

## CO<sub>2</sub> emission and energy saving potential through correct pipe insulation in cold applications

J. Chmielarski  
Armacell, Poland

### ABSTRACT

In November 2006 a “CO<sub>2</sub> 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 [3], sponsored by Armacell - worldwide producer of flexible pipe insulation products, was presented at the EPIC 2006 AIVC conference in Lyon and published in its Proceeding Acts. The aim of the study was to answer how much energy and CO<sub>2</sub> emission can be saved with optimal pipe insulation installed on space heating and domestic hot water distribution pipelines in the new building. It revealed the saving potential of CO<sub>2</sub> emission is some 3,1 kg/(m<sup>2</sup>·a)  $\approx$  500 kg/a for a 160 m<sup>2</sup> single family house.

This paper is a continuation of the previous one but with the question on saving potential of pipe insulation applied in air-conditioning chilled water systems. The saving potential of CO<sub>2</sub> emission from a 1.800 m<sup>2</sup> commercial store due to application of the optimal pipe insulation thickness (20 ÷ 30 mm) is the same as CO<sub>2</sub> emission from a 160 m<sup>2</sup> single family house.

### KEYWORDS

pipe insulation, CO<sub>2</sub> emission, CO<sub>2</sub> savings, chilled water pipelines, energy efficiency.

### INTRODUCTION

In times when energy prices are high and rising still further, when there is a growing dependence on energy suppliers and, not least, in view of the worsening climate problems, the potential for saving energy in the building sector must be exploited more rigorously. With its CO<sub>2</sub> study Armacell has proven that it is possible to achieve enormous energy savings by retrofitting insulation to accessible heating and hot-water pipes in existing buildings and by installing optimal pipe insulation in new buildings.

According to EU Directive 2002/91/EC on the Energy Performance of Buildings not only heating and hot-water systems but also cooling, ventilation and lighting systems must be taken into account when calculating the overall energy efficiency of buildings. Whereas in

the past building air-conditioning was a relatively rare luxury, nowadays the European market for air-conditioning systems has annual growth rates of up to 10%. This paper investigates whether energy savings can be achieved by improving the insulation of the pipes of air-conditioning systems and, if so, how high the savings are and to what extent the investments involved pay off.

### APPLIED MODELS

#### *Small scale model*

The assumed model is a typical application: chilled-water systems in air-conditioned buildings supplying chilled water with a nominal temperature of +7°C to the fan coils located in many places in the building.

Depending on the structure of the air-conditioned building, its length, complexity, number of floors the chilled water pipework can be designed and constructed in various ways. Usually it is divided into sections for each group of fan coils. As a rule, the higher the number of fan coils to be supplied with chilled water, the larger the pipe diameter. In this small scale model, the heat gains from the ambient air in the building to the chilled-water pipes of various diameters are calculated per running metre; the pipe length in each section is therefore irrelevant.

Table 1: Basic conditions for the calculations

supply temperature of the chilled water pipes	+7°C
ambient temperate	+26°C
relative humidity	70
air-conditioning period	6 months
EER – Energy Efficiency Ratio (assumed average value)	2,5
CO <sub>2</sub> emission factor (electricity mix Germany) [1]	0,683 kg <sub>CO<sub>2</sub></sub> /kWh
electricity cost	0,20 €/kWh
annual energy cost increase	5%
interest rate	4%

Energy saving potential can be discussed only if at least two different solutions of the same system are compared, one of them showing less overall energy consumption during the period in question which can be e.g. one air-conditioning season or many years. Assuming that the

chilled water pipework is defined, its energy performance can be influenced by pipe insulation thermal quality and thickness. The insulation taken for further consideration and calculation is Flexible Elastomeric Foam (FEF) in accordance with harmonized product standard prEN 14304. The insulating tubes are characterised by so called engineered wall thickness (insulation thickness increasing with pipe diameter in order to ensure the same surface temperature for condensation control) and offered in 6 different thickness ranges for each pipe diameter. It is assumed that the insulation thickness to which all others are compared with their energy performance is the smallest one, just basic to ensure condensation control.

Table 2: Pipes of the chilled water system and considered pipe insulation

thickness range:		AF-1	AF-2	AF-3	AF-4	AF-5	AF-6
thermal conductivity at 0°C [W/m·K]:		0,033	0,033	0,033	0,033	0,036	0,036
DN (steel pipes)	OD [mm]	engineered insulation thickness [mm]					
32	42,4	9,0	13,5	16,0	20,0	27,0	36,5
40	48,3	9,0	14,0	16,0	20,5	27,5	37,5
50	60,3	9,0	14,0	16,5	21,5	29,0	39,0
65	76,1	9,5	14,0	17,0	22,0	30,0	40,5
80	88,9	9,5	14,5	17,5	22,5	30,5	41,5
100	114,3	9,5	15,0	18,0	23,5	31,5	43,0

### Sequence of calculations

For any given pipe diameter and insulation thickness the continuous heat gains from the ambient air in the building can be calculated per running metre of pipe [in W/m]. The heat gains result in a slight increase in the temperature of the chilled water (in addition to the greater temperature increase of 5 to 6 K at the fan coils). In the central cooling unit this must be tempered back down to the initial +7°C in the most energy efficient manner possible. Although this temperature increase as a result of heat gains is not very great even over hundreds of metres of pipes, it does accumulate over many cycles and amounts to considerable energy losses after several air-conditioning seasons. In typical applications it is more usual to control the return temperature of around +12°C rather than the supply temperature of +7°C. However, it is not particularly relevant for the energy performance how the system is controlled. It is only important that the heat gains to the chilled-water pipework must be compensated for in the central cooling unit, thus resulting in higher energy consumption (mainly of the compressor but also of the fans and pumps).

Once the heat gains [in W/m] for the various insulation thicknesses are known, the difference to the highest heat gains for the AF-1 range can be calculated, thus yielding the savings [W/m] compared to the smallest insulation thickness (minimum requirement for condensation con-

trol). Furthermore, by multiplying the savings in heat gains by the time period in question, the thermal energy savings [kWh/m] can be calculated for a given period of time (e.g. one or more air-conditioning seasons). The calculations presented are based on the assumption of a 6-month air-conditioning season. For an air-conditioning system what counts are the potential reductions in the amount of electrical energy consumed by the central cooling unit over the period of time. These savings can be calculated with the aid of the energy efficiency ratio (EER) which takes into account compressors, fans and controls. The EER depends on the working conditions of the cooling unit: the ambient temperature and the temperature of the chilled water leaving the unit (supply temperature). It can vary within a range of around 1.7 to 3.0. For the purpose of these calculations an energy efficiency ratio of 2.5 is assumed for the whole air-conditioning period.

Knowing the savings on electrical energy it is also possible to calculate the savings on the CO<sub>2</sub> emission:

$$\text{electrical energy savings} = \frac{\text{thermal energy savings}}{\text{EER}} \quad [\text{kWh}]$$

The CO<sub>2</sub> emission factor depends on the electricity mix in a specific country which reflects the consumption of different fuels (gas, oil, coal, nuclear) in power stations and thus the emission of CO<sub>2</sub> during production of electrical energy. For example for Germany it amounts to 0,683 kg<sub>CO2</sub>/kWh [1].

$$\text{reductions in CO}_2 \text{ emissions} = \text{CO}_2 \text{ emission factor} \times \text{electrical energy savings} \quad [\text{kg}_{\text{CO}_2}]$$

In Table 3 are presented results: electrical energy savings and savings on CO<sub>2</sub> emission per one air-conditioning season and during 10 years of operation per one running metre for the pipe DN 80 as example from the whole range: DN 32 up to DN 160.

Table 3: results of the energy calculation for pipe with diameter DN 80 (88.9 mm) related to the running metre

pipe DN 80 (88,9 mm)							
insulation thickness range		AF-1	AF-2	AF-3	AF-4	AF-5	AF-6
insulation thickness	mm	9,5	14,5	17,5	22,5	30,5	41,5
linear thermal transmittance	W/mK	0,818	0,624	0,551	0,465	0,408	0,333
linear heat gains	W/m	16,36	12,48	11,01	9,29	8,16	6,67
savings on heat gains	W/m		3,88	5,35	7,07	8,20	9,70
thermal energy savings per season	kWh/m		16,76	23,11	30,53	35,43	41,89
electrical energy savings per season	kWh/m		6,70	9,24	12,21	14,17	16,76
electrical energy savings after 10 years	kWh/m		67,04	92,43	122,13	141,74	167,56
savings on CO <sub>2</sub> emission per season	kg <sub>CO2</sub> /m		4,58	6,31	8,34	9,68	11,44
savings on CO <sub>2</sub> emission after 10 years	kg <sub>CO2</sub> /m		45,79	63,13	83,41	96,81	114,44

*Calculation of economic efficiency*

The results presented in Table 3 may be interesting but on their own they do not prove much. It is obvious that if the insulation thickness is increased the heat gains should be reduced, thus saving thermal and electrical energy and reducing CO<sub>2</sub> emissions. The issue which has not yet been discussed is the investment for the insulation work. The initial investment for the greater insulation thickness is slightly higher than that for the minimum insulation needed to prevent condensation. The costs for fitting the insulation occur in any case and can therefore be ignored. The question is whether the higher costs are balanced by even higher energy savings, in other words, whether they pay off.

In such calculations the monetary value of electricity savings must be calculated for each consecutive year on the basis of an assumed annual increase in energy prices and then recalculated as the present value including an assumed realistic interest rate. This is necessary in order to compare future savings with the current investment. The assumed values for the annual increase in the energy price and the interest rate are 5% and 4% respectively. The assumed 5% average annual growth of the energy prices means overall increase by 55% in 10 years time or doubling the price in 20 years. It reflects the current energy price growth in the recent years, however similar results and conclusions to the ones presented below were obtained for the whole range of assumed average annual growth of the energy prices between 2% and 5%. The calculations are based on a current electricity price of 0.20 €/kWh.

The financial savings with and without deduction of the investment costs (net price of the insulation for the investor) are presented in Figure 1 for pipe diameter DN 80 (88.9 mm).

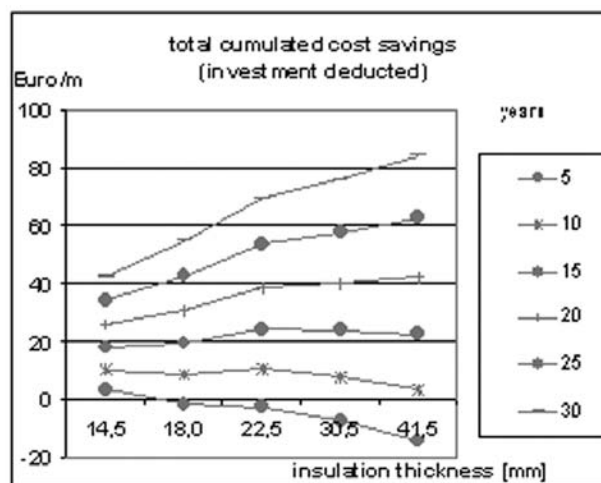
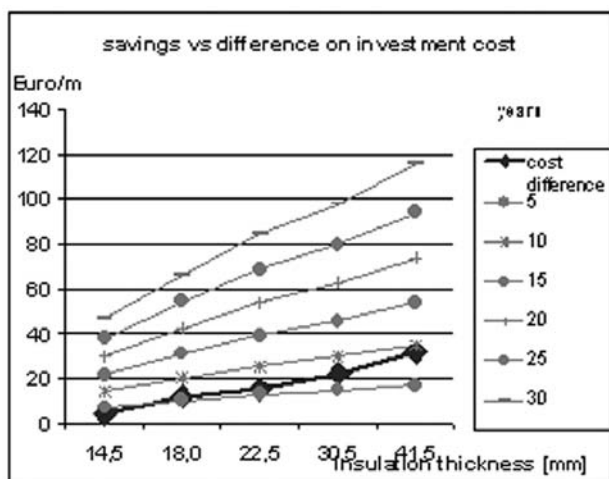


Figure 1: Comparison of the financial savings after 5, 10, 15, 20, 25 and 30 years compared to the minimum insulation thickness needed to prevent condensation for pipe diameter DN 80.

As can be seen in Figure 1 left-hand picture, on the DN 80 pipe the savings achieved after 5 years are still below the investment cost line (the bold line) which means that they are negative. However, once the break-even point has been reached after some 7 years, real savings are possible. In order to evaluate these, the investment costs (the bold line) must be deducted from the financial savings on energy thus yielding the total savings. These are presented in Figure 1 right-hand picture, again for the pipe DN 80 (88.9 mm). The financial savings are calculated as present value at the starting point of operation.

*Large scale model*

Similar calculations were conducted for large scale model of the building (e.g. grocery store) with air-conditioning chilled water system.

Table 4: Large scale model, additional assumptions

building length	180 m
building width	50 m
building area	9 000 m <sup>2</sup>
specific cooling request	70 W/m <sup>2</sup>
cooling effect supplied by chilled water system	75%

Table 5: Large scale model, pipes of the chilled water system and their lengths

pipe section	length	DN	internal diameter	outer diameter	velocity
	m		mm	mm	m/s
A	20	160	155.1	165.1	1.20
B	40	125	129.7	139.7	0.86
D	113	100	105.3	114.3	0.86
C+E+F	131	80	80.9	88.9	0.73
H	85	65	68.9	76.1	0.76
I	85	65	68.9	76.1	0.51
G	133	50	53.1	60.3	0.43
sum	608				

For the large scale model overall results were calculated: savings on cost, electrical energy and CO<sub>2</sub> emission for the total chilled water pipework system as a whole - combination of all pipe sections, their diameters and lengths as presented in the Table 5.

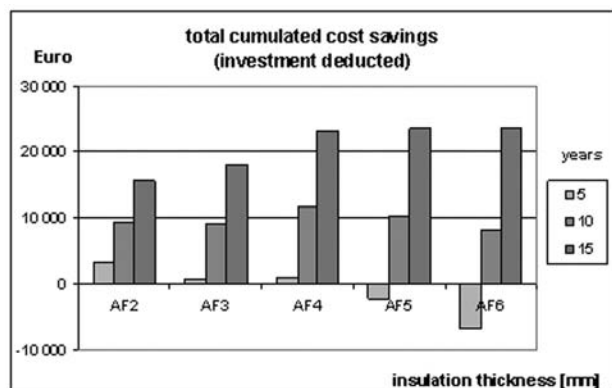


Figure 2: Total cumulated financial savings after 5, 10 and 15 years for the whole chilled water system of the large scale model.

The above Figure 2 shows that there is a pipe optimal insulation thickness, for which the total savings are the highest. In the given conditions this is the AF-4 range (20.0 ÷ 23.5 mm pipe insulation thickness). The same result is confirmed by the Figure 1 (right-hand picture) for the small scale model. The even greater insulation thicknesses (AF-5 and AF-6 ranges) will not help much with the financial savings, only when working period is considered much longer than 15 years which is seldom the case in commercial applications. However it is certain that, in absolute terms, more energy is saved the greater the insulation thickness applied. At the same time, this means greater environmental friendliness and less CO<sub>2</sub> emission even if the initial investment costs are higher. As shows the Figure 3, during 10 years the savings on CO<sub>2</sub> emission from air-conditioning system of the 1.800 m<sup>2</sup> grocery store due to application of the optimal pipe insulation thickness are of the same range than total CO<sub>2</sub> emission from a modern single family house (≈70.000 kg<sub>CO2</sub>).

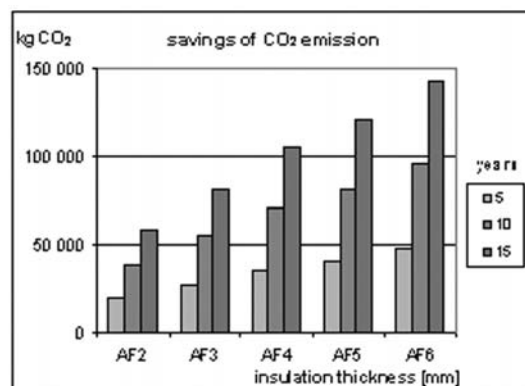
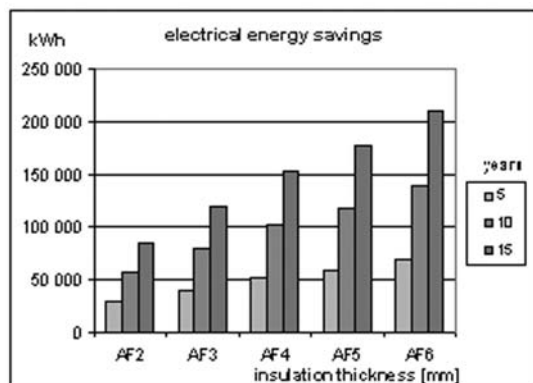


Figure 3: Total savings on electrical energy and CO<sub>2</sub> emission after 5, 10 and 15 years for the whole chilled water system of the large scale model.

## CONCLUSIONS

The results achieved allow to draw the following conclusions:

- Contrary to common belief, the minimum insulation thickness needed for condensation control on chilled water pipes is not the optimal solution as far as the energy savings are concerned.
- Additional energy savings can be achieved with a greater insulation thickness; in the given conditions by insulating with AF-4 insulation thickness range (20.0 ÷ 23.5 mm), which represents the optimum. The slightly higher investment costs can be already paid off after 5 ÷ 10 years.
- There is an upper limit to the optimization of cold-water pipes from an economic and ecological point of view. Assuming typical European basic conditions, the optimal insulation thickness is 20 ÷ 30 mm.
- The CO<sub>2</sub> saving potential may be not much significant per one running metre of the pipe but for the whole air-conditioning system and its chilled water pipework it amounts to considerable numbers and is comparable to CO<sub>2</sub> emission from a single family house during the same period of time.

## REFERENCES

- Laudenbach, J. and Koch, Th. (2003). *CO<sub>2</sub> - Saving Potential when using Pipe Insulation*, Zentrum für Umweltbewusstes Bauen e.V., Kassel, Germany.
- Chmielarski, J. and Boruta, I. (2005). *CO<sub>2</sub> and Energy Saving Potential through Correct Pipe Insulation*, Armacell, Pfaffnau, Switzerland.
- Chmielarski, J. (2006). *CO<sub>2</sub> emission and energy saving potential through correct pipe insulation of space heating and domestic hot water distribution systems in the new and existing buildings*. Armacell, Środa Śląska, Poland.
- EN 15315 (2007). Heating systems in buildings - Energy performance of buildings - Overall energy use, primary energy and CO<sub>2</sub> emissions.