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Study for reducing co_2 emissions from a building in climate zone 3 of Romania including the contribution of renewable energy

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Abstract

Energy efficiency in buildings has become a key target to lower nation-wide energy use. The goals of this paper are: to estimate the carbon emission reduction, the energy efficiency measures in a residential building in climate zone 3 of Romania according to the European Directive 2009/28/EC and to estimate the contribution of renewable energy to energy efficiency of the building using the performance indicator named Renewable Energy Ratio (RER). We will detail the methods of calculation for CO_2 emissions and we will present the results for different scenarios: gas boiler and gas condensing boiler, liquid fuel boiler and ground source heat pump in different scenarios with thermal rehabilitation measurements of the building, inclusively. The results show that conventional energy efficiency technologies can be used to decrease CO2 emissions in buildings by 20–30% on average and up to over 40% for some building types and locations. The contribution of renewable energy is between 40 and 50 % from the total energy use.

Keywords: *green, RER, EPBD, technologies, heating*

1. Introduction

This Buildings are responsible for 40% of total CO_2 emissions in the world. Combustion of fossil fuels produces CO_2 gas which is recognized as the major greenhouse gas causing global warming. To reduce the CO_2 emissions associated to the buildings sector must increase energy efficiency of the buildings and utilization of low carbon energy technology to supply the heating demands of the buildings. Heat pump is a low carbon technology proposed to be used in buildings. This technology has been considered in the European Directive 2009/28/EC which is the main directive for proportion of renewable energy in the EU's buildings sector [1,2]. Recent studies have attempted to designate energy efficiency, environmental effects in buildings and building materials. [3]. Kumar et. al. have discussed the use of embodied energy and total energy for a given sample room. This paper focuses upon the comparison of two types of structures using fire clay bricks and ash blocks structure. Though ash blocks are 3 times more expensive than fire clay bricks, the use of ash blocks has considerably reduced the size of air conditioning system, the total usage of energy and finally the total cost of the building due to its light weight and insulating feature [4], [3]. Jayasinghe has investigated and developed the embodied energy of different building materials (conventional building materials and alternative building materials). This study has also included the performance of different materials on operational energy. It is shown that the alternative building materials (cement-stabilized soil blocks and stabilized rammed earth forwalls, micro-concrete roofing tiles for roof and pre-cast reinforced concrete slab systems for floor) and systems may have either reduced or similar impact on life cycle cost, compared to the conventional building materials. According to the result of this paper, the embodied energy of alternative systems is either lower than or comparable with most of other conventional systems [5], [3]. Bribian et. al. present the results of a Life Cycle Assessment study comparing the most commonly used building materials (Steel, aluminum, copper, PVC and glass) with some eco-materials (Brick and tiles, insulation materials, cement and concrete, wood products) using primary energy demand, global warming potential and water demand impact categories. The aim of the study is to deepen the knowledge of energy and environmental specifications of building materials, analyzing their possibilities for improvement and providing guidelines for the selection of materials in the eco-design of new buildings and rehabilitation of existing buildings [6], [3]. Lee et al. explore the impact of different building materials (concrete vs steel) on the embodied energy of the building structure, and compare them with the Green Building Rating score attained under the material category for the same structure. As a result of the study, the embodied energy of the whole concrete structure is more significant than that of the steel or the hybrid structure. Besides this, the impact of building materials not only is limited to the embodied energy and the demolition energy but also to the operational energy of the building [7] [3]. Reddy's paper focuses on certain issues pertaining to energy, carbon emissions and sustainability of building construction with particular reference to the Indian construction industry. Some examples of alternative low-energy materials (Blended cements, stabilized mud blocks, compacted fly ash blocks, rammed earth walls, composite masonry jack-arch roof system) were discussed and the embodied energy analysis of a building using such materials was compared with that of a conventional building (Load-bearing brickwork, reinforced concrete solid slab floor and roof, concrete tile flooring). The analysis shows that embodied energy of buildings using the low energy materials and techniques results in 50% savings in total embodied energy. There is a large potential and scope for utilizing the industrial and mine solid wastes for the manufacture of building materials for promoting sustainable construction practices [8], [3]. The Net Zero Energy Building concept is already well known. European and national laws ask for an increased ratio of renewable energy sources and carriers of the total energy consumption of buildings. While the Renewable Energy Directive gives only a framework for national implementations in the EU and the Erneuerbare-Energien-Warmegesetz in Germany focuses on the partial coverage or the thermal energy demands of buildings or according to compensatory measures, REHVA introduces a performance indicator to calculate the actual fraction of used renewable energy sources. It is named 'Renewable Energy Ratio' (RER) and suggested in a similar manner in the proposal of the recast of DIN EN 15603-2013 where it is named 'Share of renewable energy' [9]. In EN 15603 CEN defines the renewable energy ratio as the ratio of the renewable primary energy (calculated with renewable primary conversion factor), on the total primary energy (calculated with total primary conversion factor) [10] [11, 12, 13, 14, 15, 16, 17]. In this paper we have set as main goal the study of the implementation of the Renewable Energy Directive in a building located in Romania, the climatic zone 3, to be more precise, of the calculation of the 'Renewable Energy Ratio' (RER) performance indicator, as well as to justify the choice of heat generators and heat pumps in buildings by observing the demand for CO2 emission cut. We will further detail the calculation method and we will present the results of the study in different scenarios.

2. Materials and methods

The total amount of the primary energy from the renewable sources results from the difference between the total primary energy and non-renewable primary energy of all observed energy flows which cross the balance boundaries. All conversion and system losses within the balance boundary are included [9]. Energy losses outside of the balance boundary are represented by primary conversion factors of the various energy carriers According to the draft from REHVA, the formula below applies for calculating the 'Renewable Energy Ratio' (RER) [9]. :

$$RER_p = \frac{\sum_i E_{ren,i} + \sum_i \left(\left(f_{del,tot,i} - f_{del,nren,i} \right) E_{del,i} \right)}{\sum_i E_{ren,i} + \sum_i \left(E_{del,i} f_{del,tot,i} \right) - \sum_i \left(E_{exp,i} f_{exp,tot,i} \right)} \quad (1)$$

Where:

RER_p= is the Renewable Energy Ratio based on total primary energy;

$E_{ren,i}$= is the renewable energy produced on the site or nearby for energy carrier i;

$E_{del,i}$= is the delivered energy for energy carrier i;

$E_{exp,i}$= is the exported energy for energy carrier i;

$f_{del,tot,i}$= is the total primary energy factor for the delivered energy carrier i;

$f_{del,nren,i}$ = is the non-renewable primary energy factor for the delivered carrier i;

$f_{exp,tot,i}$=is the total primary energy factor of the delivered compensated by exported energy carrier i.

2.2 CO2 emissions with gas fired boiler [1].

Where a gas fired boiler is used to supply the heating demand of a building, the annual emission rate can be calculated from the following equation [1]. :

$$e_h = F_b k_b = \frac{H}{\eta_b} k_g \quad (2)$$

Where , $\mathbf{F_b}$ is the fuel energy input to the boiler, **H** is the heating demand of the building, η_b is the thermal efficiency of the boiler and k_g is the emissions factor of the mains natural gas.

2.3. CO2 emissions with a heat pump [1].

Where a heat pump is used to supply the heating demand of the building, the annual emission rate can be calculated from the following equation [1]:

$$e_h = E_{hp} k_e = \frac{H}{COP} k_e \quad (3)$$

Where, $\mathbf{E_{hp}}$ is the electrical energy input to the heat pump, k_e is the grid emissions factor, **H** is the heating demand of the building and **COP** is the heating coefficient of performance [1].

3. Results and discussion

The building for which the study was made has the following input data:

- Children hostel located in the third climatic zone;
- The yearly energy specific consumption for heating: **184,81** kWh/(m^2 year)

Stage 1. The replacement of the boiler on liquid fuel with one on gas fuel.The emission factor for the liquid fuel: **0,270** kg CO_2/kWhheat (Fig 1)*The emission index is*:

I_{CO2}=184,81 x 0,270= 49,9 kg CO_2/m^2 year (4)

The CO_2 emission factor for gas fuel: **0,205** kg CO_2/kWhheat

The emission index is:

I_{CO2}=184,81 x 0,205= 37,9 kg CO_2/m^2 year (5)

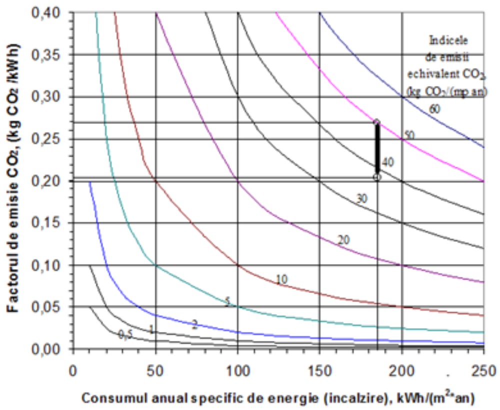

Fig. 1 **-** The annual energy consumption (heating) chart step 1

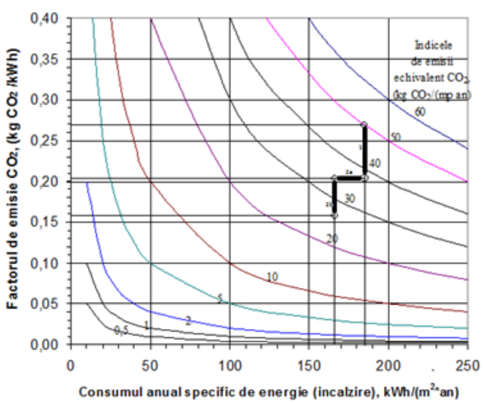

Fig.2 The annual energy consumption (heating) chart for step 2

Stage 2. The thermal rehabilitation of the building and the replacement of the boiler on gas with one on gas in condensation. The thermal rehabilitation reduces the yearly energy specific consumption for heating from 184,81 kWh/(m^2 year) to **166,08** kWh/(m^2 /year). The emission index I_{CO2}

I_{CO2}=166,08 kWh/(m^{2}year) $*$ 0,205 kg CO_2/kWhheat (6)

I_{CO2}= **34,0** kgCO_2/m^2 year.

The replacement of the traditional boiler on gas, (efficiency η=0,8) with one in condensation (efficiency η=0,98) reduces the greenhouse gases (Greenhouse Gases, GHG):

$$RE_{GHC}=0{,}205\left(\frac{1}{0{,}8}-\frac{1}{0{,}98}\right)$$

(7)

RE_{GHC}=**0,047** kg CO_2/kWh$_{heat}$

Namely *The* CO_2*emission factor for the gas fuel* when using the boiler in condensation becomes: 0,205 – 0,047 **= 0,158** kg CO_2/kWh$_{heat}$ (Fig 2)

Implicitly the I_{CO2} emission index is reduced to the value I_{CO2}= =166,08 kWh/(m^2 year) $*$ 0,158 kg CO_2/kWh$_{heat}$(8)

I_{CO2}= = **26,2** kg CO_2/m^2 year

Stage 3. Around 2020 all public buildings will have to fall into the category ‘***nearly zero energy buildings’***. As a consequence, a new rehabilitation of the envelop will be useful (before installing a heat pump). By the rehabilitation of the envelop the yearly energy specific consumption for heating decreases from 166,08 kWh/(m^2 year) to **122,2** kWh/(m^2 year).

This will lead to a reduction in the I_{CO2} emission index:

I_{CO2}= 122,2 kWh/(m^{2}year) $*$ 0,158 kg CO_2/kWh$_{heat}$ (9)

I_{CO2}= = 19,3 kg CO_2/m^2 year

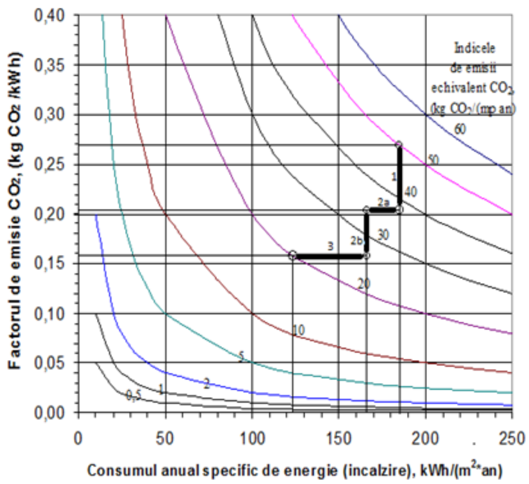

Fig. 3 - The annual energy consumption (heating) chart step 3

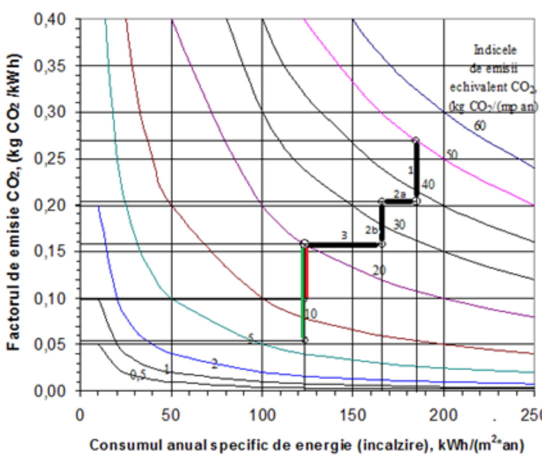

Fig. 4 - The annual energy consumption (heating) chart step 3

The issue at stake is: what type of heat pump should be chosen for the heat supply of the children hostel, either an air-water one which is cheaper but with a lower COP (2,3) or one of the ground-water type with deep probe having a COP=4,1 (thanks to the higher temperature of the soil in wintertime, compared to the atmospheric air). The heat pump valorizes the renewable energy in the surrounding area. The GHG emission reduction by the setting up of a heat pump is determined on the basis of the *Emission factor for the gas fuel specific to the condensation boiler* (I_f = 0,158 kg CO_2/kWh$_{heat}$), respectively of its functioning efficiency real conditions (η=0,98). At the same time we need to take into consideration the GHG production intensity specific to energy generation, I_e. These values are very different from one country to another: In EU the average value is I_e = 0,231 kg CO_2/kWh$_{electricity}$, but Romania has had lately a value I_e = 0,499 kg CO_2/kWh$_{electricity}$.

a) As a consequence: the replacement of the boiler in compensation with an air-water heat pump will lead to a reduction of the GHG of:

$$RE_{GHC}=\frac{0{,}158}{0{,}98}-\frac{0{,}231}{2{,}3} \qquad (10)$$

RE_{GHC}=0,0608 kg CO_2/kWh$_{heat}$

Which leads to an CO_2 emission factor 0,158–0,0608 **= 0,0972** kg CO_2/kWh$_{heat}$ (Fig 4)
Respectively to an I_{CO_2} emission factor

$$I_{CO_2}=122{,}2 \cdot 0{,}0972 \text{ kg } CO_2/m^2 \text{ year} \qquad (11)$$

I_{CO_2}= 11,9 kg CO_2/m^2 year

b) If we opt for a ground-water heat pump, (COP=4,1) in order to replace the boiler in condensation them the GHG cut will be:

$$RE_{GHG}=\frac{I_f}{\eta}-\frac{I_e}{COP} \qquad (12)$$

$$RE_{GHC}=\frac{0{,}158}{0{,}98}-\frac{0{,}231}{4{,}1}$$

RE_{GHC}=0,105 kg CO_2/kWh$_{heat}$

And the CO_2 emission factor will be 0,158– 0,105 = **0,0531** kg CO_2/kWh$_{heat}$ (Fig 4) which leads to an I_{CO_2} emission:

$$I_{CO2}=122{,}2 \cdot 0{,}0531 \text{ kg } CO_2/\text{kWh}_{heat} \qquad (13)$$

I_{CO_2}= 6,49 kg CO_2/m^2 year

Stage 4. To continue with, the cut down of the I_{CO_2} Emission index is possible only on account of the renewable energy produced far-off, close-by or even on site.

For example, a green electric energy shot of 50% produced by photovoltaic panels will reduce I_e of the network to the value 0,5 · 0,231+0,5 · 0,09 = **0,161** which will trigger, in the case of the ground-air heat pump considered above, a cut down of the GHG emissions:

$$RE_{GHG} = \frac{I_f}{\eta} - \frac{I_e}{COP} \quad (14)$$

$$RE_{GHC} = \frac{0{,}158}{0{,}98} - \frac{0{,}161}{4{,}1}$$

RE_{GHC}=0,122 kg CO_2/kWh_{heat}

And an emission factor 0,158– 0,122 = 0,0359 kg CO_2/kWh_{heat} which will lead to an I_{CO_2} emission index:

I_{CO_2}=122,2 · 0,0359 kg CO_2/m^2 year

(15)

I_{CO_2} = 4,38 kg CO_2/m^2 year

The energy necessary of the building:

- The heat necessary of the building: 184,81 kWh/(m^2year)
- The electric energy for lighting: 15 kWh/(m^2year)
- The electric energy for houseware: 21kWh/(m^2year)
- The electric energy necessary to the heat pump (COP = 4,1): 184,81/4,1=45,07kWh/(m^2year)

The renewable energy

The renewable energy taken in by the heat pump from the soil:

184,81-45,07=139,74kWh/(m^2year) (16)

The factors of primary energy

For the energy carrier *i* namely the electric energy it is considered that 20% from the mix in the electric network is obtained from renewable (Aeolian and PV), the rest of 80% being traditionally generated (fossil fuel).

- The factor belonging to the provided non-renewable primary energy (the factor of the non-renewable primary energy is considered 0, and the total factor of the non-renewable primary energy is currently in Romania 1/0,36=2,8):

$$f_{\text{del, nren, el}} = 0 \cdot 0{,}2 + 2{,}8 \cdot 0{,}8 = 2{,}24 \quad (17)$$

- The factor of the total primary energy corresponding to the provided electric energy mix (the total factor of the renewable energy is 1, and the total factor of the non-renewable primary energy is currently in Romania 1/0,36=2,8):

$$f_{\text{del, tot, el}} = 1 \cdot 0{,}2 + 2{,}8 \cdot 0{,}8 = 2{,}44 \quad (18)$$

For these conditions the Renewable energy contribution (RER) is:

$$RER = \frac{139{,}74 + (2{,}44 - 2{,}24)\cdot(15 + 21 + 45{,}07)}{139{,}74 + (15 + 21 + 45{,}07)\cdot 2{,}44}$$

$$RER = 0{,}462$$

(19)

If photovoltaic panels are installed on site, 15kWh/(m^2year) generators, then an improvement of RER will occur:

$$RER' = \frac{15+139{,}74+(2{,}44-2{,}24)\cdot(15+21+45{,}07)}{15+139{,}74+(15+21+45{,}07)\cdot 2{,}44}$$

$$RER' = 0.484 \tag{20}$$

If one exports to the national electric energy network 9 kWh/(m^2year) (that is, only 6 out of the 15 kWh/(m^2year) are used), then the improvement of *RER* is by far more obvious

$$RER'' = \frac{15+139{,}74+(2{,}44-2{,}24)\cdot(15+21+45{,}07)}{15+139{,}74+(15+21+45{,}07)\cdot 2{,}44-9\cdot 2{,}44}$$

$$RER'' = 0.515 \tag{21}$$

5 Conclusion

The attention given to the Zero Energy Building concept increased during the last years. Many countries have already established ZEBs as their future building energy target. Among different strategies for decreasing the energy consumption in the building sector, ZEBs have the promising potential to significantly reduce the energy use and the CO_2 emission, and to increase the overall share of renewable energy, as well. For this case study, to reduce the CO2 emissions by replacing the heat generators which function on liquid fuel respectively gas by the recuperation of heat from the condensation of the burning gases, decreases from 49,9 kg CO_2/m^2 year (when using liquid fuel) to 26,2 kg CO_2/m^2 year (when using gas fuel). The decrease of the CO2 emissions by almost 50 % using gas condensing boiler. Using ground heat source pumps and, by implementing rehabilitation solutions of the building's envelop, we shall obtain a decrease of the CO2 emissions to 6,49 kg CO_2/m^2 year. An injection of green electric energy produced by photovoltaic panels will lead to an emission index of 4.38 kg CO_2/m^2 year. It is obviously necessary to approach seriously the issue of the renewable energy for the heating of the buildings both from the point of view of the CO_2 emissions and from the point of view of the financial savings. Just as it results from the calculation of the RER index, simultaneous to the increased use of the renewable energy we will fulfill in Romania by 2020 our two goals: a less polluted environment and a cut of the energetic costs in buildings

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