# Optimal insulation thicknesses according to different indicators for Germany

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**Abstract** This paper shows optimal insulation thicknesses according to several indicators (such as CO2-equivalents) and energy carriers for Germany. A simplified method is applied considering environmental impacts during insulation production and environmental gains during the use phase of the house, while taking into account country specific climate conditions. The optimal insulation thickness is therefore the minimal combination of total environmental load or economic effort over a defined lifetime. The results show that the economic indicator favors low initial investment that are in the range of currently established insulation thicknesses for new buildings. However, almost all environmental indicators favor a much higher insulation thickness. Depending on the energy carrier and the heating system chosen, the exact relation of the optimal insulation values differs. As a conclusion, the design of building concepts (especially concerning the insulation thickness) should be linked closer to the energy carrier that will be used for generating the heating load. Also heating systems should be chosen that result in equal optimal insulation thicknesses for all indicators.

## 1 Introduction

### *1.1 The relevance of the building sector for the environment*

In order to prevent critical climate change as a result of $CO_2$ emissions and other factors the building sector has been proved by studies to be of exceptional relevance. In most industrialized countries the building park is associated with roughly one third of the overall emissions [1] Worldwide the building industry is responsible for 70% of changes in landscape, 50% of resource consumption and 40% of emissions [2]. Within the scope of current meteorological models the building sector is having direct impact on both emissions and surface albedo. In the current models the emission are found to be the dominating factor tough (SA Value 0.64 $Wm^{-2}$ by emissions vs. 0.14 $Wm^{-2}$ by changes in landscape according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [3].

Studies on the life cycle of buildings show that the running consumption of buildings is the dominating aspect of the overall impact until the buildings energy efficiency standard is reduced to the current state of the art. Only current lighthouse projects reach a standard where the embodied emissions are holding a share of around 50% of the overall life cycle impact of the building and become a relevant topic of optimization [4]. On the way towards such standards the running consumption is still the main concern when designing building standards.

The running consumption of buildings is also directly and irreversibly connected to the problem of resource depletion. Fossil fuels that are burnt in order to provide space heat cannot be recovered later with current technology [5]. As a result building material and energy supply should be viewed and weighted accordingly.

## *1.2 Building codes and optimal insulation thicknesses*

One of the dominating aspects of the building codes is the usage of insulation to reduce transmission losses.A main question when designing energy standards is often what insulation levels are sound to be made mandatory or advisable. In many countries the building standard includes a criteria for minimum insulation values in addition to criteria for prime energy consumption. The German EnEV being an example of such a standard [6].

A straightforward approach to communicate the benefit of the additional investment in better buildings is often pointing out the savings that can be made in the future [7]. As the calculation models for energy consumption in residential buildings have reached a certain level of exactness, the remaining potential mistake in the calculations of the savings to be made is limited to the development of the energy prices and the user behavior [8].

When reflecting the starting point of the discussion being Zero-Carbon-Buildings [9] is seem strange that the argumentation is often exclusively held on the economic level. The basic conclusion seems to be that the market has to “make it happen” and that more insulation is good for the environment anyway.

Several studies have been conducted on economically sound insulation levels for the EU25 member states. Most of them describe a balance of initial investment (buying and installing the insulation) versus the savings that can be made (lower running costs due to lower transmission losses).

However, until now, the question about what is the most optimal insulation thickness is rarely approached from an environmental point, using several indicators. Within this paper we calculate the optimal insulation thickness for both, environmental and economic indicators. The approach is based on a report created by ECOFYS [10]. ECOFYS calculated an optimal insulation thickness based on local conditions, such as labor and material cost, heating and cooling degree days and resulting energy savings according to local energy costs. A similar methodology is used to calculate the optimal insulation thickness when applying environmental indicators, namely Cumulative Energy Demand (CED) [11], $CO_2$–equivalents [12], Eco Footprint [11], IMPACT 2002+ [13] and ReCiPe [14]. The basis for the calculation therefore is the environmental impact of the production and building phase and the environmental "savings" that can be made in the usage phase. Within this paper, the German situation will be used as a case study, considering country specific energy supply systems and climate conditions. The resulting optimal insulation thicknesses are compared with the economic cost-optimal insulation thicknesses.

## 2 Methodology

Within this paper the method for calculating optimal insulation thicknesses of Boermans et. [10] was used. The method was originally designed to calculate economic optima but can be applied to calculate ecologic optima without major changes.

The method is weighting the environmental load resulting from the creation of the insulation and the environmental load from energy production. It calculates an optimum by adding initial input in the material and input in the energy needed to compensate the corresponding transmission. While the investment into the insulation increases linearly with increasing thickness the resulting energy savings by reduced transmission losses are not. As a result a clear optimum can be calculated (see figure 1).

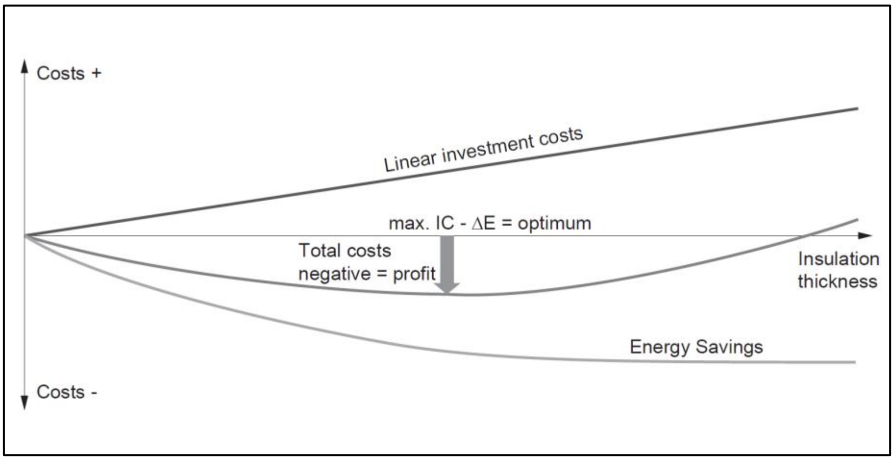

**Fig.1: Definition of the optimum**

Apart from the optimum insulation thickness a certain range of sound insulation thicknesses can be identified (labeled best practice according to Boermans et.al.) [10]. As for this paper two ranges for these best practice scenarios are given, +5% and +10% cost for both higher and lower than optimal insulation thickness.

As the focus of this paper is the comparison of different indicators and the resulting optimal insulation thickness for a wall, simplification was needed. In line with the original report from ECOFYS [10], we excluded several factors such as the interchange of different components of a given building (variable balance points due to solar gains) and the nonlinearity in initial investment or energy savings (due to changes in construction systems for insulation or the possibility to leave away heating systems like in the passive house concept). Climate Conditions for Germany were used. The calculations are based on the dataset of the German energy saving law and a fixed balance point of 18°C was used [6].

Four different types of heating systems are considered to be relevant in Germany. This includes the currently established systems as condensing boilers using gas (72%) or oil (19%) as well as relatively new systems like pellet boilers (2%) and heat pumps (4%). Percentages in brackets refer to heating systems in building permissions over the last 20 years in Germany [15]. For the heat pumps two systems are used, one with a Coefficient of Performance (COP) of 3.0 and with a COP of 4.5. The system with a COP of 4.5 is also assumed to be connected to a heat tank and therefore able to store heat for a day and therefore use night electricity.

The inventory data on heating and electricity production were directly taken from the Ecoinvent 2.2 database [11]. For electricity supply, the German electricity mix including trading for the year 2004 is considered as default. A wooden pellet furnace of 15kW is assumed for wooden heating, a condensing modulation boiler is used for natural gas and a non-modulating boiler of 10kW is assumed for oil heating.

The isolation material considered in the study is mineral wool manufactured by the company Rockwool, with a lambda of 0.035 and a density of 32kg/m3 [16, 17]. Rockwool is made from natural minerals such as basalt. The inventory data on the production of mineral wool was taken from the environmental product declaration for Rockwool [16] and the work of Schmidt et al. [17]. The production data is based on a Danish production facility. The recipe used at this facility is almost the same as for the other Rockwool facilities in Europe and can therefore be regarded as representative at European level. Cutting losses during the production processes are 100% recycled into the process. Post-consumer rockwool is considered to be 100% recycled into low grade applications such as road foundation with an exclusion of both positive and negative effects [17]. The effect of transport is not included in the rockwool impact but considered separately as a sensitivity analysis. As for the economic calculation transport, demolition and the initial costs for the heating system as well as the structural parts needed to apply the insulation were not taken into account.

To define the optimum insulation thickness seven different indicators are selected. The money indicator calculates the optimal insulation thickness from an economic point of view. The CED indicates the primary energy used throughout the system [11]. The carbon footprint is calculated using the CO2-equivalent factors produced by the International Panel of Climate Change [12] for a time horizon of 100 years (IPCC 100) and 500 years (IPCC 500). The ecological footprint represents the amount of land and water that is required to produce the resources consumed and absorb the waste generated by fossil and nuclear fuel consumption [11]. Both IMPACT 2002+ [13] and ReCiPe [14] are methodologies which combine a range of different impacts reflecting human health, ecosystem health, climate and resource depletion effects.

## *2.1 Results*

Figure 2 shows the optimal insulation thickness for the chosen heating systems and indicators. The optimal insulation thickness is given. In the same figure insulation thicknesses are given that do not give an optimal result but stay within a certain range for the resulting economic or environmental performance (within 5% or 10% respectively, defined as best practice).

The calculated optimal insulation thickness is between 20 and 80 cm and therefore within the range of established building concepts, namelybetween 20 and 30 cm [7, 8]. When we compare the different indicators, the economic calculations aim towards the lowest initial investment and a large share of running consumption. On the contrary, all environmental indicators favor high insulation thicknesses (between 50 and 70 cm), with CED as the extreme. The CED shows the highest results of around 60-80 cm insulation. For ReCiPe and IMPACT 2002+, the results show similar optimal insulation thicknesses. When we compare the different heating systems, we notice that the wood heating system results in lowest insulation thicknesses.

The calculations take into account neither discounting, nor increased energy prices and could be tipped easily in extreme scenarios for these factors. The results are however in range of the results of the original report of ECOFYS [10] that is including several sensitivity studies and is listing similar values as final conclusions.

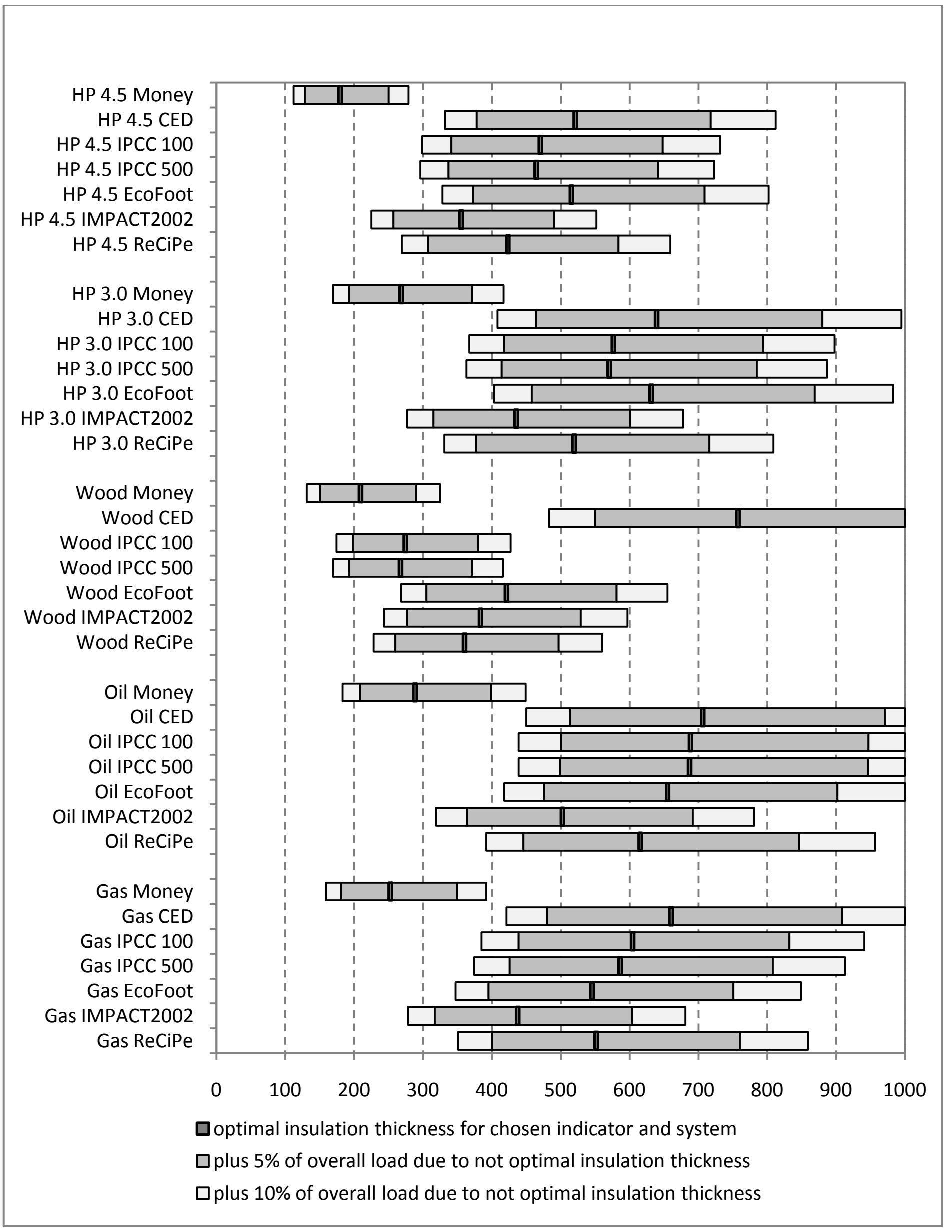

**Fig.2:** **Optimal insulation thickness and best practice range (5% and 10%), for 5 different heating systems (gas, oil, wood, heat pump with a COP of 3 and heath pump with COP of 4.5) and 7 indicators.**

# 3 Discussion and Conclusion

The difference among the calculated optimal insulation values shows clearly that it is difficult to name a thickness that is close to optimum for the economic calculation as well as for all environmental indicators. In the case of wood heating (pellet heating), the insulation thicknesses are relatively low indicating a low cost or impact for heating, except for CED. IMPACT 2002+ favors less insulation because it gives higher weight to particulate matter emissions (responsible for 45% of the impact of rockwool) and less weight to climate change and resource depletion. This result in an increased impact of rockwool and a lower impact of oil, gas and electricity heating systems (driven by climate change and resource depletion impacts) compared to ReCiPe. The exception being the wood pellet system were ReCiPe results in a lower insulation than IMPACT 2002+, due to the particulate matter emissions of pellet burning.

Note that, transport of Rockwool to and from the consumer is not considered in the calculations. When considering an open truck with load capacity of 3ton (corresponding with 90m3 Rockwool) and 0.2kg/km fuel consumption, the transport needs to reach above 230km before it contributes with 5% to the environmental load of the Rockwool production. For demolition, 100% Rockwool recycling into low grade applications is assumed, such as gravel production. This can be highly disputed. At the moment, within Germany 26% of the mineral waste is getting land filled and 74% is getting recovered without energy [18]. Furthermore, the frame conditions and simplifications for the economic calculations do not significantly change the results. The resulting change of a more detailed and realistic calculation would be in favor of even thinner insulation.

From a strategic viewpoint it can be concluded that at the moment money does not represent the environmental impact of wall insulations. This is not influenced by housing concepts, as for example by using a lot of solar heat gain, as the relation of economic and environmental cost effectiveness will not change. In order for environmentally sound concepts and economically sound concept match each other either energy has to become more expensive or insulation has to become cheaper. From an environmental point of view the opposite is true. Effort should therefore be taken to make energy more environmentally friendly (such as with the wood pellet system) and insulation material become cheaper. Further research is needed to expand this study to other countries and therefore give a clearer picture for sound insulation standards within the 20-20-20 Framework of the EU [9]. Besides additional energy carriers, heating systems and insulation materials, the methodology for the climate data (including internal load and resulting changes of the balance point) has to be improved in order to better picture local conditions.

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