International Scientific Conference CIBv - Civil Engineering and Building Services

5th-6th November 2020

HIGH PERFORMANCE BUILDINGS WITH OPTIMIZED ENERGY SYSTEMS BASED ON EXERGY PRINCIPLES

Boian Ioan Tuns Ioan

1. Introduction

The energy demand for heating and cooling in the building sector is responsible for more than one third of the final energy consumption in Europe and worldwide, energy commonly resulting from combustion processes using different fossil fuels. The resulting greenhouse gas (GHG) emissions are the core challenges in fighting climate change considering its large contribution from the built environment.

Two issues exist: a more efficient use of energy, and burning less fossil fuels. Increased efficiency is related to optimization and the concept of exergy can help a better understanding and evaluation of the processes and systems quality. An increased efficiency in energy use is possible when investigating the exergy flows in buildings. While energy is conserved – First Law o Thermodynamics – the exergy, as the entirely convertible energy into other types of energy, can be destroyed, i.e. converted in anergy, as shown in Figure 1. The heat transferred through a wall separating the warm space from the cold exterior is the same on the inside face and the outside one, 1035 W. But the exergy entering the inside-warm face, 93.15 W is different from the exergy leaving the outside-cold face, 0 W, meaning that the entire exergy was destroyed.

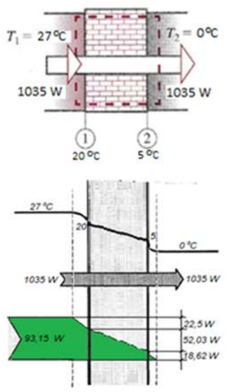

Figure 1. The flow diagram for the energy (a) and for the exergy (b).

The destroyed exergy is

$$\dot{I} = \dot{Q}_{wall}\left(1-\frac{T_0}{T_1}\right) - \dot{Q}_{wall}\left(1-\frac{T_0}{T_2}\right) = 1035\left(1-\frac{273}{300}\right) - 1035\left(1-\frac{273}{273}\right) = \mathbf{93,15\ W}$$

Minimizing the irreversible dissipation of low-value energy into the environment is possible if the heat transferred through the wall $\dot{Q}_{wall}$ is reduced by insulating it and through a lower exergy factor $\left(1-\frac{T_0}{T_1}\right)$ resulting if the temperature inside the space, T_1 is diminished, caused by the insulation, too.

The exergy factor is an exergetic efficiency defined as the ratio of the exergy output. or resulted and the exergy input

$$\left(1-\frac{T_0}{T_1}\right) = \eta_{ex} = \frac{Ex_{res}}{Ex_{in}}$$

Exergy efficiency illustrates how far the efficiency of a conversion process is from its theoretical maximum.

2. Energy versus exergy efficiency of systems and equipment

A substantial decrease of CO_2 emissions for the building stock can be realized through a better and exergy optimized building design. Additionally, enhanced heating and cooling systems lead to a lower exergy demand of buildings. Figure 2 illustrates the energy efficiency together with the exergy efficiency for four usual equipment: the energy efficiency for liquid fuel based boilers and cogeneration systems are quite similar, less than 100% as it is in case of electrical boilers, in which nearly all electrical energy is converted into heat, while heat pumps can reach values over 300%. On the other hand the corresponding exergetical efficiency do not exceed 4 to 5 per cent in case of boilers, fossil fuel based or electrical; these low values are due to the large temperature difference between the flame (more than 1000 °C) and the heated water (about 60 °C) in case of fossil fuel boilers; the electrical boiler is transforming the extremely high-quality electrical energy into a low-quality thermal energy aiming to a cover the gap between the inside temperature (20°C) and that of the outside air (5°C). The exergy efficiency of a heat pump is significant greater than that of an electric heater as a result of the fact it transfers the energy from the environment to the interior space by means of a smaller amount of electrical energy, resulting in a lower cost. Heat pumps are able to use the low-valued energy delivered by sustainable energy sources (from the environment) in order to supply the heating energy necessary for the comfort inside buildings. Saving energy is in fact an exergy saving. Additionally, heat pumps can operate in a reversible mode, cooling for comfort an interior space, working as low-temperature heating and high temperature cooling systems.

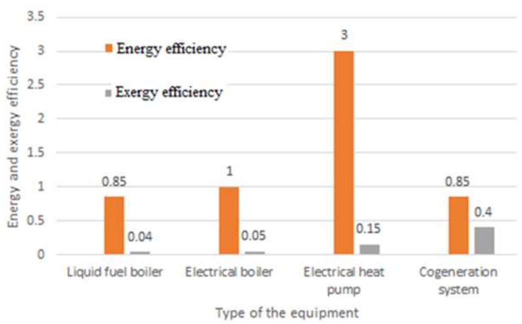

Figure 2. A comparison of the energy and exergy efficiency for some heating systems.

3. Envelope insulation or renewable energy sources use?

Minimizing GHG emissions being directly associated with the energy performance of the building and with the use of renewable energy sources a question arises: what is the contribution of each of the two components. An exergy analysis can show that a house with 20 to 30 cm thick insulated walls heated with a heat pump having a coefficient of performance COP = 3...4, supplying a low temperature radiant system will have about the same energy use as that required by a passive house, as shown in Figure 3. The development of low temperature heating and high temperature cooling systems is a necessary prerequisite for the usage of alternative energy sources.

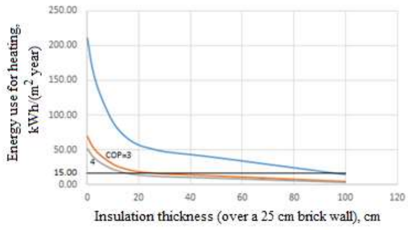

Figure 3. A heat pump supplying a 20...30 cm insulated house needs almost the same energy for heating as a passive house.

4. Low temperature heating and high temperature cooling systems

Heat sources of lower temperature for heating require a thermally-well-insulated envelope making use of building materials with appropriate heat capacity. For the cooling season a combination of night ventilation with shading devices for windows and a mitigation of internal heat gains added to previous mentioned insulation materials for walls having a corresponding heat capacity represent the prerequisite condition for high temperature cooling systems. The exergy factor (efficiency) for an isothermal heating process lies between 1.4 and 22 per cent, but is only about half if the heat carrier do not remain at a constant temperature, as can be seen in Figure 4, a and b. the same for a cooling process, Figure 5, a and b.

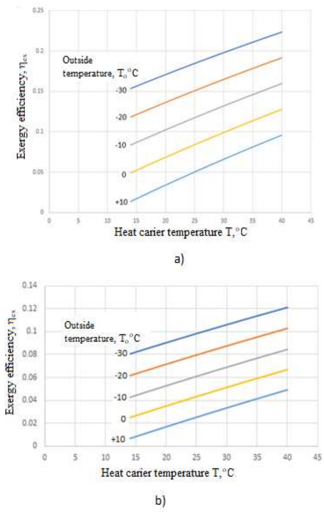

Figure 4. Exergy efficiency as a function of the heat carrier temperature for isothermal processes (a), and for non-isothermal processes (b) in case of heating.

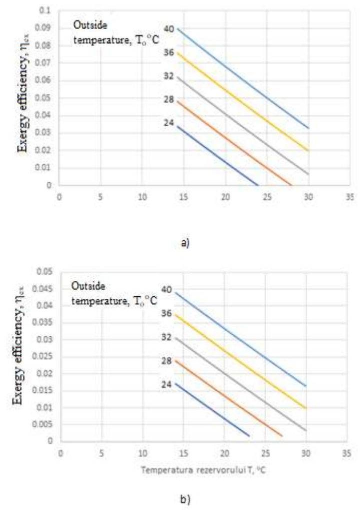

Figure 5. Exergy efficiency as a function of the heat carrier temperature for isothermal processes (a), and for non-isothermal processes (b) in case of cooling

5. Conclusions

The optimization process as a combination of energy efficiency measures and renewable energy use is aimed to lead to the nearly-zero energy target, i.e. a reduction of approx. 90% of CO_2 emissions, considering the cost-effectiveness rather than cost-optimality. The overall exergy efficiency based on the analysis of every component losses is the way to improve de performance of the system leading to a progressive mitigation of GHG emission. The exergy concept used when developing a sustainable community offers a holistic understanding of the optimization process resulting from successive improvements. The high potential of buildings to lessen the input exergy destroyed by irreversibility (84 to 93% of the exergy consumed) can be exploited through low-exergy heat-sources like the geothermal ones. Lowering the temperature of the heating agent will improv the exergy efficiency of the system. An improved thermal comfort and indoor air quality together with a reduced energy consumption are feasible when applying low-exergy systems.

References:

[1] LOWeX COMMUNITIES -OPTIMISED PERFORMANCE 0F ENERGY SUPPLY SYSTEMS WITH EXERGY PRINCIPLES. EBS NEWS ISSUE 69 JUNE 2019, Pag 8

[2} Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56) Guidebook for Professional Home Owners October 2017. EBC

[3] G. Dragomir, A. Şerban*, **G. Năstase**, and A. I. Brezeanu, "Wind energy in Romania: A review from 2009 to 2016," Renew. Sustain. Energy Rev., vol. 64, pp. 129–143, 2016, ISSN: 1364-0321.

[4] OSTI.GOV title logo U.S. Department of Energy Office of Scientific and Technical Information 2017-