Energy saving potential through optimal pipe insulation

A European comparison

Even in well-insulated houses energy consumption can be reduced further by insulating heating and hot water pipes

In the face of high and rising energy prices as well as worsening climate problems, it is necessary to examine and realize the potential for saving savings can be achieved. Through optimal pipe insulation of space heating and domestic hot-water distribution systems further energy savings accompanied by a reduction in CO_2 emissions are possible.

In order to determine this potential for savings, the heat losses from the tic hot-water pipes. The saving potential for CO_2 emissions is some 3.3 kg/(m²·a), i.e. around 500 kg annually for a 160 m² single-family house. Contrary to common belief, even for pipes which are laid completely in heated rooms, additional heat losses occur. These pipes should, therefore, be insulated.

The study investigated a detached, single-family house in selected European countries (Sweden, Poland, Germany a, Great Britain, Italy, Spain). To provide comfort one needs energy: for heating in winter and for preparing domestic hot water throughout the year. For financial, and also for environmental, reasons energy requirements should be greatly reduced.

energy in the building sector. Whilst many existing buildings are still in their original, energy-inefficient condition, houses today are built in accordance with energy-efficient standards. The building shell is insulated, thermal glazing is used for windows and efficient boilers are installed. Through these measures the energy requirements of buildings can be reduced considerably.
However, as a recent study by Armacell shows, even in modern, well-insulated houses further energy pipework and their impact on the seasonal winter heating needed for a single-family house in six different European locations were calculated. The results confirm expectations: in the mild European climate poorly insulated pipes are responsible for annual non-recoverable heat losses of up to 40 % of the net heat demand. By insulating the distribution pipes these losses can be reduced to 12 %. In southern regions, even higher heat losses were found, especially from domes-

Even in modern, well-insulated houses further energy savings can be achieved by insulating heating and hot water systems professionally

What are the possibilities for achieving energy savings? There are three main areas where the generated heat is lost. Firstly, there is the structure of the house: the walls, roof, windows, foundations etc. A further area is ventilation, where heat loss depends on the house volume. Finally there are the pipe systems for heating and domestic hot water where heat can be lost during its generation, storage, distribution and emission.

It is possible to achieve considerable energy savings during the generation, storage and emission process by installing modern boilers, storage tanks, radiators, water taps, pumps and controls. Furthermore, the optimal insulation of the distribution pipes provides huge, in many cases unnoticed and unrecognized, potential for additional energy savings. For a particular house these energy savings can be calculated in a standardized way based on international and European standards and pre-standards for calculating the energy performance of buildings.

What principles are the calculations based on? The basic assumption is that the house remains in thermal balance in winter. Losses from the building must be compensated for by heat gains and heat delivered efficiently by the space heating system. During the whole heating season the heat losses through the building structure and ventilation are equal to the net heat gains (solar, metabolic, from appliances and from heating and domestic hot-water systems) plus the energy emitted by the heating system.

Not all heat gains effectively contribute to achieving pleasant temperatures throughout the whole heating season. Whilst a large portion of the heat gains are efficiently recovered and thus termed “useful gains”, a minor part is not effectively utilized by the house. The relationship between useful and unutilized heat gains or, in other words, the utilization factor for the heat gains η depends on the structure of the house, its location and architecture, the orientation of its windows and on the ratio between heat gains and losses.

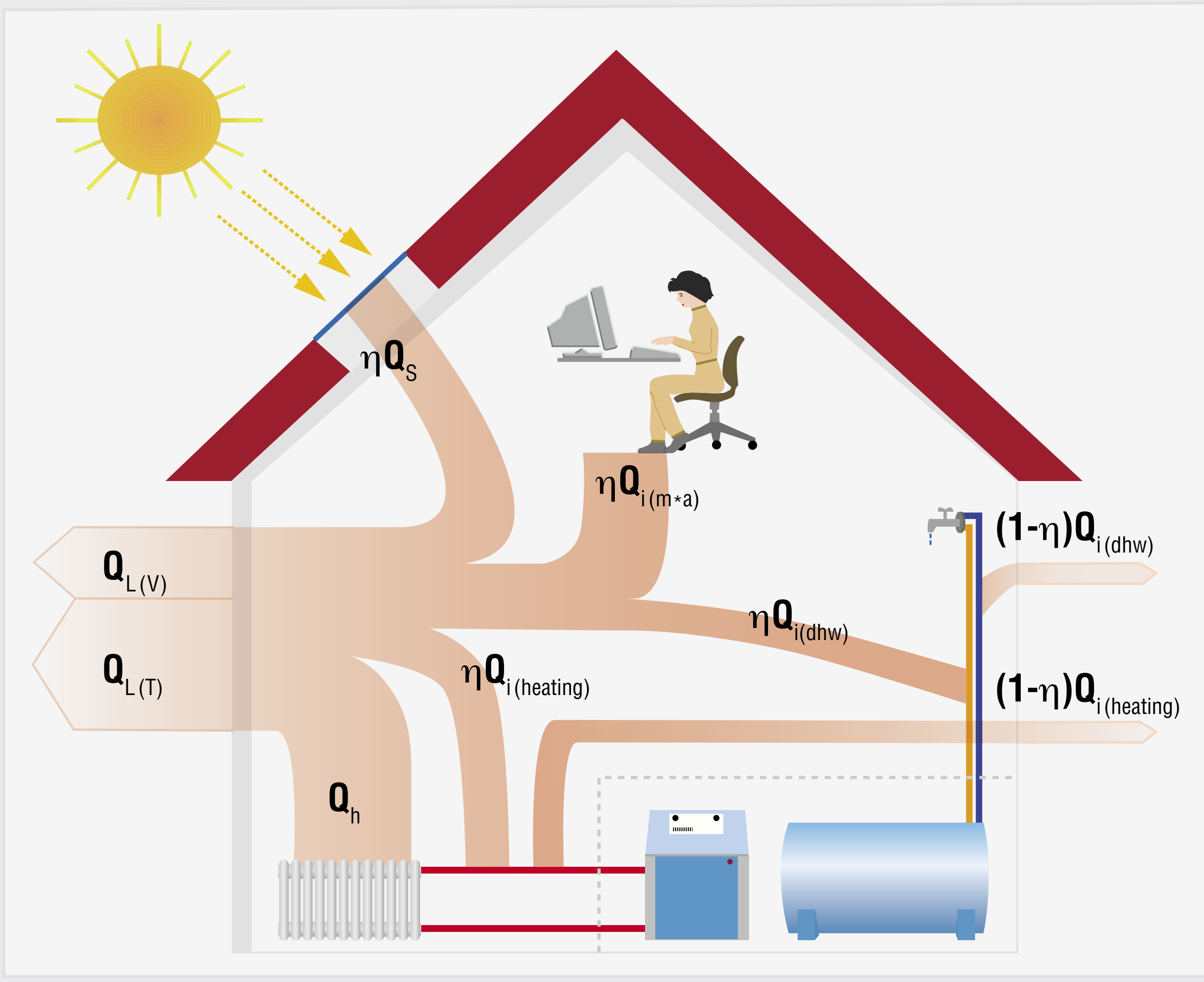


Figure 1: The energy performance of a house

$$Q_{L\,(T)} + Q_{L\,(V)} = \eta Q_S + \eta Q_{i\,(m*a)} + \eta Q_{i\,(Heizung)} + \eta Q_{i\,(BWW)} + Q_h \; [kWh]$$

With the equation given above it is possible to calculate the energy need for heating Q_h or, in other words, the net heat demand for the space heating system. This is the term for the heat which is supplied to the house via the emitters (radiators). With the exception of the internal heat gains from space heating and domestic hot water systems all other elements of energy performance depend on the house and its location. Heat loss through transmission $Q_{L(T)}$ depends on the house structure, i.e. its construction materials and sizes (of walls, windows, roof, floor, etc.). It can be reduced by good structural insulation of the walls and roof and by using windows of good thermal quality.

Heat loss through ventilation $Q_{L(V)}$ depends on the air change rate. Unless a mechanical ventilation system with a heat recovery unit is installed, this heat loss cannot be reduced much because reasonable ventilation is needed for good indoor air quality.

Total solar heat gains through glazing Q_s depend strongly on the geographical location of the house and on the surface area and orientation of the windows. South-facing roof windows have the greatest effect. Other internal heat gains are metabolic gains: the gains $Q_{i\,(m \cdot a)}$ depend on the number of people living in the house, the electrical appliances they use (light, washing machine, computer, stove, iron etc.) and length of time for which they use them. These heat gains are usually viewed in proportion to the house floor area because larger houses usually mean more occupants and appliances.

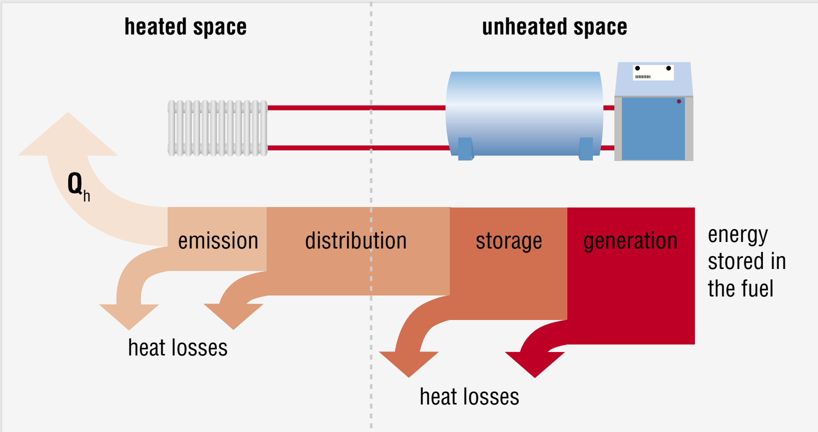


Figure 2: Heat losses in the space heating system

The total internal heat gains from space heating and domestic hot water systems, $Q_{i\,(heating)}$ and $Q_{i\,(dhw)}$ respectively, depend solely on the systems in question. However, these two heating systems cannot be considered as being totally independent of the house, because they are designed to serve its particular needs. The space heating system is sized in accordance with the heat demand of the house.

The size of the domestic hot water system is adapted to the floor space: the larger the house, the more taps it usually needs. Both heating systems can consist of generation, storage, distribution and emission subsystems.

While energy and heat are being processed in the individual subsystems a portion of the heat originally stored in the fuel is lost. Assuming that the generators and storage tanks (for domestic hot water) are usually located in an unheated room, their heat loss does not contribute to the space heating. Heat loss during emission (due to non-uniform temperature distribution and the heat stored in the water tap after each draw-off) is slight and can therefore be neglected. Within the heated rooms there are also heat losses from the distribution pipes.

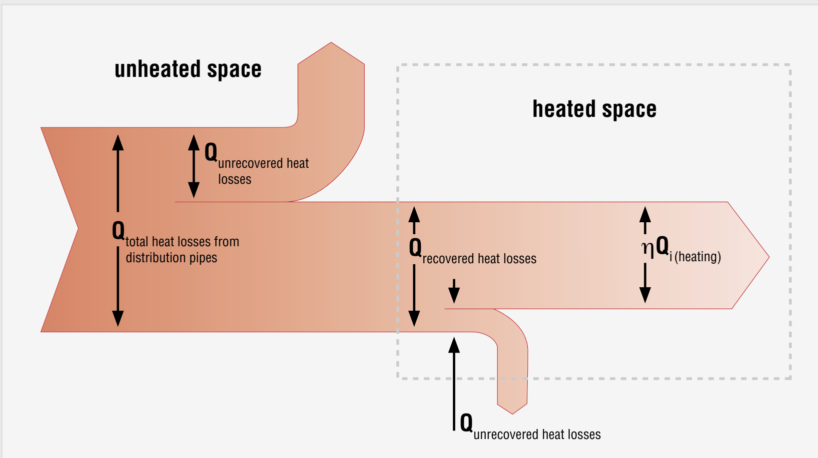


Figure 3: Heat losses from distribution pipes in the space heating system

In general, heat losses from distribution pipes in space heating and domestic hot water systems can occur both in heated and unheated spaces. Those in unheated spaces cannot be recovered by the house and so this energy is lost. In addition, heat losses from domestic hot water pipes in summer are lost completely because the house does not need heating during this period.

Contrary to common belief, heat losses from distribution pipes in heated spaces are not fully recovered and utilized for space heating. A portion of this energy is lost if the pipes run through the following rooms:

- rooms which are generally unheated (only used from time to time),
- rooms and spaces which do not need to be heated: e.g. garages, pantries or storage rooms,
- rooms and spaces with a lower design temperature: e.g. staircases, entrances, basements etc.,
- south-facing rooms where a few daylight hours of sunshine in winter are sufficient to heat the room solely due to passive solar energy gains. In this case any heat loss from a pipe does not contribute to achieving a pleasant room temperature, because this has already been achieved.

The heat lost from the distribution pipes depends on their thermal insulation: its quality (low thermal conductivity, crack-free material, thermally stable) and thickness. So it is a question of what non-recoverable heat losses there are from distribution pipes in relation to the net heat demand and how much energy can be saved by installing pipe insulation in an optimal thickness.

Model house

In order to answer this question, the model of a typical detached, modern, well-insulated single-family house, with two floors, a 45° roof angle and a net floor area of 160 m^2 was assumed. The heat transfer calculations for this house were carried out in six different European regions in accordance with the international standard ISO 13790.

Optimal insulation can greatly reduce heat losses from pipes

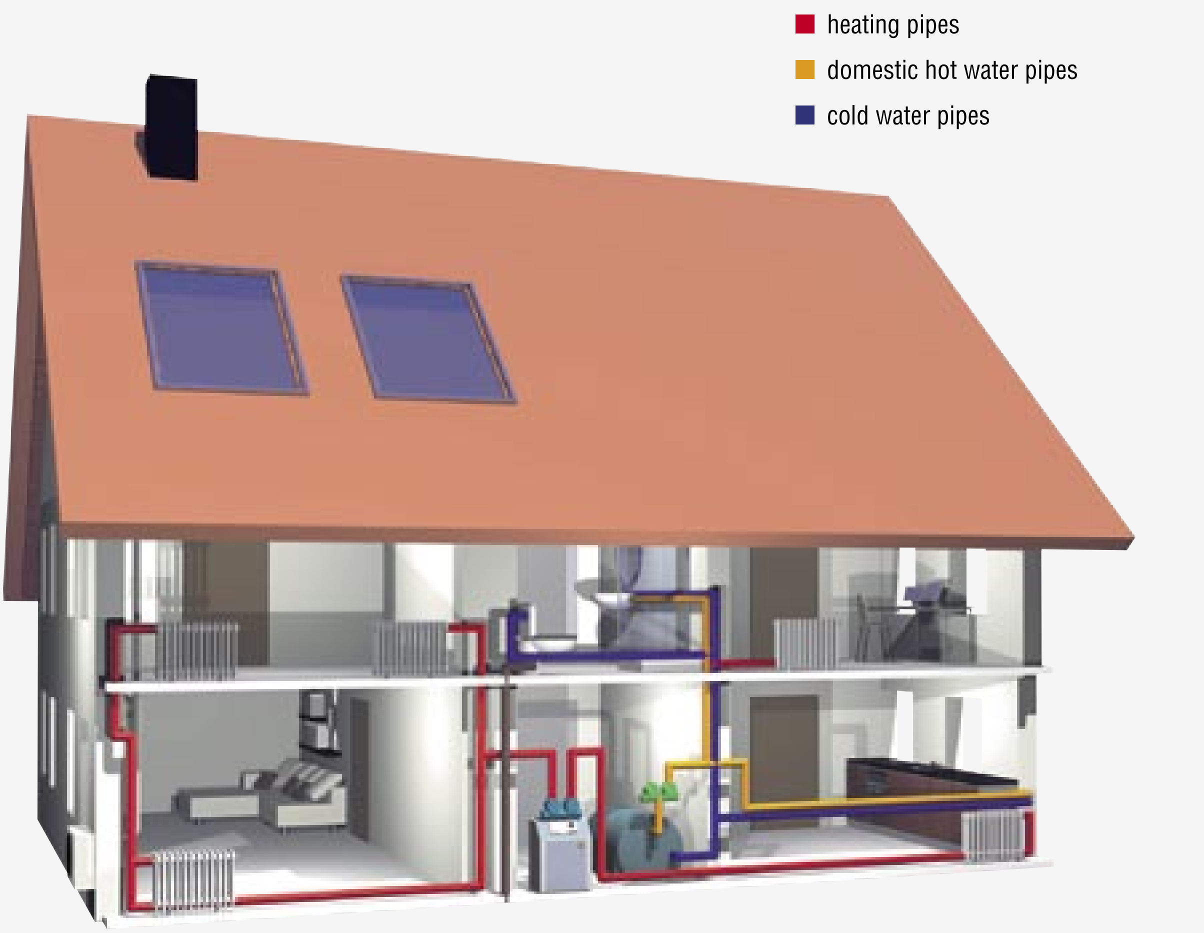


Figure 4: The model house

The self-adhesive SH/Armaflex tubes are ideal for retrofitting insulation to pipes: they can be installed quickly and easily even under difficult conditions on the building site

Allowance was made for regional differences in construction. For example, in the southern location in Spain a flat-roofed house (15° roof angle) with less structural wall insulation and smaller windows on the south façade was assumed. For the northern location in Sweden a wooden house typical for this area was assumed.
The length of the distribution pipes of the space heating and domestic hot water systems was calculated in accordance with the drafts of European standards proposed for calculating the energy efficiency of buildings. Here default input values and other assumptions proposed by the European standards were integrated into the calculation (see footnote [4]).

The calculations were carried out for the following locations: Sweden, Poland, Germany, Great Britain, Italy, Spain.

The solar irradiation and outdoor temperature for each geographical location were taken from the European Joule Programme [5].

The efficiency of the heat generator (boiler) for both space heating and hot water production was assumed to be 90 %. In accordance with the draft of the European standard prEN 15316 3 2, the domestic hot water system was assumed to be a circulation system with a default temperature of 60 °C (circulation loops) and 32 °C (individual spurs). A CO_2 emission factor of 0.270 kg/kWh was assumed for the energy contained in the fuel (oil).

The calculations were based on the use of Armacell's elastomeric insulation material SH/Armaflex to insulate the pipes. A thermal conductivity of 0.040 W/(m·K) at a mean temperature of +40 °C was used in the calculations. In many European countries, Armacell now offers the core products in its SH/Armaflex range with an improved λ-value of 0.036 [W/m·K] at a mean temperature of +40 °C.

The calculations took into account three scenarios with different levels of pipe insulation. It was assumed that for heating pipes optimal pipe insulation is approximately equivalent to the pipe diameter. For domestic hot water pipes the optimal insulation thickness was defined as 1.5 times the pipe diameter. Here heat losses occur all year round, 100 % of which cannot be recovered in summer. This approach was confirmed by economic calculations.

Table 1: Locations and their basic parameters

Country	City	Latitude	Longitude	Min. ambient temperature in winter	Outdoor temperature during the heating period (Ø)	Heating period [days]
Sweden	Stockholm	59°	18°	-22 °C	3.1 °C	254
Poland	Warsaw	52°	21°	-20 °C	3.1 °C	233
Germany	Münster	52°	7.5°	-18 °C	5.6 °C	233
Great Britain	Manchester	53.5°	-2°	-16 °C	6.6 °C	259
Italy	Milan	45.5°	9°	-14 °C	5.7 °C	196
Spain	Madrid	40.5°	-4°	-10 °C	8.5 °C	201

Table 2: The three scenarios used in the study
Insulation thicknesses for the different types of pipes

System	Pipe location (zone)		Pipe diameter [mm]	Pipe length [m]	Insulation thickness [mm]		
					optimal insulation	non-optimal insulation	poor / no insulation
heating	V	distribution pipes	28	34,0	20	9	2
heating	S	main supply pipes	22	17,6	13	6	2
heating	A	branch pipes	15	143,5	9	2	2
dhw	V	distribution pipes	22	29,2	30	9	2
dhw	S	main supply pipes	18	12,0	25	9	2
dhw	SL	branch pipes	12	12,0	20	6	2

An insulation thickness equivalent to 50 % of the optimal insulation thickness was assumed to be non-optimal. Here the individual branch pipes to the radiators and hot water tap outlets represent an exception.

In the third scenario, no insulation at all or a poor insulation effect (e.g. foil wrap with air gap) was assumed. This “insulation” is represented by a 2 mm thick layer of SH/Armaflex.

For each of these pipe insulation scenarios, the final energy demand which has to be generated for space heating as well as unrecovered (additional) heat losses from distribution pipes for space heating and domestic hot water were calculated. Based on this, it was possible to determine heating oil requirements, opportunities for financial savings and the potential reduction of CO_2 emissions.

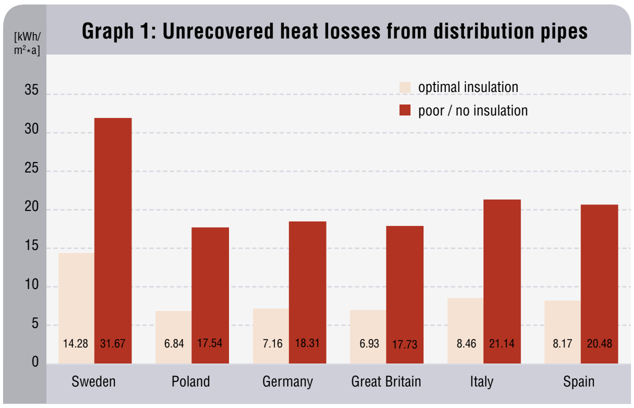
» » » As shown in Graph 1, the unrecovered heat losses can be reduced considerably by insulating the pipes optimally. In summer the heat losses occur to 100 % from the distribution pipes for domestic hot water. Therefore, the unrecovered heat losses are comparatively high in the southern regions (Spain, Italy) due to the short heating period.

» » » Graph 2 shows the ratio of the unrecovered heat losses to the net heat demand. In mild climate regions this ratio is around 12 % when pipes are optimally insulated. About 75 % of these losses arise from the domestic hot water distribution pipes, especially from pipes with circulation as assumed in this case.

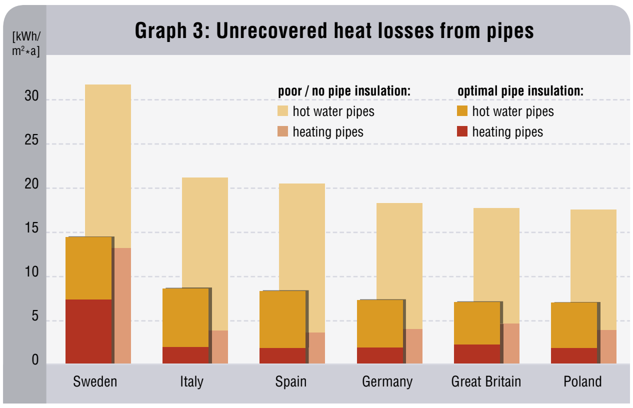
» » » Graph 3 shows the relationship between the annual unrecovered heat losses from space heating and those from domestic hot water distribution pipes. The almost identical values for the unrecovered heat losses from space heating distribution pipes in locations as far apart as Italy, Spain, Germany and Poland can be put down to different utilization factors which often offset the differences in winter ambient temperatures and heating periods when heat losses are calculated.

» » » As Graph 4 shows, substantial energy savings can be achieved by insulating pipes optimally. In turn these lead to not inconsiderable cost savings, as shown in Figure 5.

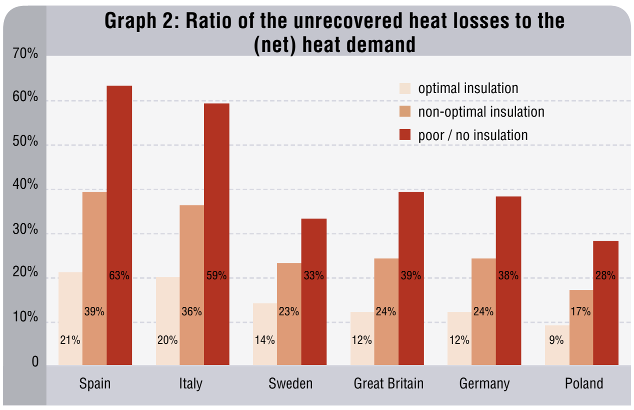
» » » Optimal pipe insulation can contribute to reducing CO_2 emissions. Unrecovered heat losses from the distribution pipes can be



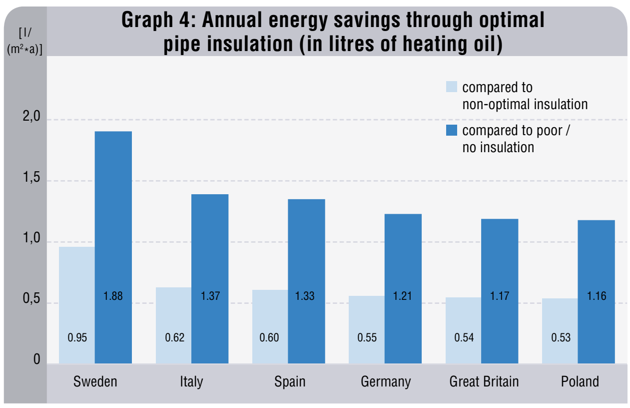
Graph 1: Unrecovered heat losses from distribution pipes



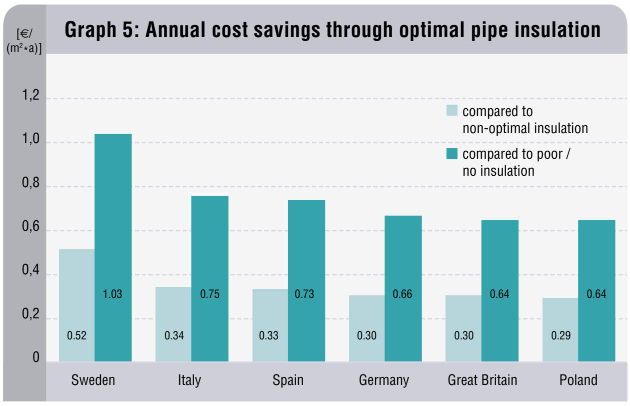
Graph 3: Unrecovered heat losses from pipes



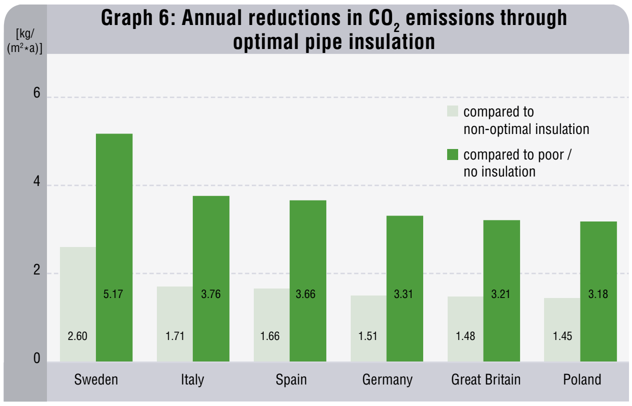
Graph 2: Ratio of the unrecovered heat losses to the (net) heat demand



Graph 4: Annual energy savings through optimal pipe insulation (in litres of heating oil)



Graph 5: Annual cost savings through optimal pipe insulation



Graph 6: Annual reductions in CO_2 emissions through optimal pipe insulation

reduced by more than half through optimal pipe insulation (Graph 6). This indicates the saving potential presented by retrofitting measures, which can be carried out in an existing building, even if only some of the distribution pipelines are optimally insulated in the course of this retrofit.

Assuming a service life of 30 years – of course, pipe insulation in heating and plumbing applications fulfills its function beyond this period – considerable energy and cost savings and CO_2 reductions can be achieved (Table 3).

The results achieved allow the following conclusions to be drawn:

- Contrary to common belief, non-recoverable heat losses occur even on pipes which are laid completely in heated spaces. Therefore, these pipes should be insulated.
- The vast majority of non-recoverable heat losses (between 50 % and 70 %) are due to heat losses from domestic hot water pipes in summer which are lost completely. These pipes in particular should, therefore, be especially well insulated.
- Heat losses from pipes which are uninsulated or not optimally insulated can be significant. Therefore, the potential heat losses must not be overlooked in the planning stage or assumed to be a constant when calculating the energy efficiency of the building. They should be calculated in detail especially for new houses.
- The insulation of pipes is a key factor for reducing energy consumption in the building sector and – when carried out expertly and with the right material – it can make a decisive contribution to reducing global energy consumption and minimizing CO_2 emissions.

Table 3: Energy saving potential through optimal pipe insulation for a life-span of 30 years

	Savings in terms of heating oil [l]	Financial savings [€]*	CO_2 reduction [kg]
Sweden	9,039	3,805	24,835
Poland	5,561	2,341	15,280
Germany	5,794	2,439	15,920
Great Britain	5,613	2,363	15,424
Italy	6,587	2,773	18,099
Spain	6,523	2,746	17,923

* Assuming a heating oil price of 0.55 €/l, an annual price increase of 2 % and an interest rate on capital of 4 %

Jarema Chmielarski,
Armacell Technical Management Europe

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3) Chmielarski, J. (2006). CO_2 emission and energy saving potential through correct pipe insulation of space heating and domestic hot water distribution systems in the new and existing buildings. – Paper for the EPIC 2006 AIVC Conference.

4) ISO 13790 standard and draft versions of the EPBD standards, mainly the prEN 15316 group. Status: summer 2006.

5) European JOULE programme for solar irradiance depending on geographical location (www.soda-is.com)