Report established by **ECOFYS** for **EURIMA** & **EuroACE**

Mitigation of CO_2 Emissions from the Building Stock

Beyond the EU Directive on the Energy Performance of Buildings

ECOFYS

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PREFACE

The European Directive on Energy Performance of Buildings which came into force 16 December 2002 will be implemented in the legislation of Member States by 4 January 2006. In addition to the aim of improving the overall energy efficiency of new buildings, large existing buildings will become a target for improvement, as soon as they undergo significant renovation.

The building sector is responsible for about 40% of Europe's total primary energy consumption and hence this Directive is an important step for the European Union in order that it should reach the level of saving required by the Kyoto Agreement. In this the EU is committed to reduce CO_2 emissions relative to the base year of 1990 by 8 per cent, by 2010.

But what will be the impact of the new Directive, how large could be the impacts of extending the obligation for energy efficiency retrofitting towards smaller buildings? Can improvement of the insulation offset or reduce the growing energy consumption from the increasing installation of cooling installations?

EURIMA, the European Insulation Manufacturers Association and EuroACE, the European Alliance of Companies for Energy Efficiency in Buildings, asked ECOFYS to address these questions. The basis for the analysis is the ECOFYS energy model of the European building stock, which was originally developed to investigate the general contribution of thermal insulation to Energy Saving and Climate protection in Europe.

1] EXECUTIVE SUMMARY

THE EUROPEAN DIRECTIVE ON ENERGY PERFORMANCE OF BUILDINGS [EPBD]

From the 40% contribution made by the building sector towards end energy consumption in the EU, the EPB Directive (2002/91/EC) aims to contribute, to the Member States' joint commitment under the Kyoto Protocol, an 8% reduction in greenhouse gas emissions by 2010. These will come from improvements in energy efficiency of newly built buildings and of existing buildings larger than 1,000 m^2 which are covered by the Directive as soon as these undergo significant renovation.

This analysis sets out to establish:

- The impact of the Directive on CO_2 emissions;
- The impact of extending the Directive towards the retrofit of smaller buildings ;
- Whether the trend for growing energy consumption for cooling can be offset or reduced by increased levels of insulation.

These questions were addressed using the ECOFYS model of the European building stock.

IMPACT OF THE EUROPEAN EPB DIRECTIVE AND POSSIBLE EXTENSIONS

Table 1 summarises the technical potential, if all retrofit measures covered by the Directive were realised for all the European (EU 15) building stock of 2002 at the same time:

- The overall emission savings associated with the heating the European building stock would amount to 82 Mt/a (EPBD);
- This potential could be increased by 69 Mt/a if the Directive were extended to retrofitting all multi-family houses and all non-residential buildings (Extended EPBD >200 m^2);
- By extending the Directive to the whole of the European building stock by adding single-family houses the additional potential, compared to the Directive, rises to 316 Mt/a (Extended EPBD all houses).

Table 1: *Technical potential of CO_2 Emission Savings of the current Directive and possible extensions*

CO_2 Emission Savings [Mt]	Cold zone	Moderate zone	Warm zone	EU-15
Technical potential				
EPBD	2	68	12	82
Extended EPBD > 200m^2	5	118	29	151
Extended EPBD all houses	14	319	65	398
Additional Savings compared to EPB [technical potential]				
Extended EPBD > 200m^2	3	50	17	69
Extended EPBD all houses	12	251	53	316

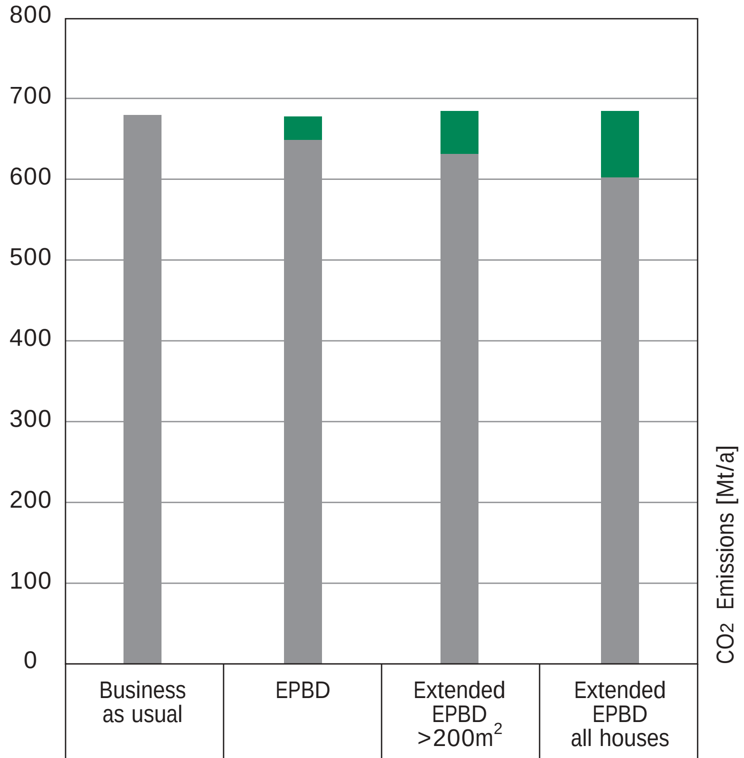
Taking into account the fact that the existing building stock cannot be retrofitted at once and that the building stock is not only affected by retrofitting but also by demolition and new construction Figure 1 and Table 2 show the result of the temporal development of the CO_2 emission savings of the European (EU-15) building stock in the year 2010 under different scenarios leading to the following impacts:

- Compared to a business as usual scenario under which the common practice for energy efficiency is applied to new buildings and retrofit measures, the current EPB Directive leads to CO_2 emission reductions of 34 Mt/a.
- An extension of the scope of the Directive to all non-residential buildings and to all multi-family residential houses, creates an additional emission savings potential, compared to the Directive of 8 Mt/a (Extended EPBD > 200m^2).
- Assuming a further extension to all buildings in the building stock, the additional potential rises to 36 Mt/a (Extended EPBD all houses).

The large increase of achievable reductions from the second (Extended EPBD > 200m^2) to the last scenario (Extended EPBD all houses) is due to the following characteristics of small dwellings:

- Single-dwelling buildings dominate the building stock with respect to living space;
- The unfavourable ratio of the building envelope compared to the floor area leads to a high specific heating energy demand.

Figure 1: *Temporal development of the CO_2 emissions for the EU15 building stock*



	Business as usual	EPBD	Extended EPBD >200m^2	Extended EPBD all houses
CO_2 Savings [Mt/a]		34	42	70
CO_2 Emissions [Mt/a]	678	644	636	609

***Table 2:** Temporal development (2010) of CO_2 Emission Savings of the current Directive and possible extensions*

CO_2 Emission Savings [Mt]	Cold zone	Moderate zone	Warm zone	EU-15
Savings compared to Business as usual 2010				
EPBD	1	26	7	34
Extended EPBD > 200m^2	1	31	9	42
Extended EPBD all houses	3	52	15	70
Additional Savings compared to EPBD 2010				
Extended EPBD > 200m^2	0	5	2	8
Extended EPBD all houses	1	26	8	36
For comparison: Remaining Kyoto-Gap for EU-15				190

COOLING DEMAND

Especially in Southern European countries, cooling demand becomes increasingly important for the overall energy consumption of a building due to higher requirements regarding thermal comfort. The Directive responded to this trend with provisions for regular maintenance of air-conditioners to ensure a minimum standard on energy efficiency.

In this study it is found that in warm climatic zones the cooling demand can be reduced drastically by a combination of lowering the internal heat loads and by improved insulation. With the reduction of the heat loads to a moderate level the cooling demand, e.g. of a terraced house located in Madrid, can be reduced by an additional 85% if the insulation level is improved appropriately.

In addition to the analysis of the terraced house, a representative office building was analysed for its cooling energy demand. In this case the cooling demand can be reduced by 24% with improved insulation in spite of the higher loads inside the building; insulation of the roof has the greatest impact of the insulation measures on energy efficiency.
Generally, the impact of insulation on cooling energy demand increases with hotter climates and lower internal heat loads of a building.

OUTLOOK

This study demonstrates that the European Directive on Energy Performance of Buildings will have a significant impact on the CO_2 emissions of the European building stock. As shown in several other studies [e.g. Caleb 99, ECOFYS 02] the main saving potential lies in insulation of the existing building stock. Beyond this, CO_2 emissions could, however, be greatly reduced if the scope of the Directive were to be extended to include smaller buildings.

The reductions should be seen in relation to the remaining gap of 190 Mt CO_2 eq. per annum between the current emission levels of EU-15 and the target under the Kyoto-Protocol for the year 2010 [EEA, 2002]. The energy and industrial sector will probably contribute only a fraction of this reduction via the newly established EU emissions trading scheme and connected projects under the flexible mechanism. In addition, the traffic sector is likely to continue its growth path leading to a widening of the gap. Thus, there is likely to be considerable pressure on the EU building sector to contribute to the EU climate targets beyond what will be achieved by means of the current EPB Directive. Legislators on the EU and national level are therefore advised to take accelerated actions to tap the very significant emission reduction potentials available in the EU building stock.

2] INTRODUCTION

2.1 THE NEW EU DIRECTIVE

The European Directive 2002/91/EC on Energy Performance of Buildings came into force on 16 December 2002 and requires implementation in the legislation of the 15 present Member States by 4 January 2006. In addition to the aim of improving the overall energy efficiency of new buildings, large existing buildings (>1000m^2) have become a target as soon as they undergo significant renovation. Four main elements define the requirements that need to be integrated into national legislation:

- Establishment of a methodology for an integrated calculation of the overall energy performance of buildings;
- Definition of minimum energy efficiency requirements per member state based on this methodology;
- Energy efficiency certification of new and existing buildings;
- Regular inspection of heating and air conditioning systems.

Existing buildings are subject to the Directive if the total useful floor size exceeds 1000m^2 and an investment in renovation exceeds 25% of the building (without land) value or 25% of the building envelope are subject to renovation.

The framework for the methodology to calculate the energy performance is given in the Annex to the Directive and defines components, which have to be integrated, facilities for energy generation as well as a distinction of building types.

Building certificates are required upon construction, change of ownership or tenant. Such certificates shall remain valid for no longer than 10 years. They have to include recommendations for improvements in energy performance as well as comparisons to standards or benchmarks. In buildings occupied by public authorities and institutions, the certificate is to be displayed in public.

Heating and cooling equipment has to be inspected by qualified personnel, boilers between 20-100 kW regularly, boilers >100kW every two years (for natural gas 4 years). If the boiler is >20kW and older than 15 years, the total heating system shall be examined for efficiency and sizing to enable suggestions for replacement or improvements.

Air conditioning systems with a rated cooling output >12kW are to be inspected regularly for efficiency and correct sizing. As for boilers, suggestions shall be included to improve energy performance or on alternative solutions.

2.2 QUESTIONS REGARDING INSULATION PROMPTED BY THE DIRECTIVE

The European Directive 2002/91/EC does not define requirements for the insulation level of buildings.

- > In which way does the Directive affect the requirements on the insulation level of the respective Member States or regions?

Overall energy performance improvements including better insulation, improved efficiency of heating/ cooling systems and energy generation systems are key objective of the Directive.

- > What is the effect of the Directive on CO_2 emissions of the European building stock?

The definition of a size threshold of $1000m^2$ for retrofits in existing building excludes a vast number of buildings and probably a significant part of the energy savings potential.

- > How large are the additional savings associated to extending the obligation for energy efficiency retrofits towards smaller buildings?

Responding to the increased installation of cooling systems, the Directive requires regular inspection of such installations.

- > How could increased insulation of the building envelope contribute to further reduce the demand for cooling?

3] MODELLING EFFECTS OF THE CURRENT DIRECTIVE

The effect of the EPB Directive on the emissions associated with the heating energy consumption of the total EU 15 building stock has been examined in a model calculation.

Input to the model calculation is a database containing the building stock distinguished by climatic regions, building type/size, building age, insulation level, energy supply, energy carrier and emission factors. This was applied in a scenario tool used for calculating the development over time of the building stock as a function of demolition rate, new building activity, renovation and energy-efficiency measures in retrofits.

The great complexity of the building stock had to be simplified by examining five standard buildings with eight insulation standards, which are assigned to building age and renovation status (see Annex I, Table 16). Furthermore, three climatic regions were distinguished for the calculation of the heating energy demand. This gave a basic 210 building types for which the heating energy demand and CO_2 emissions from heating were calculated according to the principles of the European Norm EN 832.

A detailed description of the model can be found in Annex I of this report.

3.1 THE EUROPEAN BUILDING STOCK

In order to assess the impact of the Directive, three climatic regions have been distinguished: cold, moderate and warm.

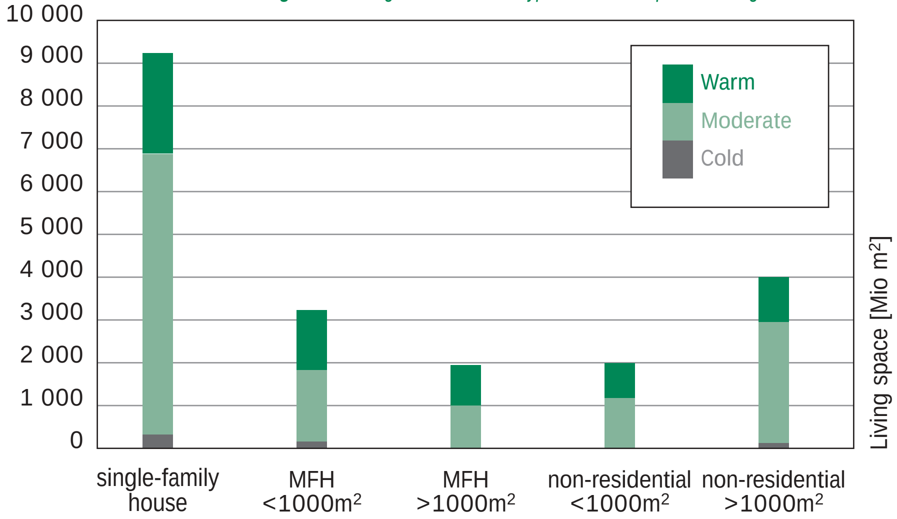
The following table assigns the building stock of Member States to these three climatic zones.

Table 3: *Attribution of Member States to climatic regions*

Cold	Moderate		Warm
Finland	Austria	Germany	Greece
Sweden	Belgium	Ireland	Italy
	Denmark	Luxemburg	Portugal
	France	The Netherlands	Spain
		United Kingdom	

The extent to which the current building stock will be affected by the new Directive is addressed in Figure 2. Buildings larger than 1000m^2, which are subject to the Directive, represent only some 28% of the total area of the building stock. The group of single-family houses represents the largest share of buildings (45%). Multi-family houses (MFH) cover 26 % of the total building stock, non-residential buildings 29 %. A detailed subdivision of the European building stock is given in Table 15 of Annex I.

***Figure 2:** Living areas of house types of the European building stock 2002*



3.2 FUTURE NATIONAL INSULATION STANDARDS

Since the Directive does not give minimum levels for energy performance or thermal insulation, the impact of the Directive on thermal insulation had to be assessed by interviews with building authorities and experts throughout Europe, which were carried out as part of the project. These showed that building regulations on energy performance have been under development in several regions and Member States with the same objective as the Directive. These regulations are now being further developed to take into account the requirements of the Directive.

The interviews yielded estimates (forecasts) for the thermal insulation levels in the three climatic zones by the time the Directive will be implemented in national legislation (see Table 4).

***Table 4:** Estimated U-values after implementation of the Directive for different climatic*

U-values [W/m²K]	EPB Directive
Cold climatic zone	
Roof	0.13
Façade	0.17
Floor	0.17
Windows	1.33
Moderate climatic zone	
Roof	0.23
Façade	0.38
Floor	0.41
Windows	1.68
Warm climatic zone	
Roof	0.43
Façade	0.48
Floor	0.48
Windows	2.71

U-values for retrofit measures are in almost all cases of (planned) national legislation identical to the requirements for new buildings (own investigations).

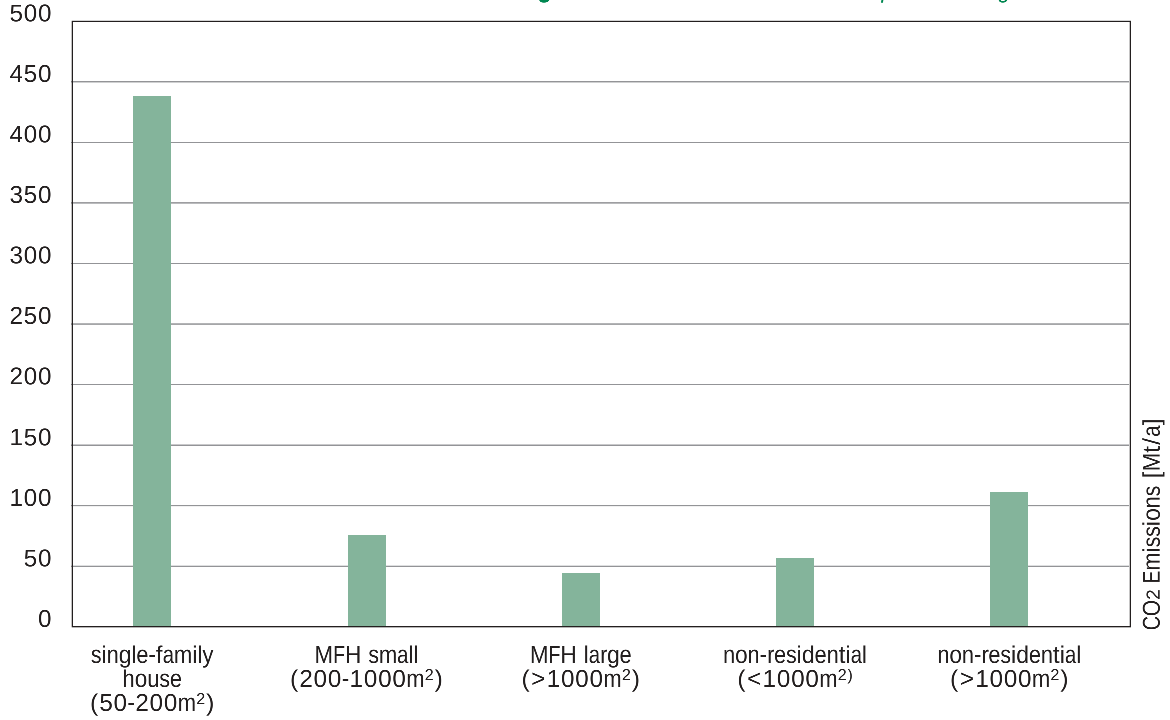
3.3 EFFECTS OF THE EPB DIRECTIVE

As shown in several studies [Caleb 98, Caleb 99, IWU 94, ECOFYS 02] the main energy saving potential lies in the existing building stock. Newly built houses are generally already built in compliance to national performance standards and therefore exhibit inherently small savings potential in CO_2 emissions. The demolition rate in the building stock can be estimated to be approx. 0.5-1 % [Kleemann 00]. New building activity is assumed to be 1% of the total living area per year thus resulting in a slight increase of the building stock.

Insulation standards as listed in the previous section were used as the basis to determine the effect of the Directive against a baseline. CO_2 emissions for 2002 (baseline) were calculated with the ECOFYS model of the existing building stock (s. Annex I for details on the ECOFYS model).

As can be seen in Figure 3, the emissions from the group of single-family dwellings becomes even more dominant than expected from their share of living space (see Figure 2) because their external surfaces relative to living space of these buildings are larger than those of compact large multi-dwelling buildings resulting in a greater specific heating energy consumption.

Figure 3: *CO_2 emissions of the European building stock 2002*



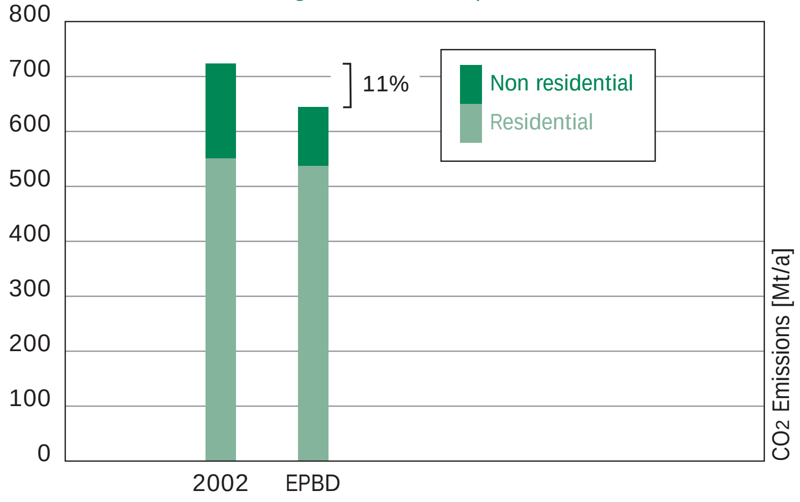
3.3.1 Technical Potential of the EPB Directive

To calculate the technical potential of the EPB Directive the theoretical assumption is made that all buildings covered by the Directive are retrofitted now according to the insulation standard coming into force after the implementation of the Directive (Table 4).

Note: To clearly distinguish between the measures the calculation excludes the effect of additional building, demolition or the certification of buildings.

Figure 4 and Table 5 show an annual saving potential of the Directive of about 82 Mio tons CO_2 emission or 11% of the current emissions.

Figure 4: *Technical potential of the EPB Directive*



3.3.2 Sensitivity Analysis to the Technical Potential of the EPB Directive

Statistics on building stock do not differentiate by living space but by storey or number of dwellings. This creates some uncertainty in the division between multi-dwelling buildings smaller and larger than 1000m^2, which makes a sensitivity analysis necessary. 35% of the multi-dwelling buildings have been found to be larger than 1000m^2 according to the statistics. However, alternative calculations assuming that 25% and 45% of the buildings are larger than 1000m^2 have been conducted.

The sensitivity analysis (Table 5) established that the result of the calculations is robust in respect to changes of this input data set.

Table 5: *Technical Potential of the EPB Directive and Sensitivity-Analysis*

CO_2 emissions heating [Mt/a]	Building stock 2002	EPB Directive	Sensitivity-analysis 1 (25%)	Sensitivity-analysis 2 (45%)
Residential sector heating	555	532	526	539
Non-residential sector heating	170	111	111	111
Total	725	643	637	650

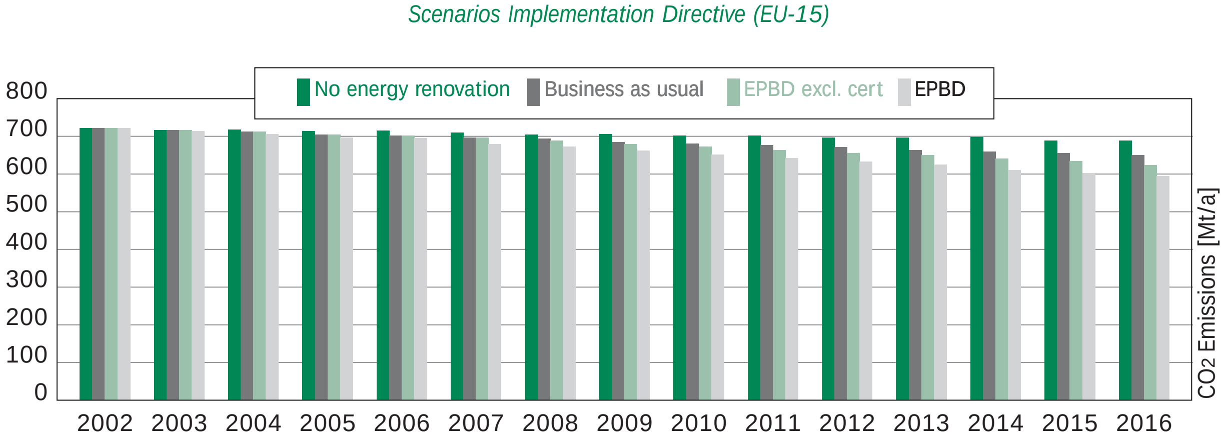
3.3.3 Scenarios

The scenarios take into account the fact that the existing building stock will not all be retrofitted at once and the building stock is not only affected by retrofitting but also by demolition and by new construction alternatives to the technical potential. The scenarios were developed to determine the effect of different measures over the time span from 2002 to 2020.

These scenarios contain new construction (1% of building stock [IWU 94, Kleemann 02, Eurostat, own investigations]), demolition (0,5% [IWU 94, Kleemann 02, Eurostat, own investigations]) and retrofit (1,8% [IWU 94, Kleemann 02, Eurostat, own investigations]) as factors for the calculations of CO_2 emissions. The following scenarios were analysed:

- Scenario 1 ("no energy renovation") assumes retrofit without energy measures, but new building activities plus demolition as in all scenarios. New buildings are erected according to current building regulations and replace older buildings with lower energy efficiency standard;
- Scenario 2 ("business as usual") represents retrofit measures directed at energy efficiency in accordance with common practice. According to Kleemann 00 and own investigations it can be assumed that 20% of the retrofit measures are combined with significant energy efficiency measures. U-values for this scenario can be found in Annex II of this report;
- Scenario 3 ("EPBD excl. certificates") covers the same cycle of building renovation as in the previous scenarios. Buildings, which are subject to the Directive, are assumed to be retrofitted according to the standards set by the Directive. Those not covered by the Directive are renovated similar to the standards assumed in the 'business as usual' scenario. The influence of certificates was excluded for this scenario;
- Scenario 4 ("EPBD") is equivalent to the scenario "EPBD excl. certificates" but assumes in addition that certificates lead to an increased rate of energy retrofit of 40%.

Figure 5: Temporal evolution of effects on emissions from different scenarios of the Directive



From the diagram the following observations can be made:

Resistance to change in the building stock is largely due to low rates of retrofit, demolition and new buildings. Energy retrofits are normally coupled to standard renovation cycles of buildings which leads to the overall effect of slow changes in the energy use pattern and CO_2 emission.

Scenario 1 “no energy renovation” shows that independent developments would result in CO_2 emission reduction due to the demolition and replacement with new buildings with better energy performance despite of continuous growth of the total building stock.

The scenario 2 ‘business as usual’ reflects more closely the actual trends in the development of energy efficiency in the building stock. Higher reduction potentials can be attributed to already existing energy efficiency standards.

The effect of certificates in the EPB Directive can be seen in the different trends of the scenarios “EPBD excl. certification” and “EPBD”.
Compared to the potential emission savings without certifications, the additional benefit of the certification is high. The reason for this can be found in the fact that the certification extends to all building types including the large group of small residential buildings triggering energy-renovation measures in this group.

In contrast to this, the “EPBD excl. certification” does not improve the energy performance in small residential buildings beyond the common retrofit practice.

In total, realisation of all measures in the EPB Directive results in CO_2 emission savings of 34 Mt/a in the year 2010 compared to the business as usual scenario. For 2015, these savings would rise to 55 Mt/a.

4] MODELLING EFFECTS OF EXTENDING THE DIRECTIVE TOWARDS SMALLER BUILDINGS

The EPB Directive requires that regulation needs to be implemented for buildings larger than 1000m^2. This section is aimed at determining the potential impact on emissions when extending the Directive towards smaller buildings.

4.1 ALTERNATIVE BUILDING CLASSES

For the examination of the impact of extending the Directive to smaller buildings, additional building types were defined.

The group of residential buildings <1000m^2 was divided into single-family buildings (<200m^2) and small multi-family buildings (200-1000m^2) in addition to the group of large multi-dwelling buildings >1000m^2. Non-residential buildings were grouped in buildings smaller and larger 1000m^2.

4.2 EFFECTS OF EXTENDING THE EPB DIRECTIVE

To determine the potential impact of extending the EPB Directive to smaller buildings the same methodology was used as in chapter 3, where the influence of the Directive in its current form was assessed:

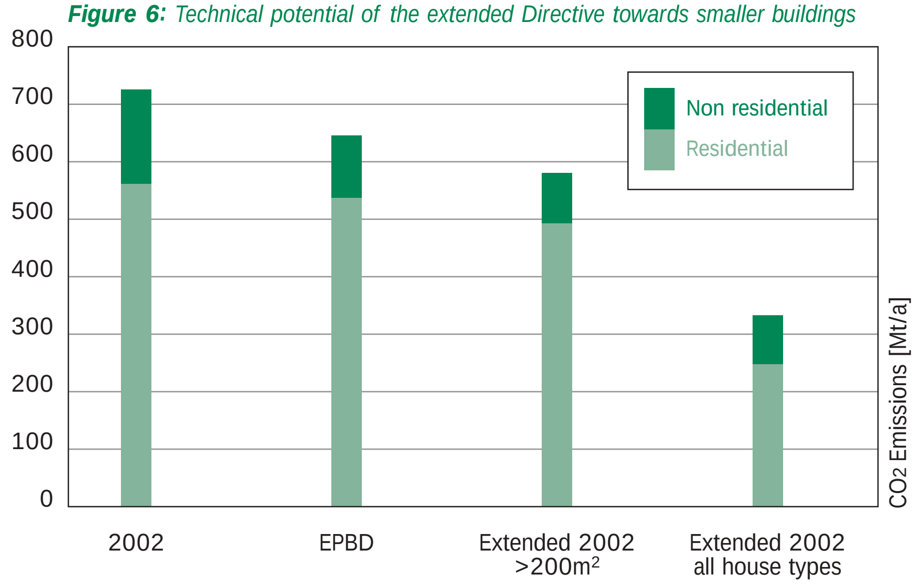
First the technical potential of CO_2 savings (4.2.1) is calculated assuming that the requirements of the Directive are fulfilled for the total EU-15 building stock at once.

In a second step (4.2.2) the temporal development of the CO_2 emissions of the EU-15 building stock is described under the different assumptions concerning the extension of the Directive to smaller buildings.

4.2.1 Technical Potential of the Extended EPBD

Figure 6 displays the technical potential of the Directive and the described extensions to smaller buildings for the existing building stock of 2002 assuming all retrofit measures were realised at once.

Figure 6: *Technical potential of the extended Directive towards smaller buildings*



From Figure 6 and Table 6 the following conclusions can be drawn:

As shown in chapter 3.3.1 the implementation of the EPB Directive with the limit for buildings at 1000m^2 leads to a technical saving potential of 82 Mt/a.

Extending the Directive in addition to all non-residential buildings and multi-family houses (Extended EPB Directive > 200m^2) the technical saving potential rises to 151 Mt/a.

If the complete European building stock is included (Extended EPB Directive all houses) then the potential rises to 398 Mt/a.

This results in an additional saving potential compared to the Directive of 69 Mt/a for all multi-family houses and non-residential buildings and rises to 316 Mt/a for the complete building stock.

It becomes evident that the extension of the Directive towards buildings larger than 200m^2 and all non-residential buildings has a small effect compared to the option of including residential buildings smaller than 200m^2. This can be explained by the large proportion of single-family dwellings in the residential sector.

The lion share of the CO_2 emission saving potential results from adding thermal insulation to the existing building stock. This corresponds to former studies: e.g. [ECOFYS 02] identifies the potential CO_2 emission savings through thermal insulation in the existing building stock of the EURIMA countries (EU-15, Norway, Switzerland, Turkey) with an annual CO_2 emission avoidance of 353 Mt/a.

Table 6: *Effect on CO_2 emissions (EU-15 building stock) of extending the Directive towards smaller buildings*

CO_2 emissions heating [Mt/a]	Building stock 2002	EPB Directive	Extended EPB Directive >200m^2	Extended EPB Directive all houses
Residential sector heating	555	532 (Δ 23=4%)	491 (Δ 64=12%)	244 (Δ 311=56%)
Non-residential sector heating	170	111 (Δ 59=35%)	83 (Δ 87=51%)	83 (Δ 87=51%)
Total	725	643 (Δ **82**=11%)	574 (Δ **151**=21%)	327 (Δ **398**=55%)
Additional reduction compared to EPBD	-	0	**69**	**316**

4.2.2 Scenarios

In addition to the technical potential, scenarios were developed to analyse the temporal influence of retrofitting, demolition and new construction as described in chapter 3.3.3.

Analysis of the effect of extending the Directive towards smaller buildings over the time span from 2002 to 2020, with two newly developed scenarios in addition to the four scenarios from chapter 3.

The scenario 5 ('Extended EPBD > 200m^2') has been created on the basis of the scenario "EPBD" including extension of the EPB Directive to all non-residential buildings and multi-dwelling buildings >200m^2. For scenario 6 ('Extended EPBD all house types') single-family houses were also included. The extension towards smaller buildings further increases the reduction potential since obligatory standards would need to be applied in any retrofit measure instead of a voluntary retrofit in cases where the owner decides on improvements in energy efficiency under the influence of the economic options presented in a certificate.

Figure 7: *Temporal evolution of effects on emissions from extending the Directive towards smaller buildings Scenarios Implementation Directive (EU-15)*

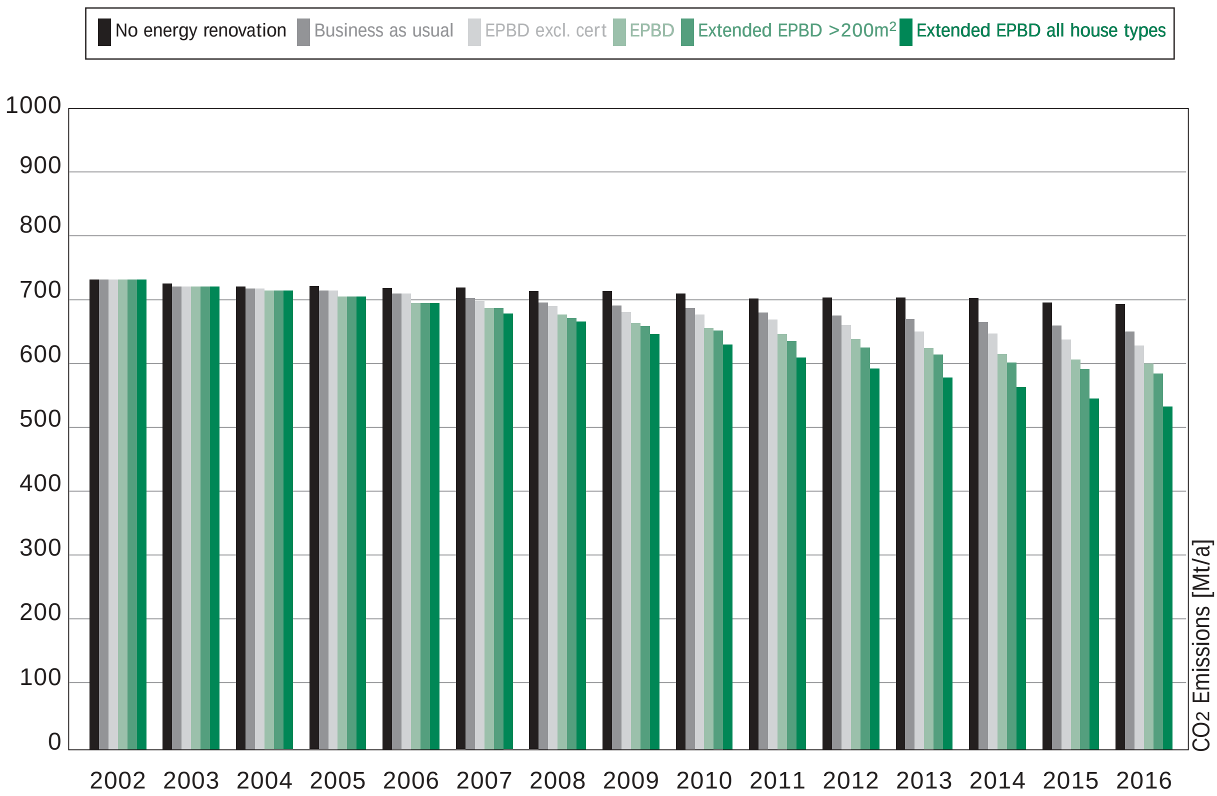


***Table 7:** Overview CO_2 emissions of the European building stock for all scenarios of chapter 3 and 4*

CO_2 Emissions [Mt/a]	2002	2010	2015
No energy renovation			
Residential sector	555	537	527
Non-residential sector	170	165	163
Total	725	703	690
Business as usual (reference)			
Residential sector	555	518	497
Non-residential sector	170	160	154
Total	725	678	651
Directive - Certificates			
Residential sector	555	515	491
Non-residential sector	170	151	137
Total	725	666	628
Directive + Certificates (EPBD)			
Residential sector	555	497	463
Non-residential sector	170	148	133
Total	725	644	596
Reduction compared to reference	-	34	55
Extended Directive >200m^2			
Residential sector	555	492	455
Non-residential sector	170	144	127
Total	725	636	582
Additional reduction compared to EPBD	-	8 (24%)	14 (24%)
Extended Directive all house types			
Residential sector	555	464	406
Non-residential sector	170	144	127
Total	725	609	533
Additional reduction compared to EPBD	-	36 (104%)	63 (113%)

From Figure 7 and Table 7 the following conclusions can be drawn:

- As shown in chapter 3.3.3 the CO_2 emission savings of the Directive are estimated to 34 Mt/a and 55 Mt/a by 2010 and 2015 respectively.
- Extending the building Directive to residential buildings > 200m^2 and all non-residential buildings leads to an emission reduction of 42 Mt/a and 69 Mt/a CO_2 in 2010 and 2015 respectively.
- Further extension of the scope of the Building Directive to all existing building stock results in emission savings of 69 and 118 Mt/a in 2010 and 2015, respectively. This is mainly a consequence of the large share of energy consumption attributable to small residential buildings within the EU-15 building stock. This corresponds to additional savings compared to the Directive of 36 Mt/a and 63 Mt/a in 2010 and 2015 respectively.

5] EFFECTS OF INSULATION ON COOLING DEMAND

Increasing requirements regarding thermal comfort have given rise to the installation of cooling systems in many parts of Europe thus increasing the energy consumption in cooling. The new European Directive responded to this trend by requiring regular inspection of cooling systems to ensure a minimum standard of energy efficiency. In addition, the question is arising in what way thermal insulation can help to reduce or even avoid the demand for cooling. To answer this question first the different influences on the indoor climate in warm regions and strategies how to reduce the cooling demand are described.

5.1 STRATEGIES TO REDUCE COOLING DEMAND

Historical Examples

Many existing buildings in hot climates, built in the last centuries, have adopted clever solutions to keep houses cool. In [BDAA 03] a historical perspective is given, demonstrating a simple but effective strategy:

> The underground dwellings at Coober Pedy in Central Australia arose from miners finding better thermal comfort in their mines than in their living quarters above ground. “These dwellings possess ultimate levels of thermal mass and “earth coupling” which are ideal for evening out the diurnal extremes of the region;

> Ancient cliff dwellings of American Indians in Mesa Verde exploit the cliff overhang for full passive solar control to not just the walls and windows, but the whole village. Natural updrafts provide excellent ventilation;

> Indonesian native buildings use thatch as insulation to deal with heat gain in a tropical climate. Open gables allow cross ventilation of the hottest air that would otherwise accumulate in the roof space. Generous eave overhangs shade the building, further reducing heat gain.

All theses solutions were based on a set of three principles, which are still relevant to reduce the cooling demand:

PRINCIPLE I: MINIMISE SOLAR RADIATION

Whereas solar gains are favourable in winter to reduce the heating demand they can cause high peak demand for cooling in summer. Depending on the climate, solar radiation can be the largest heat load in a building. Therefore some form of shading is advisable, especially for south, west and east facing facades.

PRINCIPLE II: MINIMISE INTERNAL LOADS

The energy released by people, appliances, lighting and other sources, which are not part of the heating system often have a significant effect on the indoor climate. Keeping internal loads to a minimum has a double benefit in saving energy cost directly and also in reducing air-conditioning loads.

PRINCIPLE III: REMOVAL OF HEAT

The ventilation strategy is highly relevant for the removal of heat during the day but also has to prevent infiltration when outside temperatures are higher than inside. Additional night ventilation might be useful to blow outside air at night into a building and cool its thermal mass allowing it then to absorb internal or external heat during the following day. Ambient air might be cooled in underground ducts e.g. in basements, underground car parks or gardens before introduction into the building.

UNDERSTANDING THE EFFECTS OF INSULATION ON COOLING DEMAND

As discussed in the previous section, cooling demand depends on several different influences. Due to the complexity of the problem the effect of insulation on the cooling demand has to be investigated as the sum of its component parts.

Insulation reduces the heat transfer through roofs, walls, the floor and windows. Depending on the temperature difference between inside and outside the heat flows through the building envelope from inside to outside or vice versa.

In cold regions insulation reduces the heating demand in winter, when the outside temperature is colder than inside. For all regions where the outside temperature is higher than the acceptable indoor temperature, insulation is recommended due to its reducing effect on the cooling demand [Tenorio 01], [ABCB 02], [Home 02].

But what is the effect of insulation in warm climatic zones, where for extended periods the outside temperature exceeds the desired inside temperature and hence insulation can help to reduce the cooling demand? There can also be circumstances, when the outside temperature is colder than inside, insulation reduces heat transmission to the outside, which may lead to increased cooling demand, if the internal and solar gains are heating up the building and are not ventilated to the outside.

To assess the potential effect of improved insulation on the cooling demand in Europe, different scenarios for typical buildings in different climate zones were analysed by the simulation software TRNSYS[1], which is used to compute heat flows in buildings dynamically.

5.2 SIMULATION INPUTS COOLING DEMAND

5.2.1 Exemplary Buildings

The effects of insulation on the cooling demand will be analysed for two example house types: an office and a residential building.

Table 8: *Main parameters of analysed terraced house and office building*

Parameter	Terraced house	Office building
Floor area [m^2]	120m^2	3000m^2
Storeys	2	4
Occupants	3	120
Form-factor[2]	0.64	0.34

For further investigation these house types were located in Madrid and Munich, which were chosen as representative for Southern and Central Europe with cooling degree days[3] nearest to the average of the respective climatic region (s. Figure 8 and Figure 9).

1 TRNSYS (The Transient Energy System Simulation Tool), commercially available since 1975, is a flexible tool designed to simulate the transient performance of thermal energy systems (www.trnsys.com).
2 Form-factor is the ratio of the surface of the building envelope to the volume (A/V).
3 Cooling degree days is the sum of days on which the daily average temperature rises above a certain temperature, here 18°C, multiplied by the excess degree for the respective day.

***Figure 8:** Cooling degree days for selected cities in Southern Europe [EERE 03]*

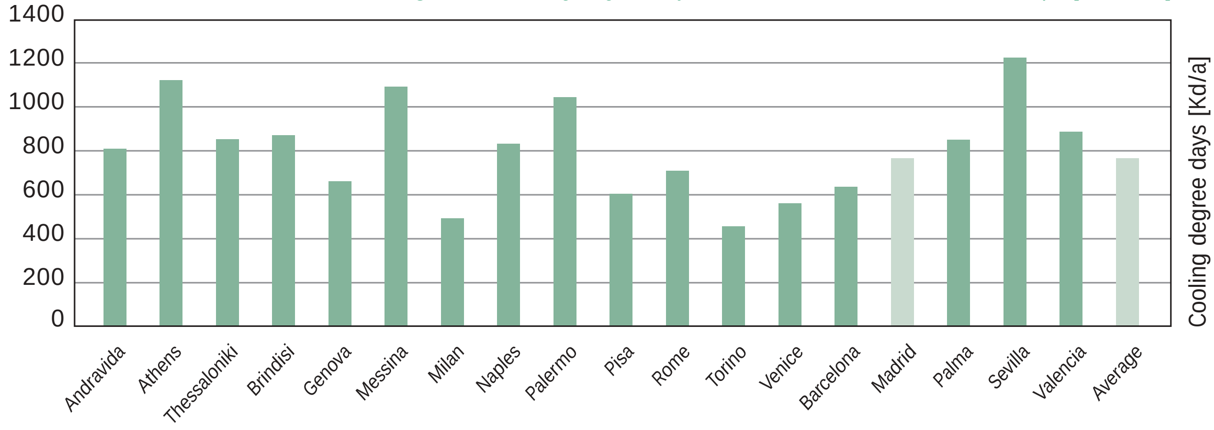
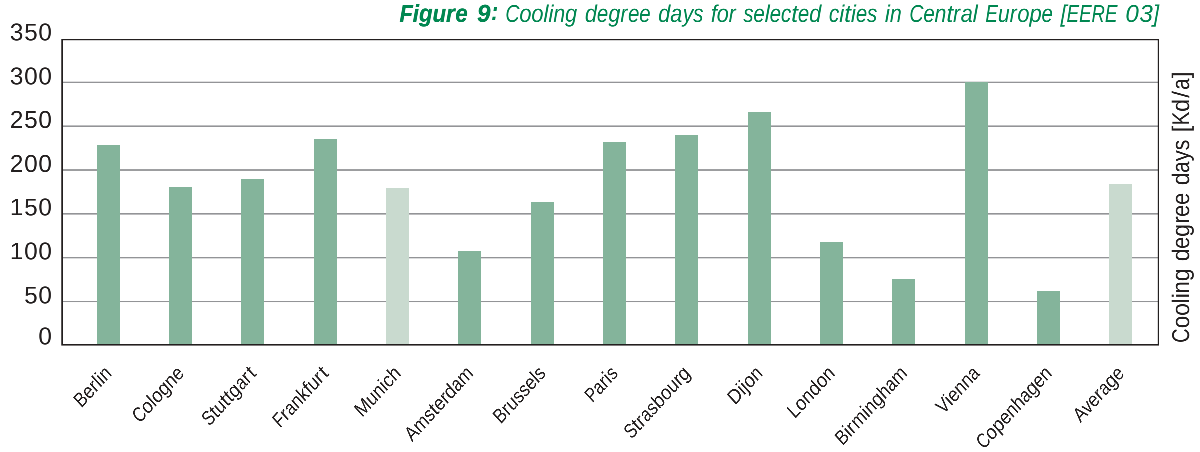


***Figure 9:** Cooling degree days for selected cities in Central Europe [EERE 03]*



5.2.2 Investigated Scenarios for Heat Loads

Due to the high relevance of the heat loads in buildings on the cooling demand, as described in chapter 5.1, two different scenarios were further investigated.

- In scenario 1 'high loads' an inefficient internal shading device is assumed leading to high solar radiation gain. Old household appliances or office appliances with high energy consumptions lead to high internal loads. Furthermore, a ventilation strategy with constant air changes is assumed.
- Examples throughout Europe demonstrate that heat loads can be reduced significantly, e.g. in passive buildings for both office and residential buildings. Low, but not minimized heat loads are assumed as an advisable yet practicable scenario 2 'low loads'. Here an efficient shading device e.g. external shading, energy efficient household and office appliances and a ventilation strategy, which depends on the outdoor temperature are combined.

A detailed description of the scenarios for the terraced house and the office building is given in Annex II of this report.

5.3 SIMULATION RESULTS COOLING DEMAND

5.3.1 Residential Buildings in Warm Climate

Based on the terraced house with low heat loads Figure 10 and Table 10 illustrate the influence of insulation on the cooling demand. In this way different combinations of insulation of the roof, the façade, the windows and the floor are examined (Table 9). It can be seen that:

- > The cooling demand of the terraced house that was examined can be reduced to about 15% with an optimized insulation strategy;
- > The insulation of the roof is a very efficient measure to minimize the cooling demand with reduced heat transmission caused not only by high outside temperatures but also by the solar radiation, which is incident on the roof;
- > High insulation of the floor causes higher cooling demand due to the avoidance of earth coupling.

Figure 10: *Cooling demand terraced house in Madrid low heat loads, different insulation standards*

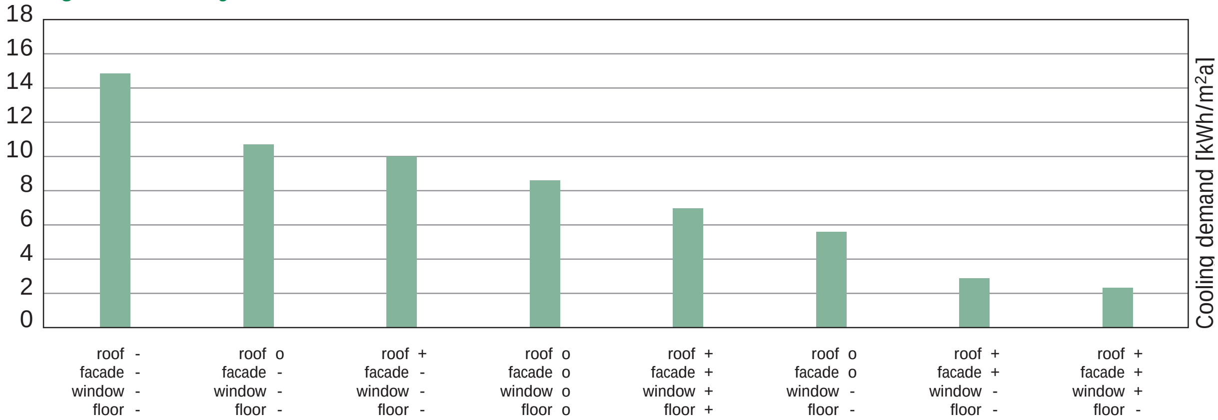


Table 9: *U-values of example buildings in Madrid*

Surfaces	U-value high standard (W/m^2K) +	U-value medium standard (W/m^2K) o	U-value low standard (W/m^2K) -
Roof	0.3	1.0	3.4
Façade	0.5	1.4	2.6
Windows	2.0 (g-value: 0.622)	3.5 (g-value: 0.755)	4.2 (g-value: 0.755)
Ground floor	0.4	1.0	1.7

Figure 11 illustrates that the combination of measures to reduce the cooling demand is of great importance. Insulating the terraced house with high loads reduces the cooling demand to a certain extent but when the heat load in the house is low, insulation is a highly efficient measure which almost avoids cooling demand. Furthermore the figure shows that the cooling demand of the terraced house with low insulation can be reduced to 53% by lowering the heat loads. This proves that the historical principles for reducing the cooling demand, as described in chapter 5.1, should to be first followed to achieve an energy-optimised residential building.

Figure 11: *Cooling demand terraced house Madrid with different heat loads and insulation standards*

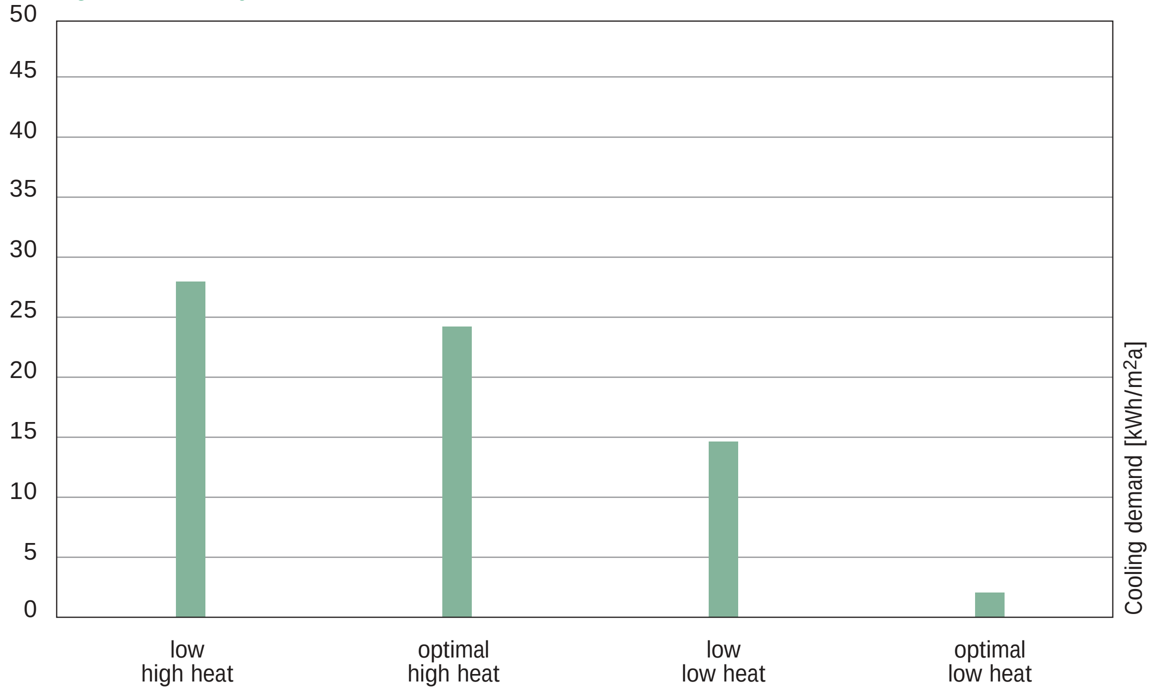


Table 10: *Overview cooling demand of analysed terraced houses in Madrid*

Madrid					Terraced house		
Heat loads	Insulation standards				Cooling demand [kWh/m^{2}a]	CO_2 Emissions [kg/m^{2}a]	Hours of discomfort >26°C
	Roof	Facade	Window	Floor			
High	Low	Low	Low	Low	28.2	5.53	1,675
High	High	High	High	Low	24.5	4.80	2,254
Low	Low	Low	Low	Low	14.9	2.91	1,056
Low	Medium	Low	Low	Low	10.9	2.12	952
Low	High	Low	Low	Low	10.0	1.95	926
Low	Medium	Medium	Medium	Medium	8.6	1.68	1,078
Low	High	High	High	High	7.0	1.37	1,251
Low	Medium	Medium	Low	Low	5.7	1.11	764
Low	High	High	Low	Low	3.0	0.58	599
Low	High	High	High	Low	2.3	0.45	564

5.3.2 Office Building in Warm Climate

In Figure 12 the impact of insulation for the example office building with low heat loads in Madrid is shown. In this case the insulation of the roofs decreases the cooling demand by 24%.

The insulation of the façade no longer has a positive effect, because the heat load of the building compared to a residential building is still relatively high and heat can be extracted either by appropriate ventilation or by transmission through the walls.

Figure 12: *Cooling demand office Madrid with different insulation standards*

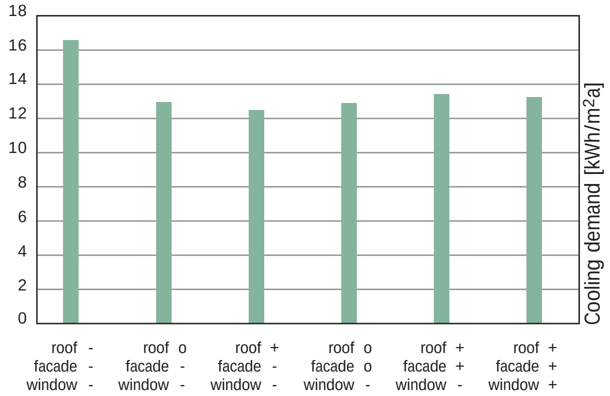


Figure 13: *Cooling demand office Madrid with different insulation standards*

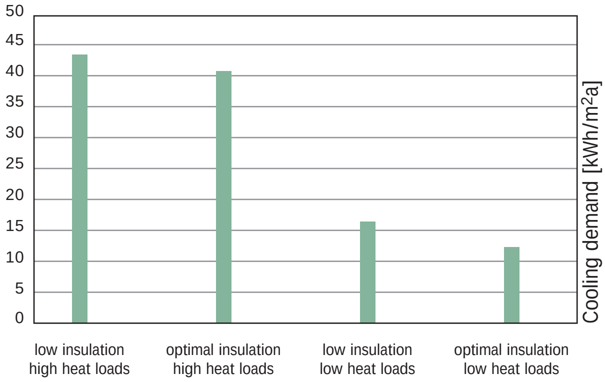


Figure 13 summaries the whole impact of the combination of the decreased heat load and the insulation of the roof for the office building in Madrid. It is shown that nearly 70% of the cooling demand can be reduced by a holistic design of the houses with an intelligent combination of measures.

Furthermore, the figure shows that insulating the roof still has a positive effect on the cooling demand even when the heat loads are high.

An overview of all analysed scenarios of a typical office building in Madrid is given in Table 11.

Table 11: *Overview cooling demand of analysed office buildings in Madrid*

Madrid Office building						
Heat loads	Insulation standards			Cooling demand	CO_2 Emissions	Hours of discomfort
	Roof	Facade	Window	[kWh/m^{2}a]	[kg/m^{2}a]	>24°C
High	Low	Low	Low	43.8	8.56	2,770
High	High	Low	Low	41.1	8.04	2,938
Low	Low	Low	Low	16.6	3.24	1,450
Low	Medium	Low	Low	13.0	2.54	1,389
Low	High	Low	Low	12.6	2.46	1,374
Low	Medium	Medium	Low	13.1	2.55	1,432
Low	High	High	Low	13.5	2.65	1,486
Low	High	High	High	13.3	2.61	1,581

5.3.3 COMPARISON WITH COOLING DEMAND IN MODERATE CLIMATE

Table 12 summarises the investigated scenarios of the terraced house and office building in Munich, whereas Table 13 gives an overview of the estimated U-values.

Table 12: *Overview cooling demand of analysed terraced houses and office buildings in Munich*

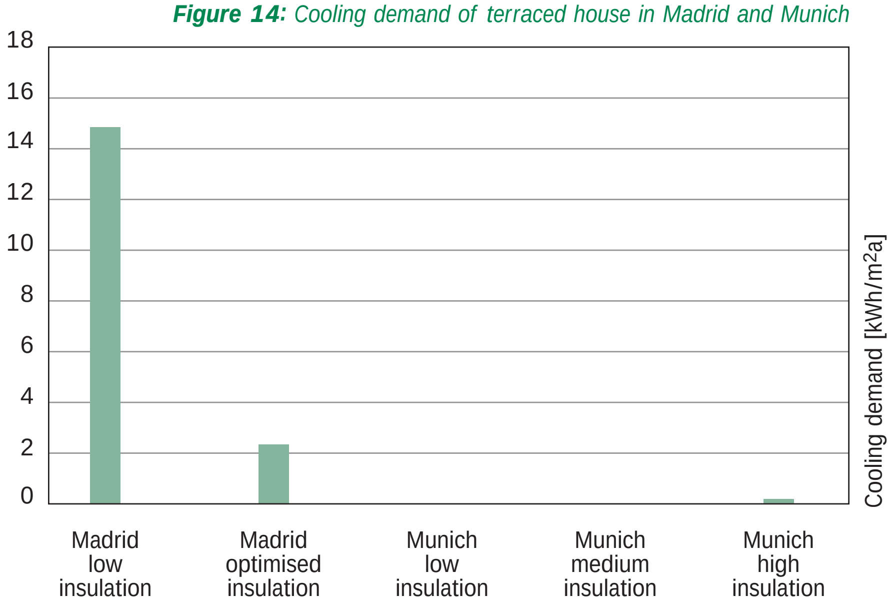
Munich					Terraced house		Office building	
Heat loads	Insulation standards				Cooling demand [kWh/m²a]	Hours of discomfort >26°C	Cooling demand [kWh/m²a]	Hours of discomfort >24°C
	Roof	Facade	Window	Floor				
low	low	low	low	low	0.0	13	0.2	240
low	low	low	low	medium	not calculated		1.3	240
low	medium	medium	medium	medium	0.0	8	1.3	240
low	high	high	high	high	0.2	14	1.2	253

Table 13: *U-values Munich*

Surfaces	U-value high standard (W/m²K)	U-value medium standard (W/m²K)	U-value low standard (W/m²K)
Roof	0,15	0,5	1,5
Facade	0,25	1,0	1,5
Windows	1,3 (g-value: 0.590)	2,0 (g-value: 0.622)	3,5 (g-value: 0.755)
Ground floor	0,3	0,8	1,2

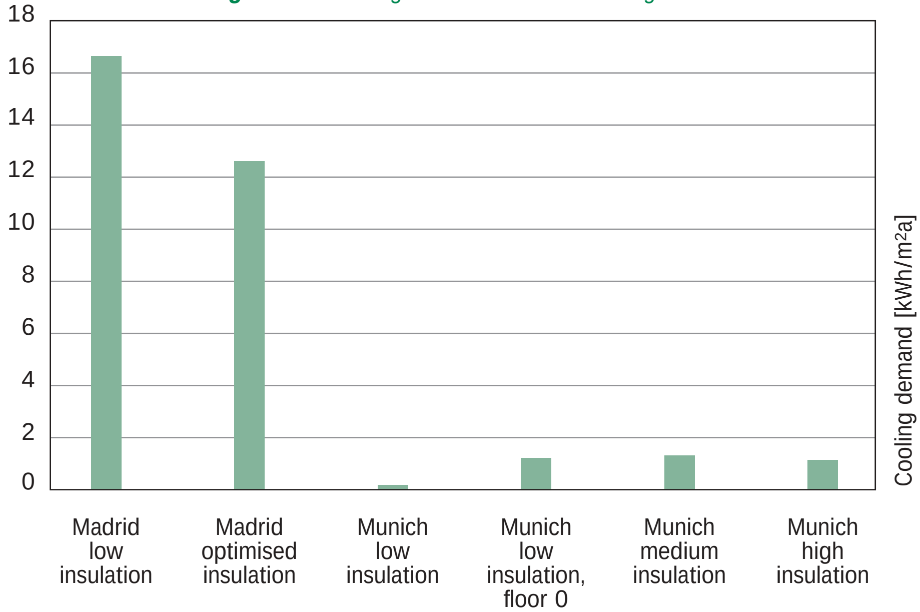
Figure 14 compares the results of the terraced house in Munich with the results of the same house type in Madrid and shows that the cooling demand in Munich is negligible for all investigated insulation standards, if heat loads are low.

Figure 14: *Cooling demand of terraced house in Madrid and Munich*



The influence of insulation on the cooling demand of the analyzed office building (Figure 15) is also almost negligible. Active cooling can be avoided when efficient shading systems, energy efficient office appliances and an adapted ventilation strategy are used to reduce the heat loads. Among the insulation measures the floor has the highest influence. Without the floor insulation earth coupling creates a positive effect on the indoor climate in summer. But the effect would be overcompensated by the higher heating demand in winter. Therefore it is advisable to design the insulation standard according to the needs of a minimized heating demand in winter.

Figure 15: *Cooling demand of office building in Madrid and Munich*



5.3.4 Outlook Cooling Demand

The selection of examples in moderate and warm climate has shown that there is a significant potential for reductions of cooling energy demand if appropriate insulation is applied in combination with other measures. This offers further potential for CO_2 emission reductions. However, the quantification of these potentials would require further research. On the basis of the information presented in the investigations it cannot be scientifically justified to extrapolate data from climatic zone results.

6] CONCLUSIONS

The model calculations conducted in the course of this study confirmed that the European Directive on Energy Performance of Buildings will have a significant effect on the CO_2 emissions by reducing the heating energy demand of buildings. The main contributor to the total of 725 Mt/a of CO_2 emissions from the EU building stock in 2002 is the residential sector (77%) while the remaining 23% originates from non-residential buildings. In the residential sector, single-family houses represent the largest group responsible for 60% of the total CO_2 emissions equivalent to 435 Mt/a.

THE TECHNICAL POTENTIAL

It was found that the main potential for CO_2 emission reduction lies in the heating energy consumption of the existing building stock thus confirming earlier studies [IWU 94, ECOFYS 02]. If all retrofit measures in the scope of the Directive were realised immediately for the complete residential and non-residential building stock the overall CO_2 emission savings would add up to 82 Mt/a. An additional saving potential compared to the Directive of 69 Mt/a would be created if the scope of the Directive was extended to cover retrofit measures in multi-family dwellings (200-1000m^2) and non-residential buildings smaller than 1000m^2 used floor space. In addition including the large group of single-family dwellings would lead to a potential for additional CO_2 emission reductions compared to the Directive of 316 Mt/a.

TEMPORAL MOBILISATION OF THE POTENTIAL

Calculations based on the building stock as it develops over time with average retrofit rates demonstrated that regulations introduced following the EPB Directive result in a CO_2 emissions decrease of 34 Mt/a by the year 2010 compared to the business as usual scenario. Extending the scope of the EPB Directive to all residential buildings (including single and multi-family dwellings), the CO_2 emission savings potential over the 'business as usual' scenario could be doubled to 69 Mt/a in the year 2010. This creates an additional saving potential compared to the Directive of 36 Mt/a.

COOLING DEMAND

This analysis demonstrated that in moderate climatic zones insulation has no significant effect of the cooling demand and therefore should only receive attention after the needs of reducing the heating demand are fulfilled. The cooling demand for residential buildings in the moderate climatic zone can be easily avoided by efficient shading systems, lowered internal gains and an adaptive ventilation strategy. In principle this is equally applicable to office buildings, but the building must be designed more carefully because of the higher internal gains. These results for the moderate climatic zone are fully transferable to the cold zone.

In warm climatic zones the cooling demand can be drastically reduced by a combination of lowering the heat loads and by insulation. When the heat loads in the investigated terraced house example, located in Madrid, is lowered to a moderate level, the cooling demand can be further reduced by improved insulation by 85%.

For the office building investigated in Madrid insulation, in particular roof insulation, results in a 24% reduction of cooling energy demand in spite of the high internal loads.

For cities like Athens, the effect of additional insulation increases: with hotter climate and lower heat loads inside the building, the benefit of insulation on the reduction of cooling energy demand grows.

7] LITERATURE

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ANNEX I: MODEL DESCRIPTION

For the research project "The contribution of Mineral Wool and other Thermal Insulation Materials to Energy Saving and Climate Protection in Europe" [ECOFYS 2002], ECOFYS has developed a model displaying the actual condition and future developments in the European building stock to analyze potential energy savings through thermal insulation. Statements concerning energy savings through thermal insulation are based on a calculation model structuring the building stock in a simplified manner. This has to be taken into account when evaluating the accuracy of the results. However, the results provide safe indicators of the probable size of energy saving potentials.

The investigation of the questions, which were raised in connection with the EU Directive, requires certain modifications and additions of the **ECOFYS** model (e.g. the implementation of additional classes of smaller buildings).

BUILDING TYPES

For the modeling of the European building stock 5 standard houses were taken into account:

- Model house 1 : Two-storey terrace-end-house (120m^2);
- Model house 2 : small apartment house (less than 1000m^2);
- Model house 3 : large apartment house (larger than 1000m^2);
- Small office building (less than 1000m^2);
- Large office building (larger than 1000m^2).

CLIMATIC ZONES

Different climatic conditions in Europe have been summed up in three climatic zones. The Northern cool climatic zone comprises the following countries: Finland and Sweden. Austria, Belgium, Denmark, France, Germany, Great Britain, Ireland, Luxembourg and the Netherlands belong to the moderate central climatic zone while the Southern warm zone includes Greece, Italy, Portugal and Spain.
According to the STOA report [STOA 1998] the following heating degree-days were assumed for the different climatic zones.

Table 14: *Heating degree days*

	Heating degree days [Kd/a]
Warm climatic zone	1800
Moderate climatic zone	3500
Cold climatic zone	4500

BUILDING AGE GROUPS

The building stock has been subdivided into three building age groups, which differ substantially due to the respective valid national or regional regulations and the insulation standard connected to them:

- Buildings erected before 1975 (subdivided into buildings already energetically redeveloped and buildings in their initial condition);
- Buildings erected between 1975 and 1990;
- Buildings erected after 1990.

CHARACTERIZATION OF THE EUROPEAN BUILDING STOCK[4]

Table 15: Characterisation of the European building stock

	Building age	Total	One family house	Apartment house <1000m2	Apartment house >1000m2	Small non-residential buildings <1000m2	Non-residential buildings >1000m2
	Year	[Million m^2]	[Million m^2]	[Million m^2]	[Million m^2]	[Million m^2]	[Million m^2]
Cold climatic zone	< 1975	534	220	109	59	55	92
	1975-1990	154	63	31	17	16	27
	1991-2002	120	31	26	14	18	30
Moderate climatic zone	< 1975	9,145	4,607	1,242	669	780	1,848
	1975-1990	2,551	1,290	348	187	216	511
	1991-2002	1,708	670	181	97	226	535
Warm climatic zone	< 1975	3,116	1,197	769	414	319	416
	1975-1990	1,945	748	480	259	199	259
	1991-2002	1,175	399	256	138	166	216

U-VALUES OF THE BUILDING TYPES

According to climatic zone and building age group, different insulation standards and their respective U-values have been applied :

Table 16: U-values for climatic zones and building ages

U-values [W/m^{2}K]	Built before 1975 Not retrofit.	Built before 1975 Already retrofit.	Built from 1975 until 1990	Built from 1991 until - 2002	New building 2003-2006[5]	Retrofit 2003-2006	New building after 2006	Retrofit after 2006
Cold climatic zone								
Roof	0.50	0.20	0.20	0.15	0.15	0.15	0.13	0.13
Facade	0.50	0.30	0.30	0.20	0.18	0.18	0.17	0.17
Floor	0.50	0.20	0.20	0.18	0.18	0.18	0.17	0.17
Windows	3.00	1.60	2.00	1.60	1.42	1.42	1.33	1.33
Moderate climatic zone								
Roof	1.50	0.50	0.50	0.40	0.25	0.25	0.23	0.23
Facade	1.50	1.00	1.00	0.50	0.41	0.41	0.38	0.38
Floor	1.20	0.80	0.80	0.50	0.44	0.44	0.41	0.41
Windows	3.50	2.00	3.50	2.00	1.84	1.84	1.68	1.68
Warm climatic zone								
Roof	3.40	1.00	0.80	0.50	0.50	0.50	0.43	0.43
Facade	2.60	1.40	1.20	0.60	0.60	0.60	0.48	0.48
Floor	3.40	1.00	0.80	0.55	0.55	0.55	0.48	0.48
Windows	4.20	3.50	4.20	3.50	3.04	3.04	2.71	2.71

It should be noted that the applied values are only roughly established and some of them had to be estimated despite extensive data investigation. For an exact determination of saving potentials through thermal insulation a detailed building typology of Europe would be necessary.

CALCULATION OF ENERGY SAVINGS

The starting point for the calculations has been the actual energy consumption for space heating in buildings in the EU for 2002. In order to take into account annual weather conditions the values have been adjusted by using the respective heat degree days.

For the different model buildings which were subdivided according to building type, building age group, insulation standard and weather condition, the respective saving potentials for thermal insulation have been determined. The calculations are based on the EN 832 standard. The amount of energy saving through thermal insulation determined for the model houses has been projected to the energy consumption values in the Member States and normalized for floor space. In order to find the CO_2 emissions the average annual efficiency of heating systems have been assumed for each energy carrier depending whether it is an old or new system.

USED ENERGY DATA

The forecast for the energy consumption of buildings in 2002 is based on IEA statistics for 1998 and average annual percent change in the period 1998 and 2005. The energy consumption for space heating of buildings is derived from various literature sources (amongst others [Eurostat 01, 02]) and if possible determined at country level.

IEA statistics are also used for the energy consumption data of the residential sector as well as the non-residential and public services sector in this study.

The data of the reference year 1990 and 2010 is slightly different from the data used in the sectoral objective study due to the statistical source that has been used (PRIMES database (sectoral objective study) versus IEA statistics (EURIMA study)).

4 Main source for residential sector: [Fin 01]; main source for non-residential buildings: [Eurostat 01, 02]
5 The European Directive 2002/91/EC requires implementation in the legislation of the Member States by 4 January 2006

ANNEX II: ASSUMPTIONS FOR CALCULATING THE COOLING DEMAND

Two different heat loads are assumed in the TRNSYS calculations:

Table 17: *Scenarios for heat loads and ventilation strategy*

Scenario	Solar loads	Internal loads	Ventilation
Scenario high loads	Internal shading devices	High internal loads	constant air-change
Scenario low loads	External shading devices	Low internal loads	variable air-change depending on outside temperature

INTERNAL LOADS

For the purposes of the analysis of the cooling demand, three categories of internal gains were distinguished for both residential and office buildings: “high”, “medium” and “low” (Table 18).

Table 18: *Classification of internal gains in offices (Source: [Knissel 99])*

Internal loads [W/m²]	High	Medium	Low
Office appliances	14.5	14.5	8.8
Lighting	27.1	16.3	12.5
Persons	5.7	5.7	5.7
Persons and office appliances	20.2	20.2	14.5
Total	**47.3**	**36.4**	**26.9**

Lighting is mainly used during the winter; most office appliances are only operated during office hours, which requires the distinction of base load and office hours. In addition to this, adjoining rooms (corridors, halls, etc.) have not been accounted for in the values included in Table 18. To compensate for this, the following internal gains were assumed:

Table 19: *Internal heat gains in office buildings corrected for usage*

Office buildings	Base-load	During office time (8:30-17:00)
Internal heat load low	3.5 W/m²	Additional 11 W/m²a
Internal heat load high	5.0 W/m²	Additional 20 W/m²a

In dwellings the internal gains mainly depend on the electricity use for household appliances and loads from people (compare Table 20). People are assumed to be present in their homes for 14 hrs on average.

Table 20: *Classification of internal gains dwellings*

Internal loads	High	Medium	Low
Household appliances [kWh/a]	43.8	33.3 average household	18.5 low energy house
Internal gains [W/m²]	5 [EN832]	3.8	2.1
Persons [W/Pers]	150	150	150

In the course of this study the scenarios high and low have been chosen for further examination.

VENTILATION SCENARIOS

Air exchange can be achieved either by mechanical means (mechanical ventilation), or through opening the windows (natural ventilation). Air is also exchanged through small openings such as leakages or gaps in the building envelope (infiltration).

The analysis focuses on quantity and time of air exchange rather than the method of air exchange.

Ventilation strategy 1 constantly supplies ambient fresh air, e.g. by forced mechanical ventilation. Table 21 summarizes air exchange rates (fresh air inflow relative to room volume), for ventilation strategy 1.

Table 21: *Air exchange according to strategy 1 for office and residential buildings*

Building	Infiltration	Ventilation
Office building	0.2/h	0.8/h
Residential building	0.1/h	0.8/h

Additional to the supply of fresh air, the objective of ventilation strategy 2 is to adapt air exchange towards reduced energy consumption:

- minimize air-exchange when outside temperature is higher than inside temperature;
- remove excess heat in summer when inside temperature is higher than ambient temperature.

The related air exchange rates for ventilation strategy 2 are given in Table 22.

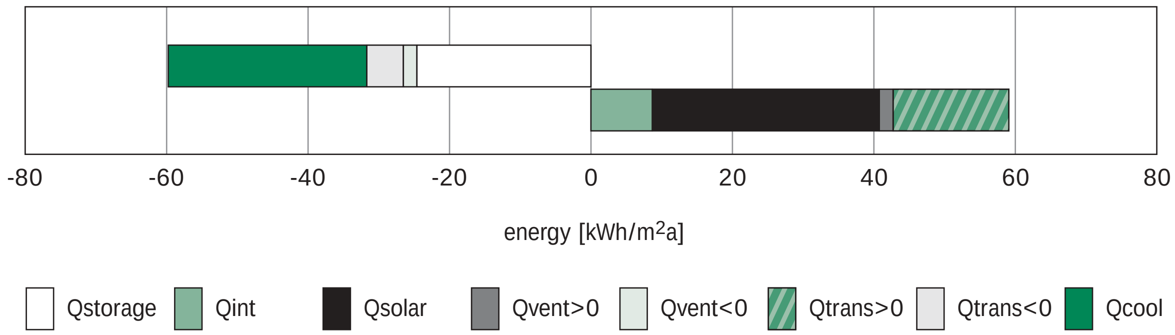
Table 22: *Air exchange according to strategy 2 for office and residential buildings*

Building	Infiltration	Ventilation
Office building	0.2/h	$T_{outside} > T_{inside}$ 0.6/h $T_{outside} < T_{inside}$ 2.0/h
Residential building	0.1/h	$T_{outside} > T_{inside}$ 0.3/h $T_{outside} < T_{inside}$ 1.0/h

ANNEX III: COOLING DEMAND OF A TERRACED HOUSE MADRID

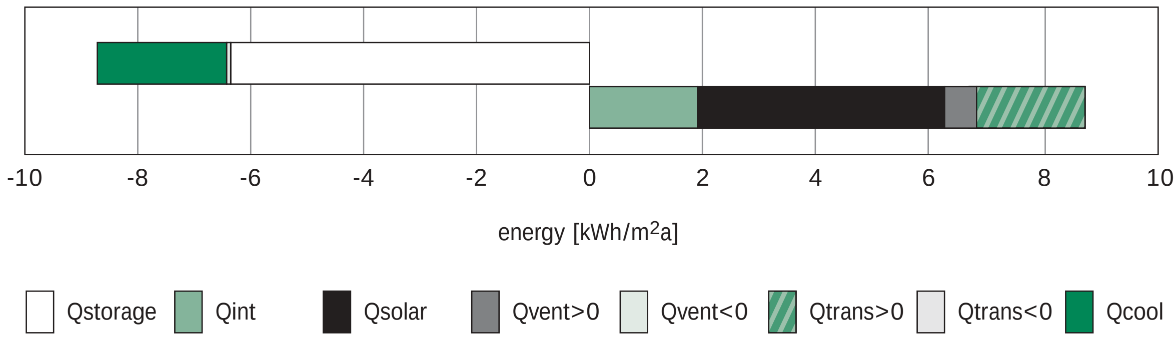
The different influences of heat-transmission, solar radiation, internal loads, ventilation and heat storage for the low insulated terraced house in Madrid are illustrated in Figure 16. The energy flows have been balanced for the periods, in which the cooling appliance is operated in order to withdraw excess heat from the building. This covers both situations in which ambient temperature is lower as well as higher than the internal building temperature. Ventilation and transmission may therefore cause positive and negative energy flows into the building. Negative energy flows are those extracted from the building to the outside.

Figure 16: *Subdivision of cooling demand terraced house Madrid, low insulation, high loads*



From the figure can be seen that insulation is beneficial because the heat flow into the building (Q_{trans}>0) during times of operation of cooling appliances is larger than the transmission losses out of the building (Q_{trans}<0) at times when the indoor temperature exceeds the ambient temperature. Another lesson to be learned is the importance of thermal mass in warm climates: heat taken up during the day reduces the temperature increase in the building and can be released during the night. The large proportion of energy radiated stresses the importance of efficient shading. Taking into account all options to reduce internal loads and solar radiation as well as optimized insulation (roof+, façade+, window+, floor) Figure 17 shows the impact on the cooling demand. It should be noted that scale is unlike Figure 16.

Figure 17: *Subdivision of cooling demand terraced house Madrid, optimal insulation, low loads*



A comparison of Figure 16 and Figure 17 shows that the cooling demand can be reduced significantly from 29 kWh/m^2a to 2 kWh/m^2a.

NOTES:

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