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GREENHOUSE GAS EMISSIONS REDUCTION THROUGH THE GROWTH OF THE THERMAL INSULATION OF BUILDINGS AND THE USE OF HEAT PUMPS

A. BULMEZ [1] **V. CIOFOAIA** [2]

Abstract: *The purpose of the paper is to analyze the energy performance of a building for reducing greenhouse gas emissions. Energy consumption for using different fuels has been determined. The role of building envelope and fuels in reducing greenhouse gas emissions has been observed. Highlighting the role of the heat pump COP. Improving the production of electricity. The resulting conclusions relate to the reduction of greenhouse gas emissions by using a heat pump, the minimum value of the heat pump COP to avoid producing more greenhouse gases due to the power generation process.*

Key words: *Heat pump, greenhouse gas emissions, building envelope, fuel.*

1. Introduction

Initially, primary energy was introduced as a key indicator to highlight the fact that soon the fossil fuels will end, global reserves of fossil fuels being depleted at a fast pace in the last century. Primary energy was subsequently associated with the fossil fuel content of the energy consumed, but today it is also correlated with the contribution of various forms of renewable energy more or less exploited.

At the moment, the focus is much more on climate change than on resource depletion, especially in political discussions [1]. It is therefore expected that in the future carbon dioxide will replace primary energy as a primary environmental indicator for buildings. In most cases, carbon dioxide analysis reveals that it leads to the same conclusions as the one centered on primary energy, but in some cases, such as nuclear energy, there is no explicit link between them. In these situations, it is preferable to use both indicators for long-term evaluations.

According to the European Directive on Energy Efficiency of Buildings (EPBD), a 90% reduction in CO_2 emissions is foreseen for 2050 compared to 1990, which at that time had a level of $1.1 \cdot 1011$ kg of CO_2 (direct and indirect emissions related to space heating, domestic hot water and air conditioning). Taking into account the estimated value of the surface built for 2050, namely $38 \cdot 109$ m^2, it results that the CO_2 emissions will have to be about 2.89 kg/m^2year. In fact, the renovation of existing buildings may not fit in the

[1] Faculty of Civil Engineering, Departament of Building Services, *Transilvania* University of Braşov.
[2] Faculty of Civil Engineering, Departament of Civil Engineering, *Transilvania* University of Braşov.

planned course and consequently the new "Near Zero Energy Buildings" will have to fall within the range of 0 ... 3 $kgCO_2/m^2year$ [6].

In the energy performance certificate two indicators are shown: "Specific annual energy consumption" (for example for heating, expressed in $kWh/m^2\cdot year$) as well as: "CO_2 equivalent emission index" ($kgCO_2/m^2year$). The CO_2 Emissions Emission Index is the product of the Specific Annual Energy Efficiency and CO_2 Emission Factor, the latter having values specified by "Building Energy Performance Engineering Methodology" MC001-2006, page 53, Table 1.14 presented in Table 16. [5]

CO_2 emission factor depending on the fuel used Table 1

Fuel	CO_2 emission factor [kg/kWh]
Coal	0.342
Liquid fuel	0.270
Gas	0.205
Wood	0.036
District heating system	0.240

Therefore, apartments and houses with different annual energy consumption may be characterized by identical equivalent emission indices based on the fuel used for heating.

2. The Impact of the Fuel Type Used for Building Services on the Environment

For the studied situation, the house has a specific annual energy consumption of 139 kWh/m^2year and is heated by a ground-source heat pump with a CO_2 emission factor of 0.09 kg/kWh using only electricity and is characterized by an index of equivalent emissions: $ECO_2 = 139\cdot 0.09 = 12.59$ [$kgCO_2/m^2year$].

For the same building, we calculated the specific annual energy consumption if the building used natural gas, wood or it would be connected to a district heating system for heating and domestic hot water.

Specific annual energy consumption in the following situations is 331 kWh/m^2year.

Using wood as the heating solution, the equivalent emission index is $ECO_2 = 17.06$ $kgCO_2/m^2year$. It can be noticed that the equivalent emission indices have a value close to that of the present case where a ground-source heat pump is used.

The same equivalent emission index has the ECO_2 value = 66.64 $kgCO_2/m^2year$ when using natural gas as primary energy for heating and domestic hot water consumption. In this case, the difference in $kgCO_2$ between the use of renewable energy with the heat pump and the use of natural gas is clear.

Finally, for the heat supply from a district heating system, the equivalent emission index has the ECO_2 value = 77.84 $kgCO_2/m^2year$. It can be seen that this value is the highest; this is possible due to the whole process of producing the thermal energy through a district heating system that uses coal as the primary source of energy. [3]

The above can be represented in a coordinate system that highlights the decrease of the equivalent emission index depending on the source of the primary energy used for heating and the preparation of domestic hot water.

From the graph below, one can clearly see the impact of using a soil-water heat pump on the environment for one year usage. This substantial impact becomes more visible over longer periods of time.

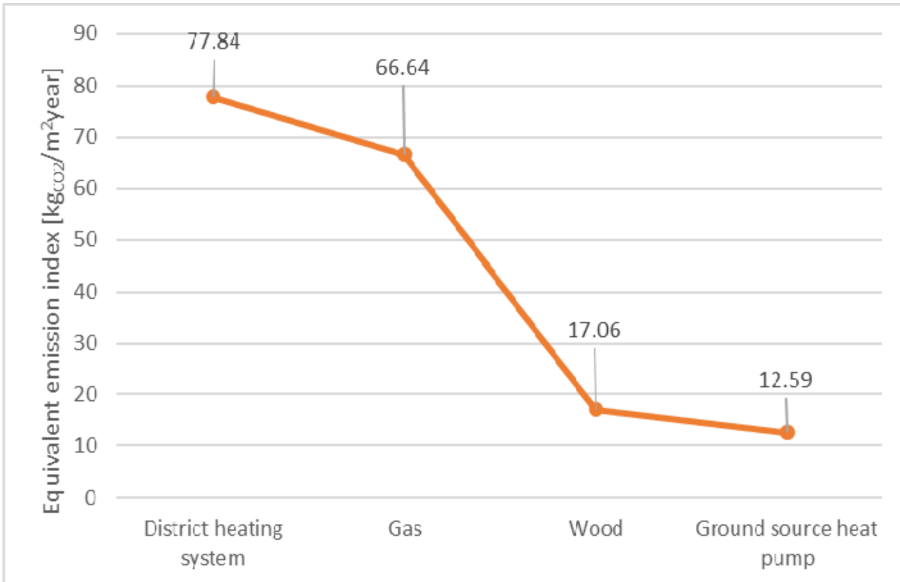

Fig. 1. *Equivalent emissions index for the four situations outlined above*

3. Building Envelope and Fuel Usage in Relation to the Reduction of Carbon Dioxide Emissions

The next obvious role in reducing carbon dioxide emissions is the degree of thermal insulation of the building envelope, which directly affects the specific annual energy consumption [kWh/m^2year]. From this point of view, for the situation studied in this article the thermal insulation of the building is represented by 10cm expanded polystyrene for exterior walls, 15 cm mineral wool for the roof and 5cm extruded polystyrene for the ground plate. Specific annual energy consumption in this situation is 139.90 kWh/m^2year.

In the most disadvantaged case, the one in which the building is not insulated, the value of energy consumption is 231.62 kWh/m^2year. It can be seen that if a ground-source heat pump has a coefficient of performance of over 2.5 and the building is thermally insulated with an average of about 10 cm of thermal insulation, the specific annual energy consumption (electric) required for the building decreases by about 39% compared to the same situation but without thermal insulation, for example by 91.72 kWh/m^2year. This can be seen in the following Figure 2.

If it is desired to increase the degree of thermal insulation it was observed that from this situation to an exaggerated situation in which the building would be insulated with 30 cm of thermal insulation, the specific annual energy consumption would decrease by only 9%, respectively by 15.19 kWh/m^2year, which decreases more and more with increasing thermal insulation.

From this point of view, the thickness of the thermal insulation that maintains the balance between the cost and the reduction of the energy consumption for heating varies between 10-15 cm of thermal insulation.

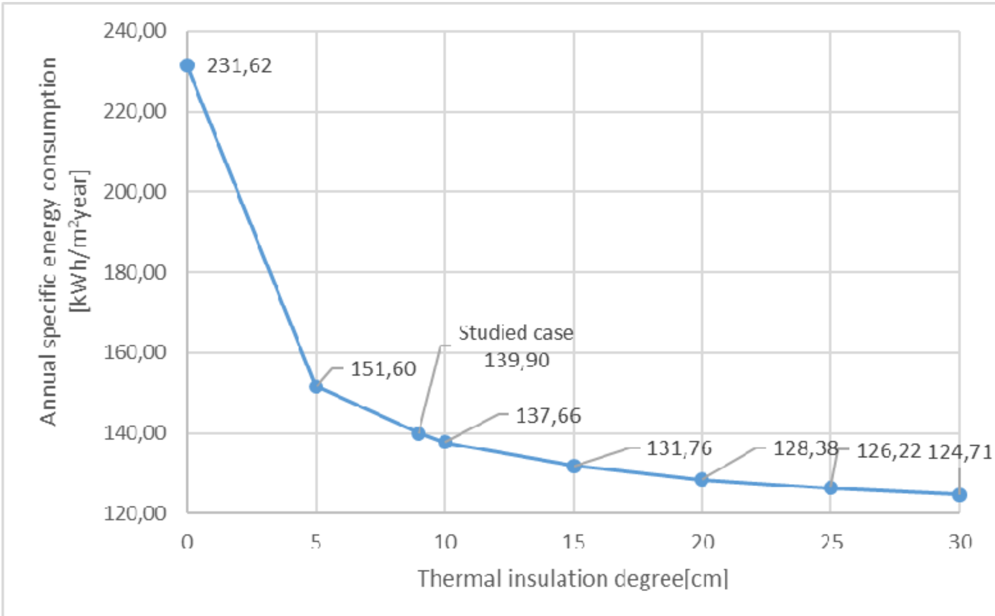

Fig. 2. The *reduction of specific energy consumption annually depending on the thermal insulation of the building*

Clearly expected, the increase the thermal insulation of the building envelope favors lowering the carbon dioxide emissions of the building.

For the case studied, the Emissions Index equals 12.59 $kgCO_2/m^2year$. If the thermal insulation of the building is 0 then the value of the same index would be 20.84 $kgCO_2/m^2year$. It can be seen from this point of view that the reduction of carbon dioxide emissions is directly proportional to the reduction of the energy consumption of the building, which means that the thermal insulation of the building envelope plays an equally important role as the use of the fuel in the absorption of the gas emissions with the greenhouse effect of buildings.

4. The Importance of the Heat Pump Coefficient of Performance

By replacing the boiler or classical sources intended for space heating and for the preparation of domestic hot water with a heat pump, it is particularly important to save energy and reduce greenhouse gas emissions, mostly carbon dioxide. Since the heat pump is mostly driven by electricity, the specific reduction in carbon dioxide emissions depends on the heat pump coefficient of performance:

COP=SUPPLIED ENERGY/USED ENERGY (1)

Therefore, the reduction of greenhouse gases was analyzed according to the heat pump coefficient of performance.

It can be seen from the Figure 3 the important role of the heat pump coefficient of performance on greenhouse gas emissions. The heat pump coefficient of performance varies daily and monthly depending on the outdoor temperature and the domestic hot water consumption mode, and can range from 2 to 5 for the studied building.

Considering this, it can be seen that when the heat pump uses more electricity to cover the energy needs to be delivered to the building, greenhouse gas emissions are considerably increased and even doubled if the coefficient of performance of the heat pump (COP) drops below 2.

For this reason, it is necessary to operate the heat pump throughout the heating season with a minimum COP = 2.3 [1], as can be seen in the following Figure 4, because below this value there is no reduction greenhouse gas emissions due to the process of the generation of electricity.

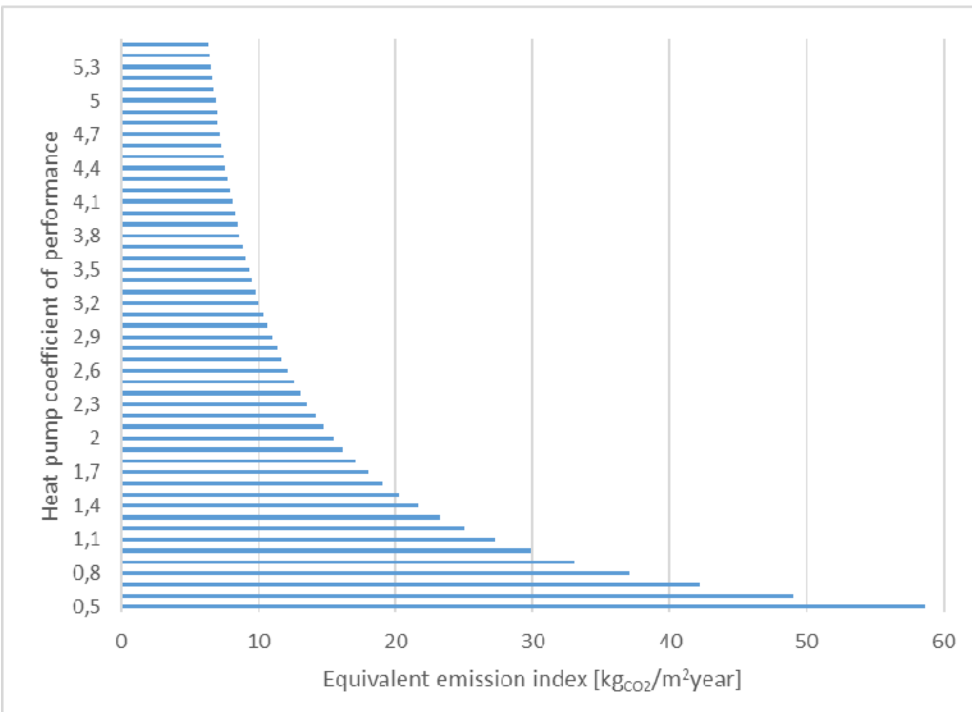

Fig. 3. *The reduction of annual greenhouse gas emissions according to the heat pump coefficient of performance*

5. Improving the Power Generation Process

The electricity generation process varies depending on the Greenhouse Gas Intensity, I_f that is specific to the fossil fuel used to generate electricity.

In the data provided related to this issue, the carbon dioxide emissions reported are based on the unit of electricity generated, depending on the country in which they are produced. These values cover a relatively wide interval depending on the multitude of sources and fuels used for this purpose, namely from a few grams of CO_2/kWh to 1 kgCO_2/kWh and even above that value.

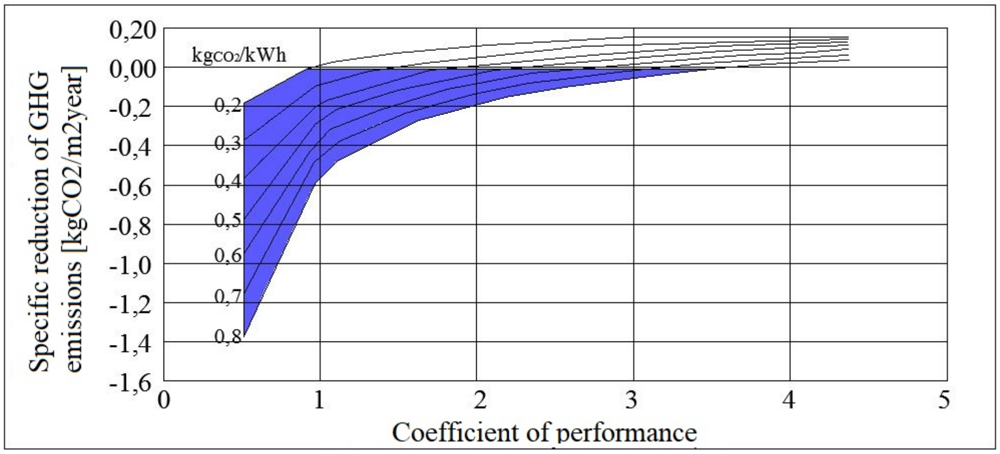

Fig. 4. *The interval for the efficiency of the power generation process correlated with the COP of the heat pump for which reduction in GHG emissions cannot be achieved.*

The specific carbon dioxide emissions will be higher as the contribution of solid fossil fuel and the less evolved the burning technology is. For example, for Romania in the 1990s, the value was 1.373 $kgCO_2/kWh$, falling to 0.499 $kgCO_2/kWh$ in 2010. On the other hand, natural gas reduces this indicator. At the same time, countries with a significant share of hydroelectric sources (such as Romania) are characterized by zero-point indicators (for example Norway 0.017 $kgCO_2/kWh$ or Switzerland 0.027 $kgCO_2/kWh$). France and Canada occupy top positions due to nuclear power plants (0.079 $kgCO_2/kWh$ and 0.186 $kgCO_2/kWh$ respectively). The overall value for Europe, characteristic for 2010, was 0.231 $kgCO_2/kWh$ [2].

Regarding nuclear energy, there is a natural divergence between primary energy consumption and carbon dioxide emissions. Current values for the nuclear power factor in Europe are 2.8 while the carbon dioxide emissions are at 0.016 $kgCO_2/kWh$ (according to EN 15603). In the case of fossil fuels, the situation of zero energy consumption automatically leads to zero carbon emissions. But in the case of nuclear energy, zero-carbon emissions do not necessarily imply zero energy consumption.

Thus, at a specific emission intensity for the electricity generation process $I_e = 0.8$ $kgCO_2/kWh_{el}$ no specific GHG emission reduction (REGHG≤0) can be obtained other than with a heat pump COP>3.5. For current conditions in Romania ($I_e = 0.499$ $kgCO_2/kWh_{el}$) and for a gas boiler (If = 0205 $kgCO_2/kWh$), condensation ($\eta = 0.95$) requires the heat pump to operate throughout the season heating with a minimum value COP = 2.31 [4].

Analyzing the Figure below, it is noted that under the best conditions Ie = 0.017 $kgCO_2/kWh_{el}$, a reduction of the specific emission index up to 1 $kgCO_2/m^2$year could be achieved for the studied building.

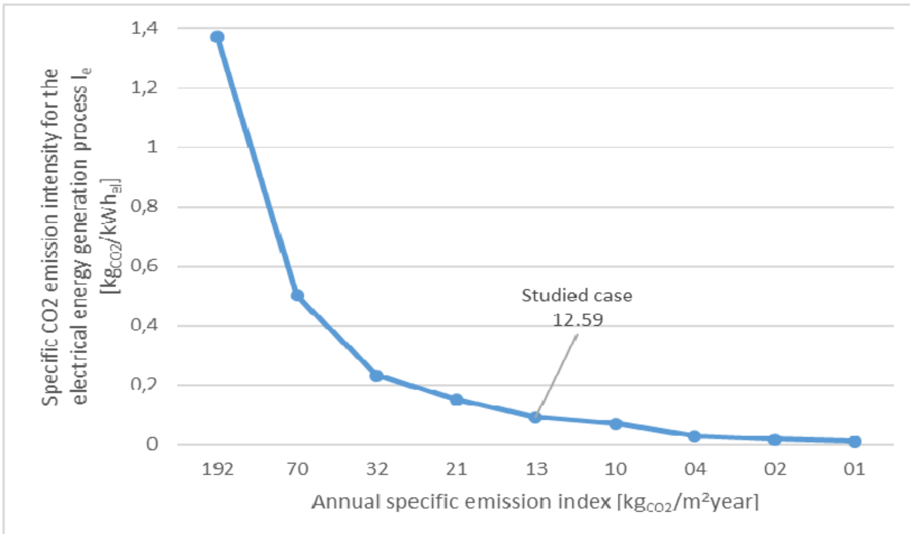

Fig. 5. *Specific reductions in GHG emissions that may be achieved through technological advances in the domain of electricity generation*

Under these conditions, for example, the house with a specific heating consumption of 139 kWh/m^{2}year using the heat pump could reduce the CO_2 equivalent of 12.59 kgCO_2/m^{2}year to values of about 1 kgCO_2/m^{2}year, as can be seen in the following Figure.

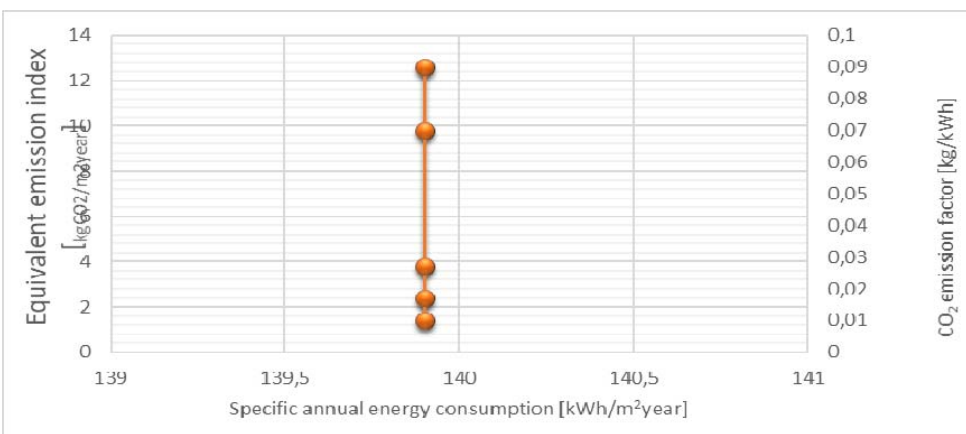

Fig. 6. *The reduction of the CO_2 Equivalent Emission Index from 12.59 to around 1 kgCO_2/m^{2}year as a result of the reduction in the CO_2 Emission Factor*

6. Conclusions

For the studied building the carbon dioxide emission index (12.59 kgCO_2/m^{2}year) was calculated and this index was also calculated for alternative energy sources such as wood (17.06 kgCO_2/m^{2}year), natural gas (66.64 kgCO_2/m^{2}year) or a district heating system

(77.84 $kgCO_2/m^2$year). From the values obtained it can be noticed that the carbon dioxide emission index decreases by about 81% for the use of the heat pump instead of a natural gas boiler and about 84% for the use of the heat pump instead of a district heating system.

In order to observe the impact of the thermal insulation of the building envelope, the energy consumption of the building in the most disadvantaged case, the one where the building is not isolated the energy consumption would be 231.62 kWh/m^2year was calculated. It has thus been observed that if a ground-source heat pump having a coefficient of performance of more than 2.5 is used and the building is thermally insulated with an average of about 10 cm of thermal insulation, the specific annual energy (electrical) of the building (139.90 kWh/m^2year) decreases by about 39% compared to the same situation, but without thermal insulation, more exactly by 91.72 kWh/m^2year.

From this point of view, the analysis concluded that the reduction of greenhouse gas emissions is inversely proportional with the increase of the thermal insulation of the building envelope and depends very much on the type of fuel used. However, when using the ground-source heat pump it has been found that a minimum heat pump COP of about 2.31 is required for the reduction of greenhouse gas emissions to exist. If the heat pump COP is lower than the above value, it uses more electricity that generates more greenhouse gas emissions than is likely to be reduced by using the heat pump.

Due to the fact that the greenhouse gas emissions differs according to the electricity generation process, the impact on greenhouse emissions for the studied building was analyzed. It has been noticed that under the best conditions of operation where the specific emission intensity I_e = 0.017 $kgCO_2/kWh_{el}$, a reduction in the specific emission index could be achieved to 1 $kgCO_2/m^2$year. However, this specific emission intensity can be achieved by using renewable energies to produce electricity in the form of hydropower plants, photovoltaic panels, wind power plants, but at the same time with the cessation of electricity production from conventional sources such as coal or nuclear power plants. This Specific Emission Intensity I_e = 0.017 $kgCO_2/kWh_{el}$ is not the ideal situation, but it is actually the value currently in place in Norway.

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