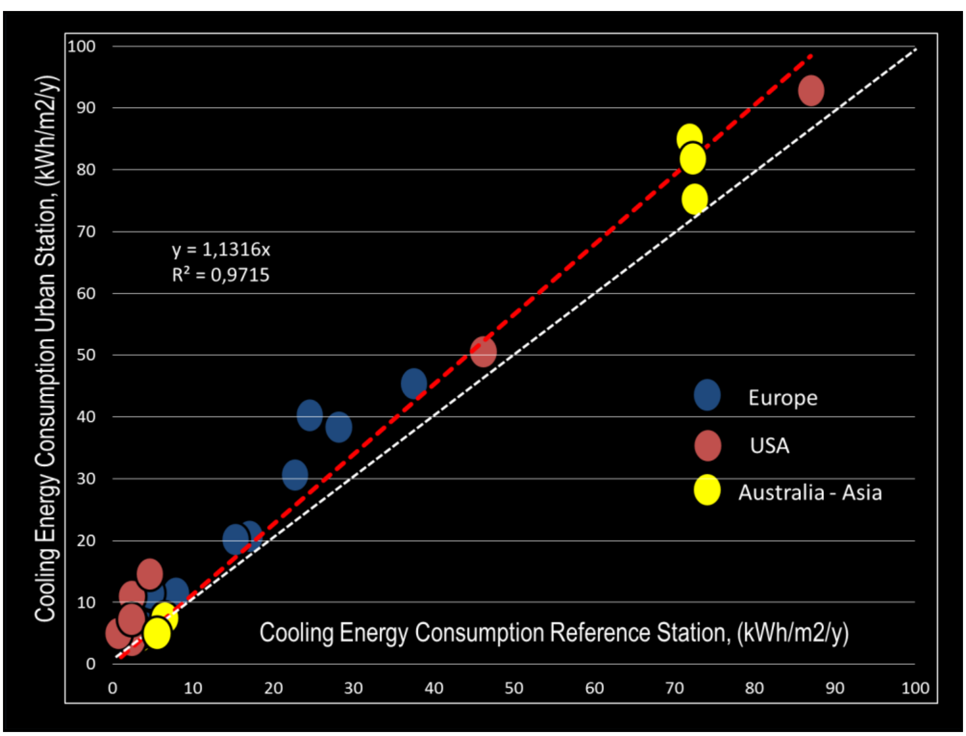
Higher urban temperatures increase the energy consumption for cooling, raise the concentration of pollutants, deteriorate thermal comfort conditions and create important health problems to vulnerable populations

Local and Global Climate Change have a serious impact on the energy balance of Europe



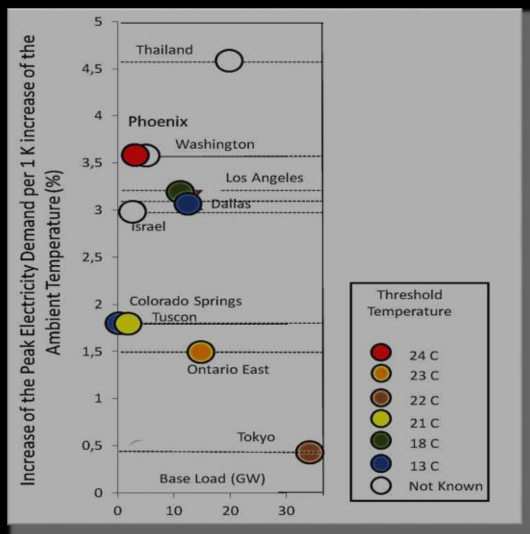


Measurements based on Standard Fixed Stations
Urban Heat Island Intensity (K)
Average Annual UHI Intensity
Average Maximum UHI Intensity
Absolute Maximum UHI Intensity



Cooling Energy Consumption Urban Station, (kWh/m2/y)
Cooling Energy Consumption Reference Station, (kWh/m2/y)
y = 1,1316x
R² = 0,9715
Europe
USA
Australia - Asia

THE IMPACT ON PEAK POWER DEMAND

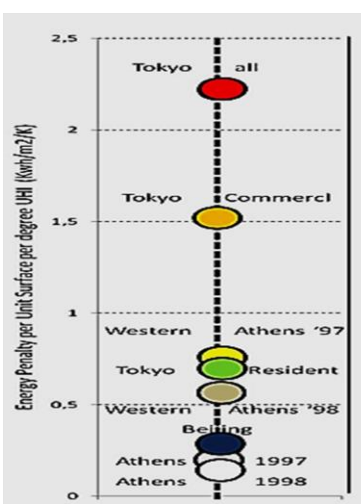


The peak electricity demand of electricity per degree of increase of the ambient temperature varies from 0,4 % for Tokyo to 4,6 % for Thailand.

In average, there is a penalty on peak electricity demand of about 20 W per person and degree of temperature increase

Source : M. Santamouris et al On The Impact of Urban Heat Island and Global Warming on the Power Demand and Electricity Consumption of Buildings–A Review, Energy and Buildings, 2015

THE IMPACT ON ENERGY



The index related to Global Energy Penalty per unit of city surface and per degree of the UHI intensity, GEPSI,

It presents the same characteristics as the GEPS index taking into account the average UHI intensity characteristics in the considered city.

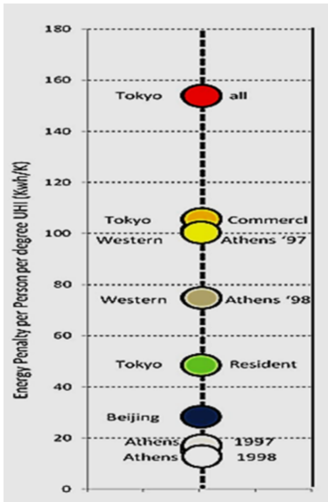
Values of GEPSI, vary between 2,2 kWh/m^2/K for Tokyo to 0,17 kWh/m^2/K for the Municipality of Athens.

UHI triggers A Global Energy Penalty per unit of city surface and per degree of the UHI intensity, GEPSI, close to

0,8 kWh/m^2/K,.

Source : M. Santamouris On The Energy Impact of Urban Heat Island and Global Warming on Buildings, Energy and Buildings, 82, 2014

THE IMPACT ON ENERGY



Global Energy Penalty per Person and per degree of the UHI intensity, GEPPI

It has the same characteristics as the GEPP index while it includes the local UHI intensity as additional information.

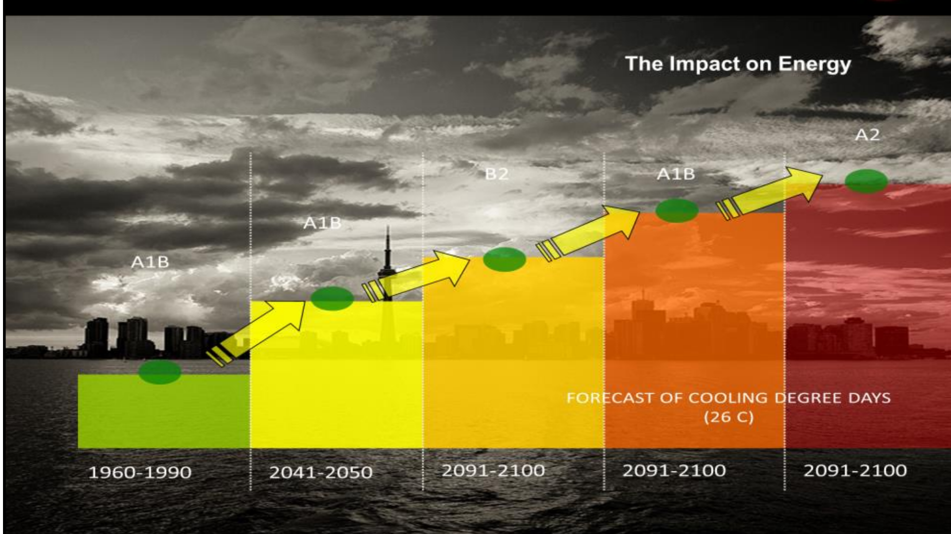
Values of GEPPI varied between 15 kWh/k for the Municipality of Athens to 154 kWh/K for Tokyo.

UHI triggers an average Global Energy Penalty per Person and per degree of the UHI intensity, GEPPI, close to

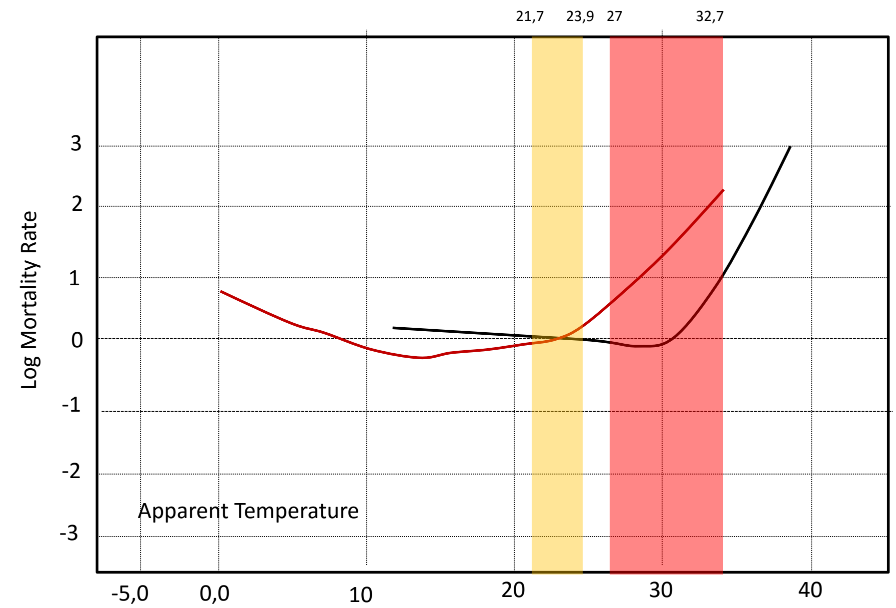
68 kWh/p/K.

Source : M. Santamouris — On The Energy Impact of Urban Heat Island and Global Warming on Buildings, Energy and Buildings, 82, 2014

FORECAST OF THE FUTURE ENERGY CONSUMPTION



Source : D.A. Asimalopoulos
M. Santamouris et al — Modelling the energy demand projection of the building sector in Greece in the 21st century Energy and Buildings, Volume 49, June 2012, Pages 488-498



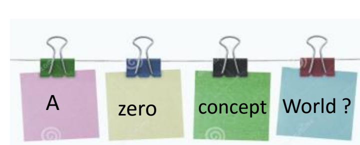
Energy poverty is a threat for Europe. Energy poverty is 'the situation in which a household lacks a socially and materially necessitated level of energy services in the home',

Energy poverty is a problem for over 150 million Europeans who are unable to pay bills and maintain comfortable standards'.

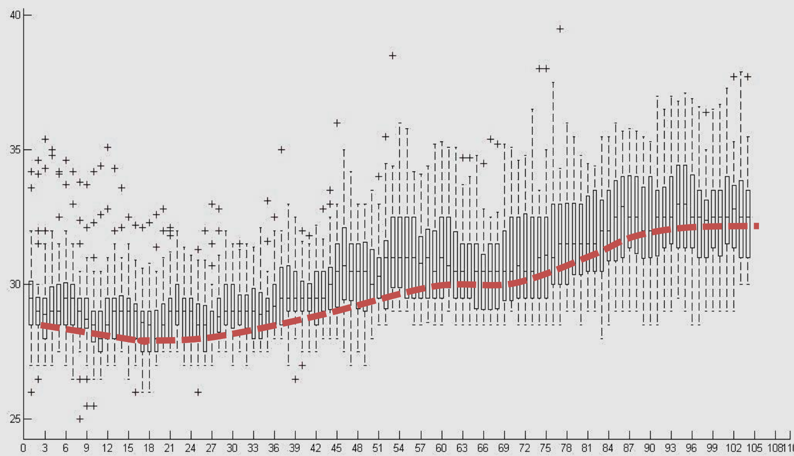
This is particularly valid for the citizens of the States with GDP below the EU average, where over 30% of the population face energy poverty.

It has a very serious impact on the quality of life of citizens affecting indoor comfort conditions, social attainment and health.

It is the result of combined factors like the insufficient family income, the poor quality and the low size of the house and the possible high energy prices, while other demographic drivers may play an important role



THE IMPACT ON INDOOR SUMMER COMFORT



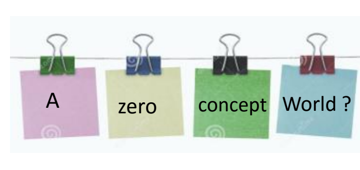
Source : A. Sakka , M. Santamouris et al — On the thermal performance of low income housing during heat waves, Energy and Buildings, Volume 49, June 2012, Pages 69-77

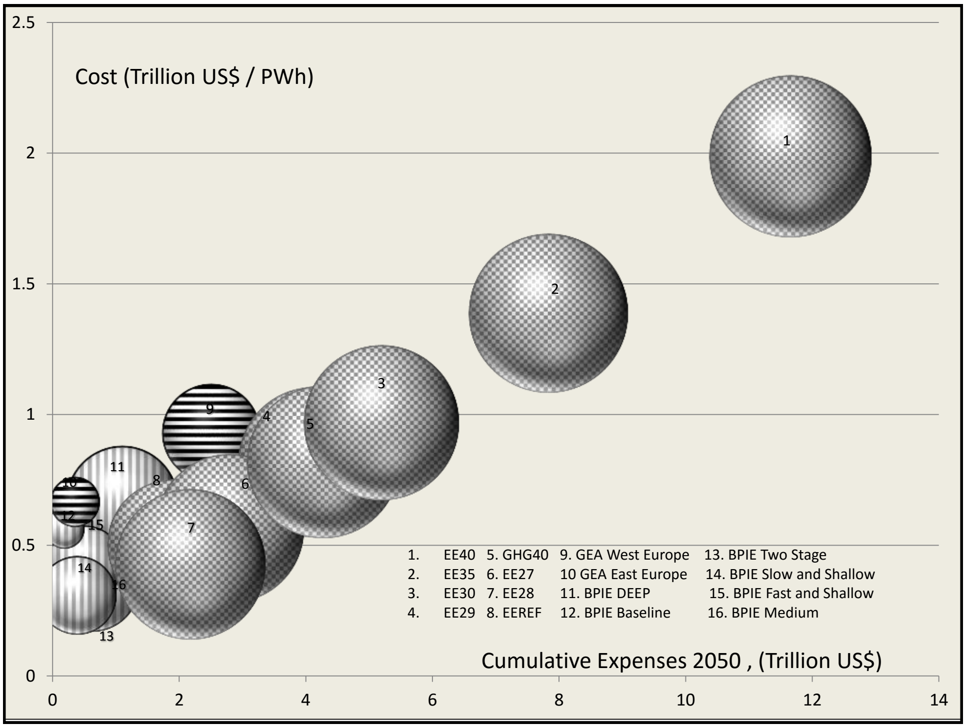
The need to reduce the energy consumption of the building sector, is widely recognized.

It can be achieved through deep retrofitting of the building stock combined with a radical reduction of the needs of the new buildings.

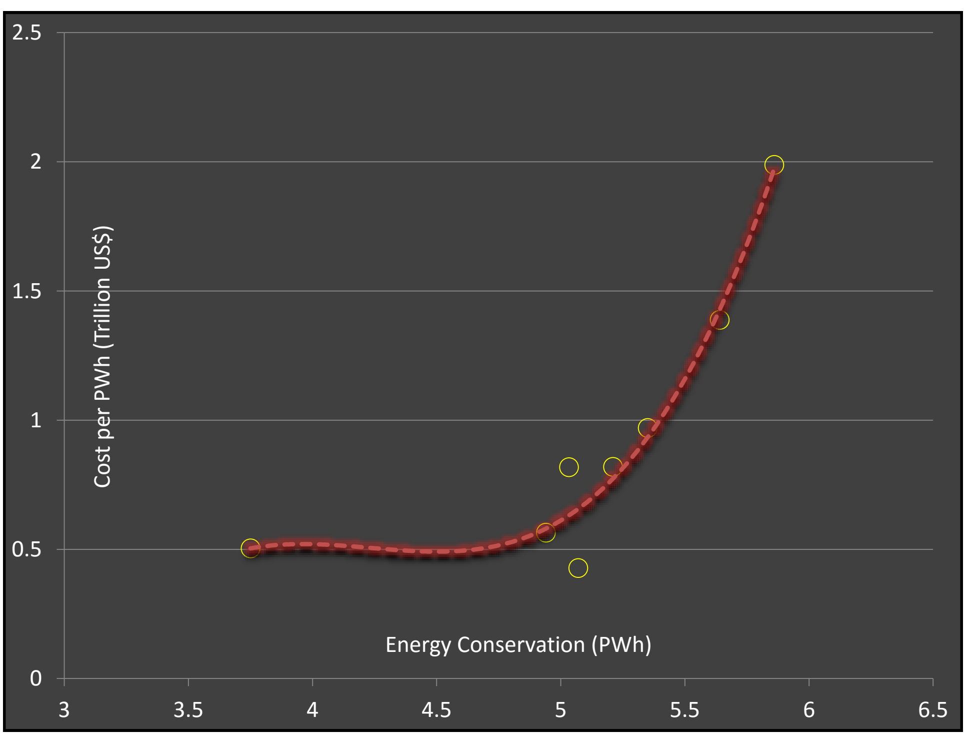
The level of the required investments to minimize the energy consumption is considerably high, while the impact on the economy and the society is very significant and may create an intensive growth while offering substantial opportunities for development.

In parallel, large scale energy investments should boost energy related scientific developments and innovations and should promote technological breakthroughs





Cost (Trillion US$ / PWh)
Cumulative Expenses 2050 , (Trillion US$)
1. EE40 5. GHG40 9. GEA West Europe 13. BPIE Two Stage
2. EE35 6. EE27 10 GEA East Europe 14. BPIE Slow and Shallow
3. EE30 7. EE28 11. BPIE DEEP 15. BPIE Fast and Shallow
4. EE29 8. EEREF 12. BPIE Baseline 16. BPIE Medium



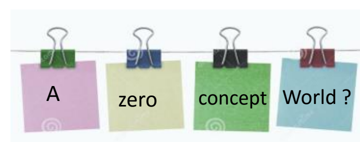
Cost per PWh (Trillion US$)
Energy Conservation (PWh)

Policies aiming to minimize the energy consumption of buildings should concentrate on three main technological axes aiming:

a) to increase the global energy efficiency of the building energy systems in order to seriously decrease the energy load and the final needs,

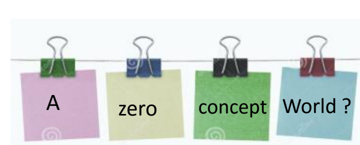
b) to supply the remaining energy load through clean and renewable technologies and

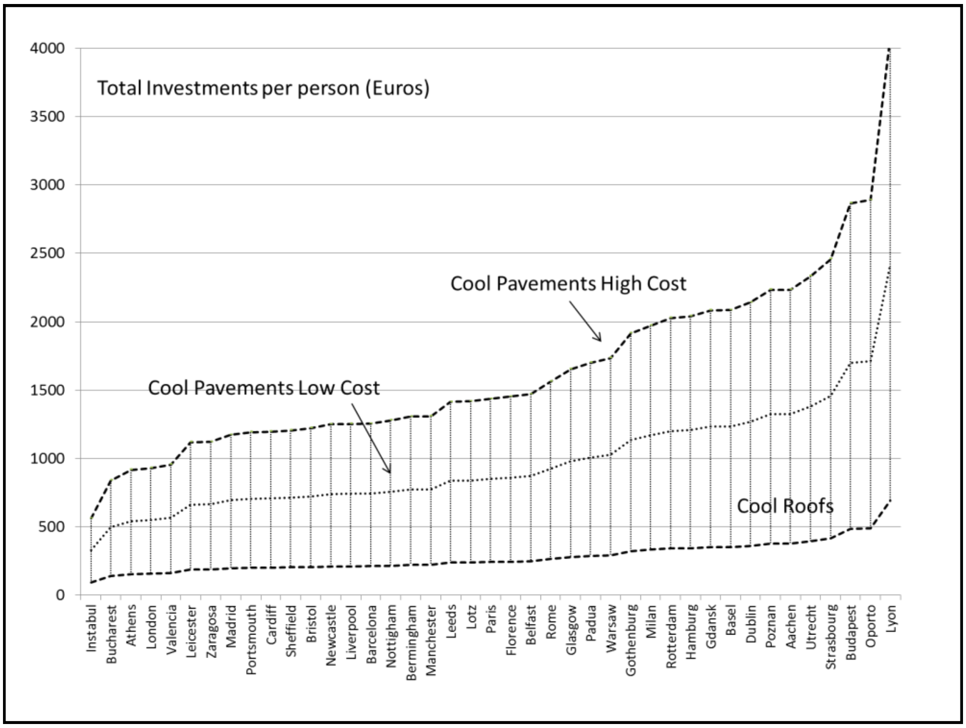
c) to optimize the management of the energy and environmental systems of the buildings through the use of smart and intelligent technologies

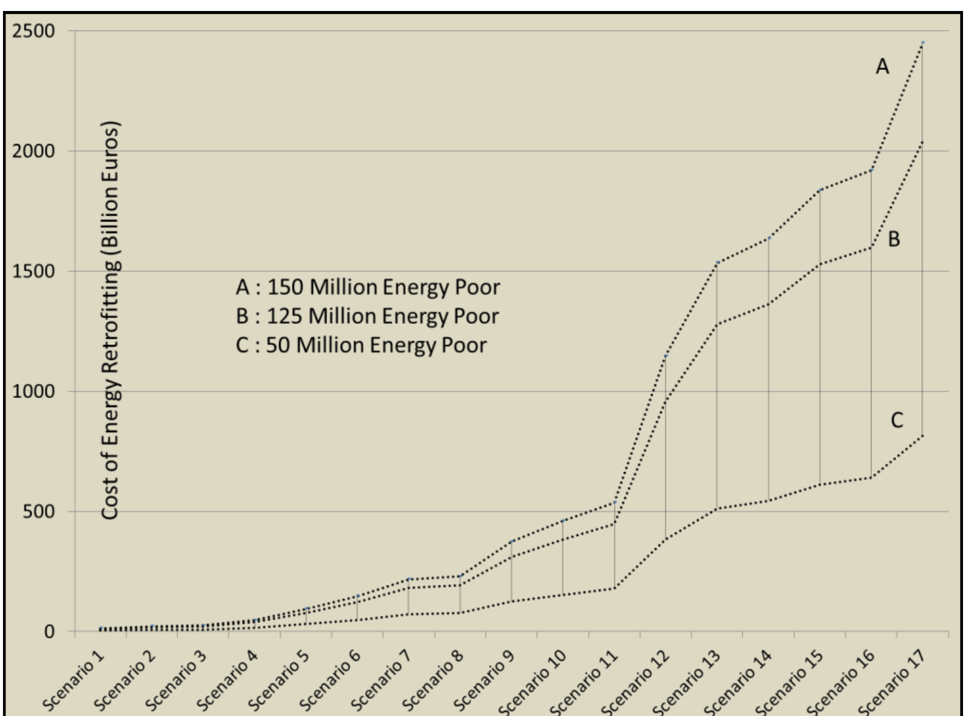


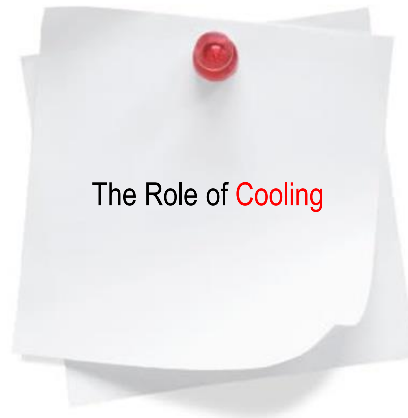
Smart products for the envelope like natural and hybrid ventilation components and cool coatings are very attractive and it is foreseen that the corresponding market will increase rapidly in the future.

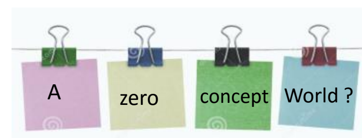
In parallel, high performance HVAC systems, are the most rapidly developing industrial sectors and it may reach 162 billion Euros by 2018 presenting a growing rate of 10,5 %.




Total Investments per person (Euros)
Cool Pavements High Cost
Cool Pavements Low Cost
Cool Roofs
4000
3500
3000
2500
2000
1500
1000
500
0
Instabul
Bucharest
Athens
London
Valencia
Leicester
Zaragosa
Madrid
Portsmouth
Cardiff
Sheffield
Bristol
Newcastle
Liverpool
Barcelona
Nottigham
Bermingham
Manchester
Leeds
Lotz
Paris
Florence
Belfast
Rome
Glasgow
Padua
Warsaw
Gothenburg
Milan
Rotterdam
Hamburg
Gdansk
Basel
Dublin
Poznan
Aachen
Utrecht
Strasbourg
Budapest
Oporto
Lyon


Cost of Energy Retrofitting (Billion Euros)
A : 150 Million Energy Poor
B : 125 Million Energy Poor
C : 50 Million Energy Poor
A
B
C
2500
2000
1500
1000
500
0
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
Scenario 7
Scenario 8
Scenario 9
Scenario 10
Scenario 11
Scenario 12
Scenario 13
Scenario 14
Scenario 15
Scenario 16
Scenario 17

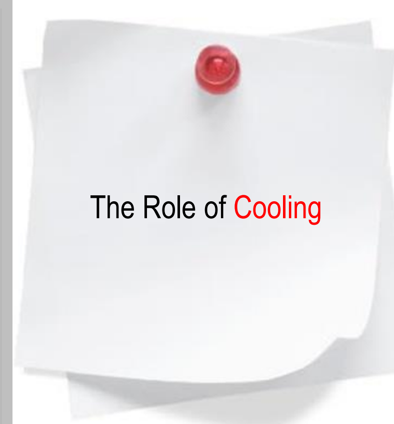


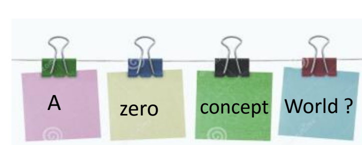


High Energy consumption of the building sector, local climate change and energy poverty are the major problems of the built environment in Europe. Cooling is increasing rapidly and may be the major consumption component in the future.

The three sectors are strongly interrelated presenting very significant synergies

Existing policies aiming to reduce the energy consumption of the buildings usually underestimate the importance and the impact of the local and global climate change as well as the technical, social and economic implications related to the energy poverty.





Failure to consider all issues in an integrated and holistic way may inevitably result in higher energy consumption for cooling and social discrepancies.

Innovating to zero the built environment of Europe assumes a minimization of the energy consumption of buildings, eradication of the energy poverty and mitigation of the urban heat island and the local climate change.

Such an objective, although it seems very ambitious is an unequivocal choice that will create substantial opportunities for future growth and will alleviate the population from the consequences of the specific problems and will create short, medium and long term benefits and opportunities.

Ventilative cooling in the Belgian regulation

dr Geoffrey Van Moeseke
Architecture et Climat, UCLouvain, Belgium

QUALICHeCK webinar
in cooperation with IEA Annex 62, venticool, and AIVC

Context

- Belgian epbd based on ISO 13790 monthly balances
- Authorities straigthened cooling demand requierement for offices and schools (<15kWh/m²a)
- Field worried about feasibility and cooling need calculation method

Actual method

$$Q_{cool,net,\sec i,m} = 1.1\ p_{cool,\sec i}(Q_{g,cool,\sec i,m} - \eta_{util,cool,\sec i,m} Q_{L,net,\sec i,m})$$

$$Q_{L,cool,\sec i,m} = Q_{T,cool,\sec i,m} + Q_{V,cool,\sec i,m}$$

Air quality and uncontroled infiltrations only

Probabiblity that active cooling will be used determined based on « excess energy » estimation

Conventional factor : cooling device surface condensation

Questions

- No intermittence ?
- Conventional 1.1 factor ?
- Active cooling probability factor ?
- Temperature hypothesis ?
- Ventilative cooling ?

Modified method

$$Q_{\text{cool, gross, fct f,m}} = a_{lat,cool} \cdot \frac{Q_{\text{cool, net, fct f,m}}}{\eta_{\text{sys,cool}}}$$

Conventional factor : cooling device surface condensation

$$Q_{cool,net,\text{fctf},m} = a_{cool,int,fctf,m}(Q_{g,cool,fctf,m} - \eta_{util,cool,fctf,m} \cdot Q_{L,cool,fctf,m})$$

No more cooling probability : a cooling need is calculated for all offices and schools… but ventilative cooling is now considered

EN ISO 13790 intermittence factor

$$a_{cool,int,fctf,m} = max\left[f_{cool,fctf}; 1 - 3\frac{\tau_{0,cool}}{\tau_{cool,fctf}} . \gamma_{cool,fctf,m}(1 - f_{cool,fctf}\Big)\right]$$

Modified method

$$Q_{V,cool,fctf,m} = \begin{bmatrix} H_{V,hyg,cool,fctf,m} \cdot (\theta_{i,cool} - \theta_{e,V,cool,day,m}) \\ +H_{V,add,cool,day,fctf,m} \cdot (\theta_{i,cool} - \theta_{e,V,cool,day,m}) \\ +H_{V,add,cool,night,fctf,m} \cdot (\theta_{i,cool} - \theta_{e,V,cool,night,m}) \\ +H_{V,in-exfiltr,cool,fctf,m} \cdot \left(\theta_{i,cool} - (\theta_{e,m} + \Delta\theta_{e,m})\right) \\ +H_{V,nat,cool,day,fctf,m} \cdot \left(\theta_{i,cool} - (\theta_{e,m} + \Delta\theta_{e,m} + \Delta\theta_{e,day,m})\right) \\ +H_{V,nat,cool,night,fctf,m} \cdot \left(\theta_{i,cool} - (\theta_{e,m} + \Delta\theta_{e,m} + \Delta\theta_{e,night,m})\right) \end{bmatrix} . t_m$$

Distinction between IAQ, infiltration, natural ventilative cooling and mechanical ventilative cooling

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Modified method

$$
Q_{V,cool,fctf,m} = \begin{bmatrix} H_{V,hyg,cool,fctf,m} \cdot \left(\theta_{i,cool} - \theta_{e,V,cool,day,m}\right) \\ +H_{V,add,cool,day,fctf,m} \cdot \left(\theta_{i,cool} - \theta_{e,V,cool,day,m}\right) \\ +H_{V,add,cool,night,fctf,m} \cdot \left(\theta_{i,cool} - \theta_{e,V,cool,night,m}\right) \\ +H_{V,in-exfiltr,cool,fctf,m} \cdot \left(\theta_{i,cool} - \left(\theta_{e,m} + \Delta\theta_{e,m}\right)\right) \\ +H_{V,nat,cool,day,fctf,m} \cdot \left(\theta_{i,cool} - \left(\theta_{e,m} + \Delta\theta_{e,m} + \Delta\theta_{e,day,m}\right)\right) \\ +H_{V,nat,cool,night,fctf,m} \cdot \left(\theta_{i,cool} - \left(\theta_{e,m} + \Delta\theta_{e,m} + \Delta\theta_{e,night,m}\right)\right) \end{bmatrix} . t_m
$$

Monthly mean value corrected to match last decade warming climate

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Modified method

$$
Q_{V,cool,fctf,m} = \begin{bmatrix} H_{V,hyg,cool,fctf,m} \cdot \left(\theta_{i,cool} - \theta_{e,V,cool,day,m}\right) \\ +H_{V,add,cool,day,fctf,m} \cdot \left(\theta_{i,cool} - \theta_{e,V,cool,day,m}\right) \\ +H_{V,add,cool,night,fctf,m} \cdot \left(\theta_{i,cool} - \theta_{e,V,cool,night,m}\right) \\ +H_{V,in-exfiltr,cool,fctf,m} \cdot \left(\theta_{i,cool} - \left(\theta_{e,m} + \Delta\theta_{e,m}\right)\right) \\ +H_{V,nat,cool,day,fctf,m} \cdot \left(\theta_{i,cool} - \left(\theta_{e,m} + \Delta\theta_{e,m} + \Delta\theta_{e,day,m}\right)\right) \\ +H_{V,nat,cool,night,fctf,m} \cdot \left(\theta_{i,cool} - \left(\theta_{e,m} + \Delta\theta_{e,m} + \Delta\theta_{e,night,m}\right)\right) \end{bmatrix} . t_m
$$

Monthly mean value corrected for day only and night only ventilative cooling

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Modified method – t° correction

Mois	External mean temperature		
	$\theta_{e,cool,m}$ (°C)	$\theta_{e,cool,day,m}$ (°C)	$\theta_{e,cool,night,m}$ (°C)
Jan	3,9	4,2	3,4
Feb	4,8	5,3	4,0
Mar	6,1	7,0	4,7
Apr	9,8	11,2	7,8
Mei	13,8	15,4	11,2
Jun	17,1	18,8	14,4
Jul	17,8	19,3	15,4
Aug	18,1	19,7	15,6
Sep	16,3	17,5	14,6
Oct	11,9	12,8	10,6
Nov	6,7	7,2	6,0
Dec	3,5	3,8	3,1

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Modified method – indoor t°

- Cooling need of unconditioned places includes adaptive comfort t° limits (based on EN 15251-A1)

Month	With active cooling $\theta_{i,cool,fct\ f,m}$ (°C)	Without active cooling $\theta_{i,cool,fct\ f,m}$ (°C)
Jan	25,0	25,0
Feb	25,0	25,0
Mar	25,0	25,0
Apr	25,0	25,0
Mei	25,0	25,2
Jun	25,0	26,1
Jul	25,0	26,6
Aug	25,0	26,6
Sep	25,0	25,8
Oct	25,0	25,0
Nov	25,0	25,0
Dec	25,0	25,0

Modified method – natural airflows*

Correction of t° hypothesis variations between methods

Fraction of time = f(gain/loss coefficient)
Based on sets of dynamic simulations

$$H_{V,nat,day,cool,fct\,f,m} = \max\left\{ \begin{array}{l} 0; 0{,}34 \cdot b_{V,nat,day,cool,fctf} \cdot f_{V,nat,day,cool,fctf,m} \cdot \dot{V}_{V,nat,day,cool,fct\,f,m} \\ - f_{V,nat,day,cool,fctf,m} \cdot H_{V,in\text{-}exfiltr,cool,fct\,f,m} \end{array} \right\}$$

Infiltrations not considered when windows are opened

Conventional single sided ventilation
~73m³/hm²

*day ventilation is considered only when there is a balanced IAQ ventilation and no active cooling

Modified method – forced airflows

Pre-heating coefficient

Pre-cooling coefficient

T° hypothesys correction

$$H_{V,add,day,cool,fct\,f,m} = 0{,}34 \cdot r_{preh,cool,fct\,f} \cdot r_{precool,fct\,f,m} \cdot b_{V,add,day,cool,fctf,m} \cdot$$
$$\cdot f_{V,add,day,cool,fctf,m} \cdot (\dot{V}_{add,fct\,f} - \dot{V}_{hyg,fct\,f} \cdot f_{reduc,vent,cool,fct\,f})$$

measured air flow capacity

Fraction of time = f(gain/loss coefficient)
Based on sets of dynamic simulations

Modified method – fans

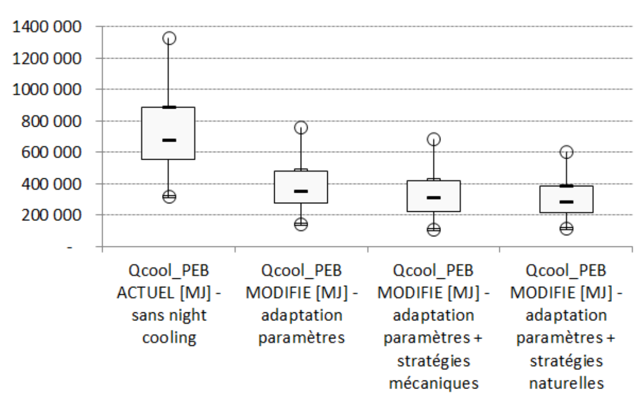
$$W_{fan,fctf,m} = \sum_j \left(W_{fan,fctf,hyg,m,j} + W_{fan,fctf,add,cool,day,m,j} + W_{fan,fctf,add,cool,night,m,j} \right)$$

$$W_{fans,hyg,fct\,f,m} = \sum_j 0{,}8 \cdot f_{ctrl,j} \cdot f_{fan,mod} \cdot P_{instal,j} \cdot \frac{\dot{V}_{hyg,fct\,f,j}}{\dot{V}_{hyg,j}} \cdot f_{fans,hyg,fct\,f,m} \cdot \frac{t_m}{3{,}6}$$

$$W_{fans,add,day,cool,fct\,f,m} = \sum_j 0{,}8 \cdot \left(1 - f_{ctrl,j} \cdot f_{fan,mod}\right) \cdot P_{instal,j} \cdot \frac{\dot{V}_{add,fct\,f,j}}{\dot{V}_{add,j}} \cdot f_{V,add,day,cool,fct\,f,m} \cdot \frac{t_m}{3{,}6}$$

$$W_{fans,add,night,cool,fct\,f,m} = \sum_j 0{,}8 \cdot P_{instal,j} \cdot \frac{\dot{V}_{add,fct\,f,j}}{\dot{V}_{add,j}} \cdot f_{V,add,night,cool,fct\,f,m} \cdot \frac{t_m}{3{,}6}$$

Impact



Conclusion

- Ventilative cooling is now (2016) considered
- In a comprehensive framework
- But with a limited impact due to conservative hypothesys
- Other cooling need adaptations are more sensible
- Further studies (including large scale field studies) may help reconsider these hypothesis
- But first answer the question of monthly VS hourly calculation

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Towards better quality and compliance

Compliant Energy Performance of Buildings Certificates and better quality of the works — ground status, initiatives and perspectives

Compliance to summer thermal comfort requirements: control of overheating in new Estonian apartment buildings

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Tallinn University of Technology

TALLINN UNIVERSITY OF TECHNOLOGY

Co-funded by the Intelligent Energy Europe Programme of the European Union

www.qualicheck-platform.eu

Summer thermal comfort

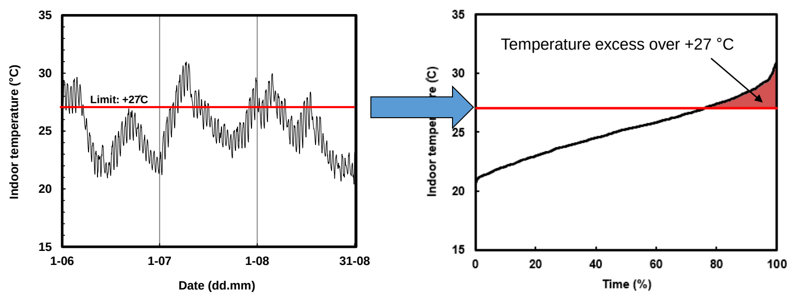
EPBD Annex I requirement:

"1. The energy performance of a building shall be determined … and shall reflect the … **cooling energy needs (energy needed to avoid overheating)** to maintain the envisaged temperature conditions …"

Estonian legislation:

- Addressed by a requirement not allowing to exceed +27°C more than 150Kh in residential buildings and +25°C more than 100Kh in non-residential buildings from June 1 till Aug 31
- Compliance verification to be done with specific temperature simulation based procedure - needs to be simulated in critical rooms with standard use data and test reference year, cannot be measured
- The study included:
  - Simulations in total in 158 dwellings from 25 new apartment buildings
  - Measurements in 22 dwellings

The requirement of temperature excess ≤ 150 Kh (degree-hours)



- In residential buildings window airing is taken into account.
- Compliance is proved by performing a simulation calculation based on standard room types.
- Passive cooling solutions should be preferred over active cooling systems.
- The summertime indoor temperature is checked in types of room in which the heat gain is the highest.
- In residential buildings, the summertime indoor temperature calculation is performed with respect to at least one living room and one bedroom.

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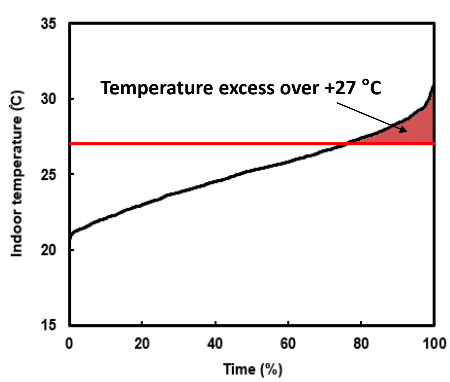
The requirement of temperature excess ≤ 150 Kh (degree-hours)

Date	Time	Temp, °C	Excess, Kh	
...	...	...	...	
5. July	10:00	26.4	0.0	
5. July	11:00	26.8	0.0	
5. July	12:00	27.3	0.3	
5. July	13:00	27.4	0.4	
5. July	14:00	27.6	0.6	4.2Kh
5. July	15:00	27.8	0.8	
5. July	16:00	28.6	1.6	
5. July	17:00	27.5	0.5	
5. July	18:00	27.0	0.0	
5. July	19:00	26.8	0.0	
...	...	...	...	Requirement
		Σ	158.0	≤ 150 Kh



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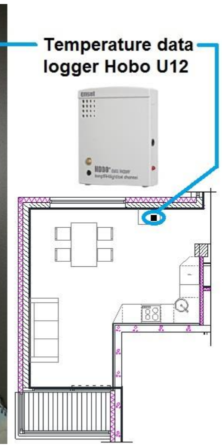
Methods

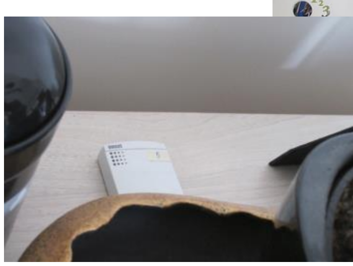
- 25 apartment buildings
  - Randomly selected newly built modern apartment buildings
  - 18 dwellings measured
  - 158 dwellings simulated
- Description of the studied buildings
  - Most of the buildings were designed with precast or monolithic concrete structures with more than four floors above ground
  - The thermal transmittances of the buildings envelope were between 0.15 and 0.25 W/(m^2•K) for external walls, 0.09 ÷ 0.17 for roofs and 0.60 ÷ 1.65 W/(m^2•K) for windows.
  - The SHGC-s of the windows for different buildings varied from 0.40 to 0.71

Measurements

- Temperature measurements in dwellings

- Measuring period:
1. June – 31. August 2014
- Logger saving interval:
1h, hourly mean





Simulations

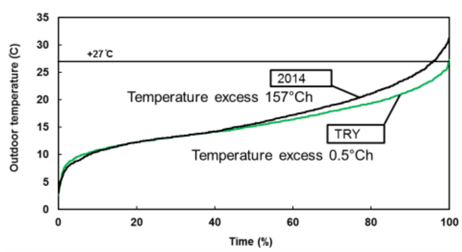
- Indoor climate and energy simulation tool IDA-ICE
- Simulation of selected dwellings with possible risk of overheating

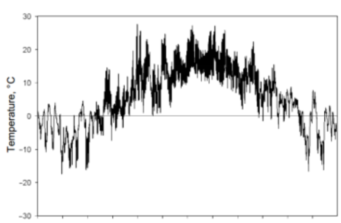
Simulations – TRY

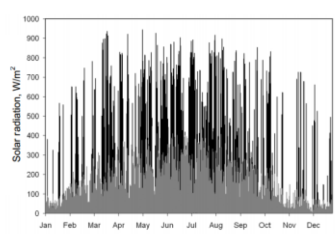
- Outdoor climate

Regardless of the building's location, verification of compliance with the summertime indoor temperature requirement are performed on the basis of the data of the Estonian Test Reference Year (TRY).

- The TRY represents the typical outdoor climate of three decades (1970–2000), containing hourly-average data of outdoor temperature, relative humidity, wind speeds and solar radiation.



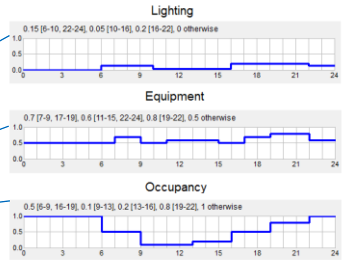


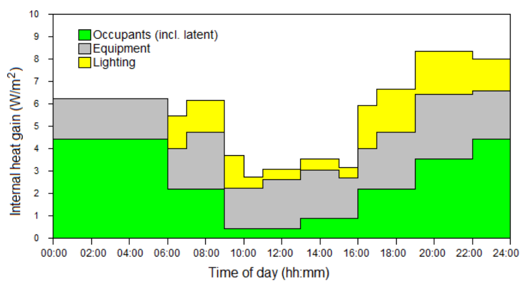


Simulations – standard use

- **Occupied hours and heat gain**

Standard use of buildings				
Building's purpose of use	Lighting W/m²	Appliances W/m²	Occupants W/m²	Occupants m²/person
Multi-apartment building	8	3	3	28.3





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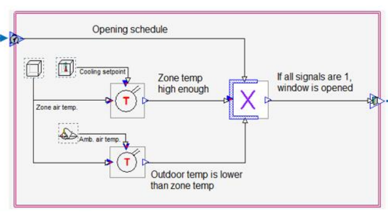
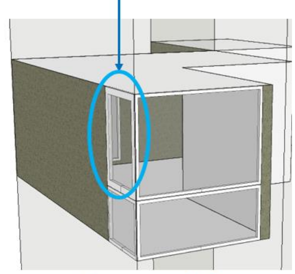
Window opening

Window opening schedule



Actual room



Room model

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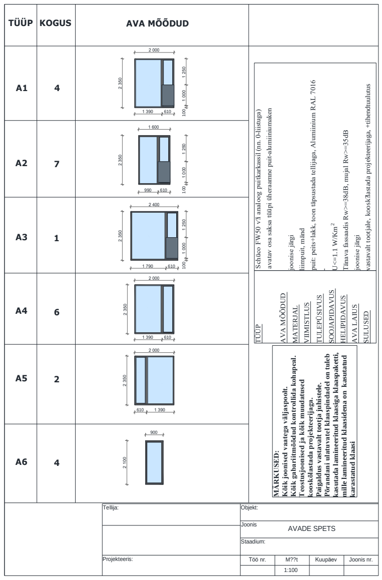
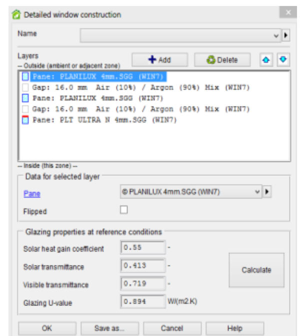
Window modelling

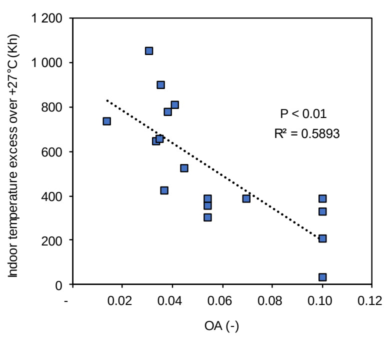


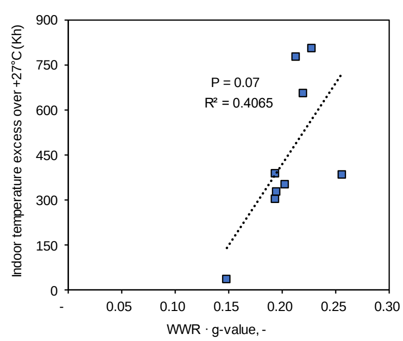


Measurements –

Openable area of windows and WWR*g

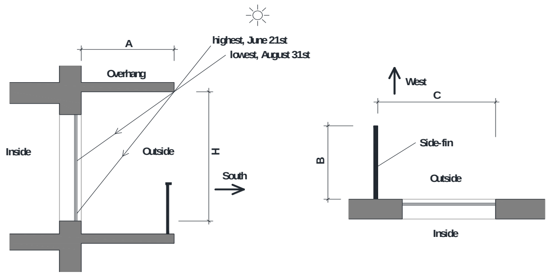
- Openable windows area (OA) below 5% result in higher temperature excess values
- In south and west oriented dwellings, WWR*g-values over 0.2 result in higher temperature excess values

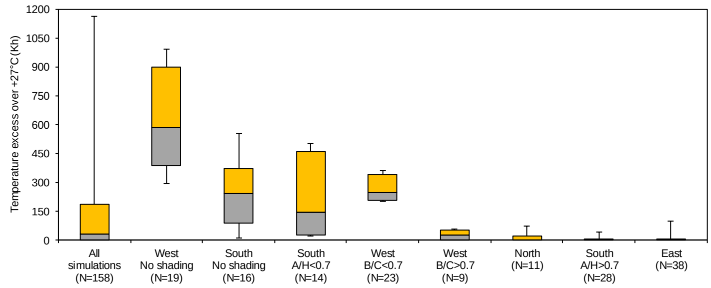




Shading balconies

- Overhangs with A/H>0.7 in south orientation
- Side-fins with B/C>0.7 in west orientation
- North and east oriented rooms did not experience values over the threshold





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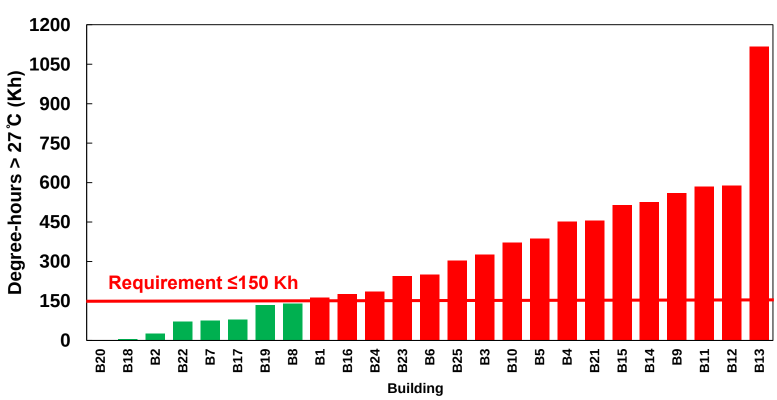
Overheating assessment results

- In total 158 dwellings from 25 buildings were simulated.
- Overall building results:

17 out of 25 (68%) did not comply with the regulation



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Conclusions (1/2)

- Measurement results confirm that high temperatures over +27˚C did exist also in reality in majority of buildings for a remarkable portion of the measuring period, indicating **high risk of overheating in new apartment buildings**
- **Many occupants had complaints**, but this data was not systematically collected
- **Shading balconies had the largest effect** on overheating risk reduction
- ‘Critical room’ was defined by combination of the following factors: **south and/or west oriented windows**, **lack of external shading elements** or insufficient dimensions of shading, with **WWR · g-values > 0.2** and total windows’ **airing area < 5%**.

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Conclusions (2/2)

- Out of the 25 new apartment buildings studied, 17 buildings (68%) did not comply with the summer thermal comfort requirements
- This relatively new building code requirement was not fully established in practice, as only in 8 buildings the required calculations were included in the building permit documentation
- Measured and simulated results cannot be directly compared because of differences in weather data and occupancy behavior (e.g. opening windows, internal gains) – simulations are to be used for the compliance assessment
- The methodology proved to be sound and robust

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Quality of works, compliance with existing legislation and reliability of EPC data in Greece

Karlessi Theoni
Efthymiou Chrysanthi
Papadopoulos Nikos

National and Kapodistrian UNIVERSITY OF ATHENS

Greek New Study Collection

Scope

- 26 residential and non residential buildings
- Newly built/renovated buildings
- Well documented buildings
- Focus area: Quality of Works, Compliance with reference values, Reliability of EPC input data
- Location: Greece

Aim

- The aim of the study is to examine in newly built and renovated buildings the quality of works through on-site inspections and measurements, the compliance with the reference values of the National Technical Guides, the reliability of EPC input data

Methodology

- The quality of works through on-site inspections and measurements include:
  - Air tightness tests
  - Infrared thermography of the building envelope
  - Site visits and inspections to check actual construction
- The compliance with the reference values of the National Technical Guides includes
  - Ventilation measurements
  - Measurements of temperature and relative humidity
- The reliability of EPC input data by:
  - Comparing the U-values of the design with actual U-values of the materials used in the construction as reported in the final EPC.
  - Comparing the design values of technical characteristics of the solar collectors with the technical characteristics used in the construction as reported in the final EPC.
  - Checking the accuracy of EPC calculations

Selected case studies and methods

	Type of interventions			Type of quality and compliance control			
Case Study	Frames	Insulation	Solar panels	Measurements	On-site visits	Invoices checking	EPC calculations checks
01	-	-	-	✓	✓		
02	✓		✓	✓	✓	✓	✓
03	✓		✓			✓	✓
04	✓					✓	✓
05	✓	✓	✓			✓	✓
06	✓		✓			✓	✓
07	✓			✓	✓	✓	✓
08							
09	✓	✓	✓	✓	✓	✓	✓
10	✓	✓	✓	✓	✓	✓	✓
11	✓	✓	✓	✓	✓	✓	✓
12	✓	✓	✓	✓	✓	✓	✓
13	✓		✓	✓	✓	✓	✓
14	✓	✓	✓	✓	✓	✓	✓
15	✓	✓	✓	✓	✓	✓	✓
16	✓	✓	✓	✓	✓	✓	✓
17	✓	✓	✓	✓	✓	✓	✓

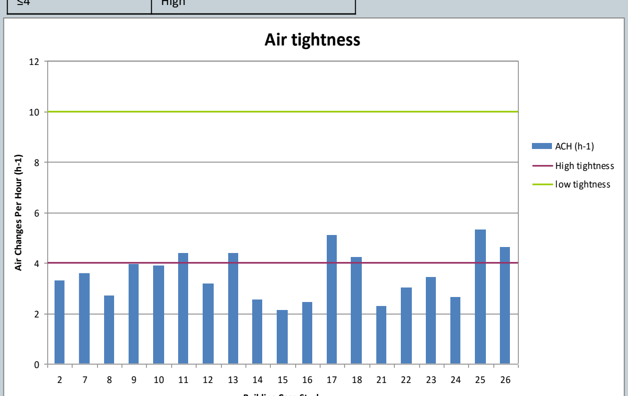
Selected case studies and methods

	Type of interventions			Type of quality and compliance control			
Case Study	Frames	Insulation	Solar panels	Measurements	On-site visits	Invoices checking	EPC calculations checks
18	✓		✓	✓			
19	✓	✓				✓	✓
21	✓	✓	✓	✓	✓	✓	✓
22	✓	✓	✓	✓	✓	✓	✓
23	✓		✓	✓	✓	✓	✓
24	✓	✓		✓	✓	✓	✓
25	✓	✓	✓	✓	✓	✓	✓
26	✓	✓	✓	✓	✓	✓	✓

Quality of works

n_{50} [h^{-1}]	Envelope tightness level
≥10	Low
$4<n_{50}<10$	Medium
≤4	High

Tightness levels for natural ventilated, non-shielded single-family buildings (EN 13790)



The majority of the buildings (68%) that were examined has ACH values lower 4 and that shows a high level of envelope air tightness

Quality of works

➢ **Thermographic inspections**

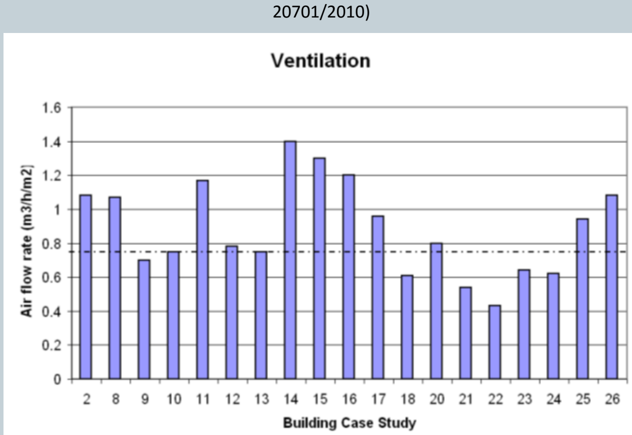
Thermographic inspections were carried out in 7 buildings that external thermal insulation was implemented in order to detect defects in the insulation. The inspections showed that the external thermal insulation of the buildings' envelope was well implemented without any gaps between the insulation boards. This shows a good quality of works in these buildings.

➢ **On-site visits**

On-site visits took place in nineteen buildings and the quality of works was investigated. More specifically the implementation of the window frames and the external insulation was checked and the inspection showed that the frames' installation was of good quality and no gaps between the frames and the wall were detected. The checking of implementation of external insulation confirms the findings of thermal mappings. These findings are due to the fact that the vast majority of the case studies are buildings renovated under the "Energy Efficiency at Household Buildings" Program and this program has strict quality assurance measures.

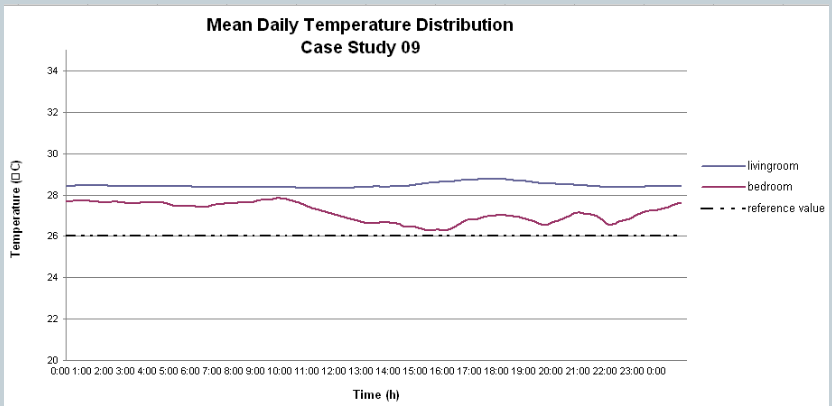
Compliance with the reference values

Air flow for single and multi family buildings compared to the reference value of 0.75m3/h/m2 (Technical Chamber of Greece Directive TOTEE 20701/2010)



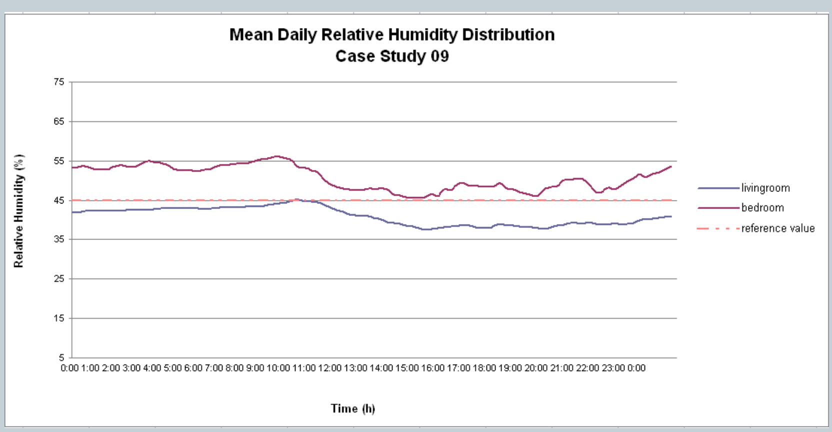
Compliance with the reference values

Reference values (Technical Chamber of Greece Directive TOTEE 20701/2010)



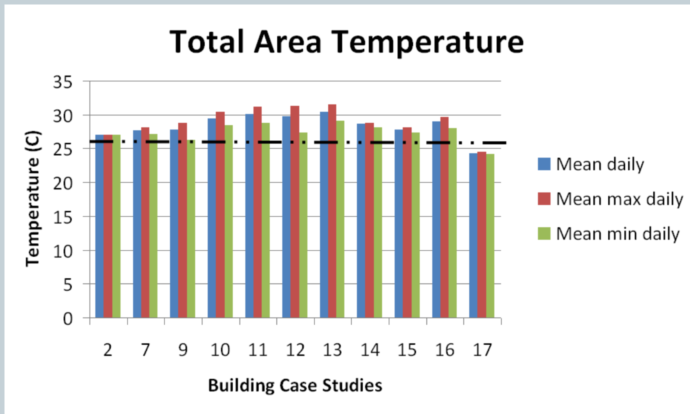
Compliance with the reference values

Reference values (Technical Chamber of Greece Directive TOTEE 20701/2010)



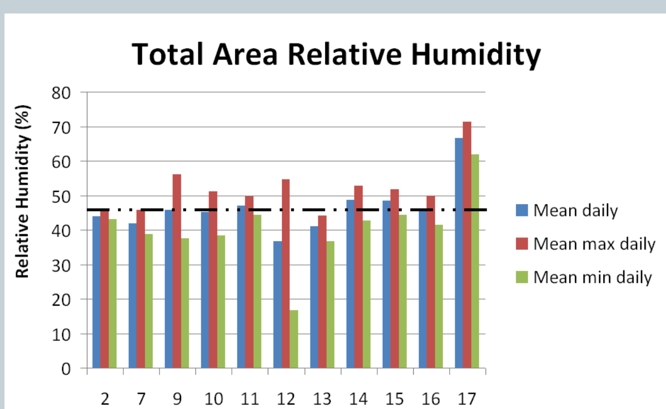
Compliance with the reference values

Reference values (Technical Chamber of Greece Directive TOTEE 20701/2010)



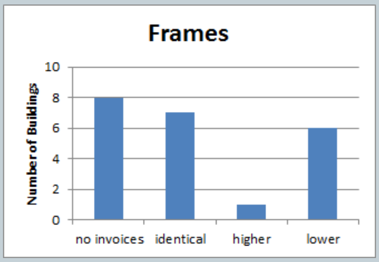
Compliance with the reference values

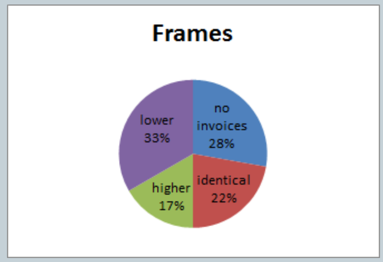
Reference values (Technical Chamber of Greece Directive TOTEE 20701/2010)



Reliability with EPC input data

Comparison of the materials' implementation values as reported in the final EPC with the design values

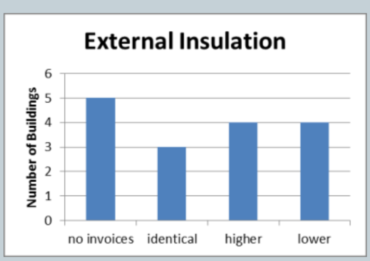


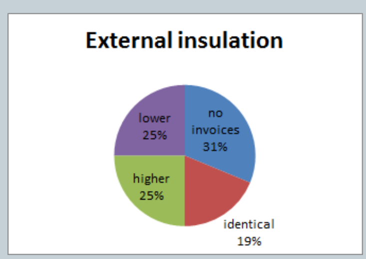


	Implementation values higher than the design	Implementation values lower than the design
Range of difference for frames U-values	25%	0.6-35%

Reliability with EPC input data

Comparison of the materials' implementation values as reported in the final EPC with the design values

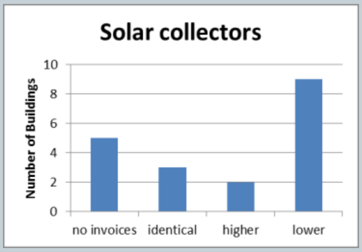


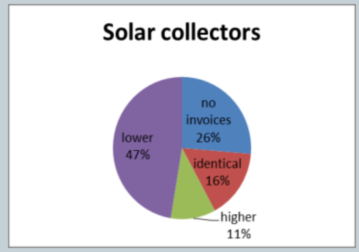


	Implementation values higher than the design	Implementation values lower than the design
Range of difference for external insulation U-values	12%	8-23%

Reliability with EPC input data

Comparison of the materials' implementation values as reported in the final EPC with the design values





	Implementation values higher than the design	Implementation values lower than the design
Range of difference of solar collectors' area	4-15%	5-22%

Reliability with EPC input data

In order to investigate **the accuracy of EPC calculations** the following documents were collected:

•Drawings, construction characteristics of the buildings and corresponding technical reports.

•Files of EPC calculations: These are the input files and incorporate all the required data for the execution of the calculations with the software that is approved by the Technical Chamber of Greece.

•Certificates and invoices of the materials used in the construction in each case study.

•Energy Performance Certificates (EPCs) before and after the renovation including the energy performance classification of the buildings

Reliability with EPC input data

The validity of the calculations in EPCs was examined and input values were also checked and compared with the proposed values by the National Building Codes (TOTEE).

This control was made by cross checking the values that are inserted in the corresponding EPC input file of each case study with the implemented values and when a mistake was found it was replaced by the right one. After the completion of the cross checking the EPC software was executed again in order to assess the building's energy class.

The procedure showed that in most of the cases faults weren't involved. This can be attributed to the fact that these buildings are renovated in the framework of "Energy Efficiency at Household Buildings" Program and the controls and the sanctions are strict. However, in one EPC errors were found affecting the energy classification of the building, making it an actual G instead of F

Greek New Study Collection

Challenges

- The number of completed case studies with EPC before and after renovations is small so there were difficulties in finding them
- Not easily accessible data, persons in charge in some cases were reluctant/negative in providing information
- Even if data was accessible, there were difficulties from the owners to provide permission
- Inhomogeinity of accessible data (eg. it was not possible for one parameter to be checked in all case studies)

Lessons learnt

- Other building types such as commercial buildings that are constantly air conditioned would also give interesting results regarding the internal temperature and relative humidity.
- In buildings that are under construction is easier to check issues such as the insulation and the right installation of it as well as the installation of the window frames. In the present study these buildings were not available.