CASE STUDY – ENERGY RETROFIT OF A HUNGARIAN DETACHED HOUSE

1. GENERAL INFORMATION

Building type: detached house

Net heated floor area: 91 m^2

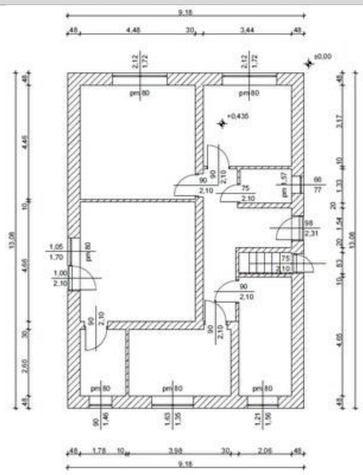
Gross floor area: 105 m^2

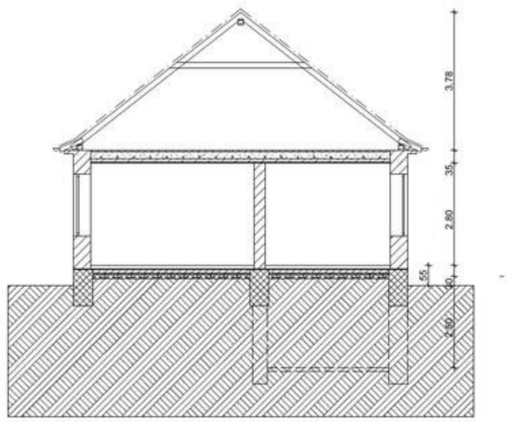
Short description: The case study building is a typical Hungarian detached house, built with a nearly rectangular floor plan of approx. 100 m^2 and a pyramid hip roof. These buildings were built in large volumes between the 1950s and the 1970s, there are approx. 800 000 of them all around Hungary. Their nickname is "Kádár cube", named after a Hungarian communist leader of the period

2. ORIGINAL STRUCTURES AND TECHNICAL SYSTEMS

- External wall: The original external wall is made of concrete blocks with plastering. The thermal transmittance of the wall does not comply with the current regulations (U = 1.1 W/m^2K > Umax = 0.24 W/m^2K)
- Floor slab under the loft: the loft slab is made of prefabricated reinforced concrete beams and blocks with some slag on the top. The structure does not comply with the current regulations (U = 0.95 W/m^2K > Umax = 0.17 W/m^2K)
- There is a small unheated cellar under one part of the building and the rest has a slab-on-ground.
- The windows are old box-type windows with 2 layers of glass, without any special coating.
- Space heating is provided by by a non-modulating atmospheric gas boiler and radiators, and hot water by an electric boiler operating with off-peak electricity.
- Lighting is provided with incandescent light bulbs.

Please note that these structures are meant to be characteristic of the typical original conditions. In many buildings, some retrofit measures have already taken place in the recent years, for examples the windows may have been exchanged.





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3. COMPARED ALTERNATIVES

We compared the following alternatives:

- 0**. Reference case:** the original building without and retrofit measures. Only the heating energy of the building is included in the costs and in the environmental impacts.
- 1**. Insulated:** additional insulation of the external wall with expanded polystyrene and additional insulation of the floor under the loft with mineral wool between wooden planks so that these structures comply with the current Hungarian regulation.
- 2. **Ins-windows**: same as v1 + exchange of the windows to triple glazed windows.
- 3**. Condensing**: no insulation, but the exchange of the boiler to a new condensing gas boiler that can supply space and water heating. Only the cost of the boiler was included, the cost of upgrading the heat emitters (radiators) was not included.
- 4**. Ins-wind-condensing:** combination of v2 and v3, additional insulation, window exchange and new boiler.
- 5. **Ins-wind-awhp**: same as v2 + a new air-to-water heat pump is installed for space and water heating.
- 6. **Ins-wind-awhp-pv:** same as v5 + photovoltaic system (PV) is installed.
- 7. **Ins-wind-pellet**: same as v2 + a pellet boiler is installed for space and water heating
- 8**. Ins-wind-electric**: same as v2 + direct electric space heating is installed. Hot water is with an off-peak electric boiler as in the reference case.
- 9. **Ins-wind-cond-LED:** same as v4, but the old light bulbs are exchanged for LED lighting.

With these ten models, we would like to present the most important elements of a residential house renovation and what environmental impact they cause. Of course, we could not follow the logic of a renovation: e.g. in only one case we installed a solar panel, we did not replace the original boiler with a more modern one after 15 years in the reference example, we only replaced the light sources with LEDs in the last version.

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	Wall insulation	Loft floor insulation	Window exchange	Space heating	Domestic hot water	Photo-voltaics	Lighting
0. Reference	-	-	-	Old gas boiler	Off-peak electric boiler	-	Old light bulb
1. Insulated	13 cm EPS	20 cm mineral wool		Old gas boiler	Off-peak electric boiler	-	Old light bulb
2. Ins-windows	13 cm EPS	20 cm mineral wool	Triple glazed wooden	Old gas boiler	Off-peak electric boiler	-	Old light bulb
3. Condensing	-	-	-	Condensing gas boiler	Condensing gas boiler	-	Old light bulb
4. Ins-wind-condensing	13 cm EPS	20 cm mineral wool	Triple glazed wooden	Condensing gas boiler	Condensing gas boiler	-	Old light bulb
5. Ins-wind-awhp	13 cm EPS	20 cm mineral wool	Triple glazed wooden	Heat pump, air-to-water	Heat pump, air-to-water	-	Old light bulb
6. Ins-wind-awhp-pv	13 cm EPS	20 cm mineral wool	Triple glazed wooden	Heat pump, air-to-water	Heat pump, air-to-water	4 kWp (20 m2) PV	Old light bulb
7. Ins-wind-pellet	13 cm EPS	20 cm mineral wool	Triple glazed wooden	Pellet boiler	Pellet boiler	-	Old light bulb
8. Ins-wind-electric	13 cm EPS	20 cm mineral wool	Triple glazed wooden	Direct electric res. heater	Off-peak electric boiler	-	Old light bulb
9. Ins-wind-cond-LED	13 cm EPS	20 cm mineral wool	Triple glazed wooden	Condensing gas boiler	Condensing gas boiler	-	LED

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4. CALCULATION METHODOLOGY

The heating energy demand was calculated according to the Hungarian regulations for the energy certification of buildings. This methodology takes into account the thermal characteristics of the building envelope, the ventilation losses due to the fresh air need, winter solar gains through the windows and the internal heat gains from people and household appliances. The efficiency and losses of the technical building systems are also considered. Please note that this calculation assumes a 'standard' occupants' behaviour, for example a set temperature of 20 °C in the winter in the whole building. If the occupants choose to set a lower or higher temperature or heat different rooms to different temperatures, this will affect the heating energy demand and the results would change. Also, for the technical systems, default efficiency and losses are considered, so if the efficiency of the chosen system is better than the default, the energy saving would increase. Other electricity consumption (lighting and appliances) was considered as a typical average.

The environmental impact was calculated with the method of Life Cycle Assessment (LCA) with the help of the OneClickLCA software, according to the Level(s) life cycle assessment methodology. As the number of materials with an Environmental Product Declaration is limited in Hungary, the most representative international datasets have been selected from the available databases.

The life cycle costs (LCC) or global costs were also calculated with the OneClickLCA software. These costs are the sum of the investment cost and the annual costs for every year (energy costs, maintenance, replacements, etc.), all expressed as Net Present Value referring to the starting year, for a calculation period of 30 years. The investment cost of the retrofit, including the price of material and labour, were taken from a Hungarian cost database (Építőipari Költségbecslési Segédlet, 2021) and include the VAT. A discount rate of 3% and an inflation rate of 3% were assumed.

Only the newly added materials and systems were included in the assessment, the existing structures not. The renovation measures that are the same in every option (e.g. regular painting of the internal walls) were also excluded.

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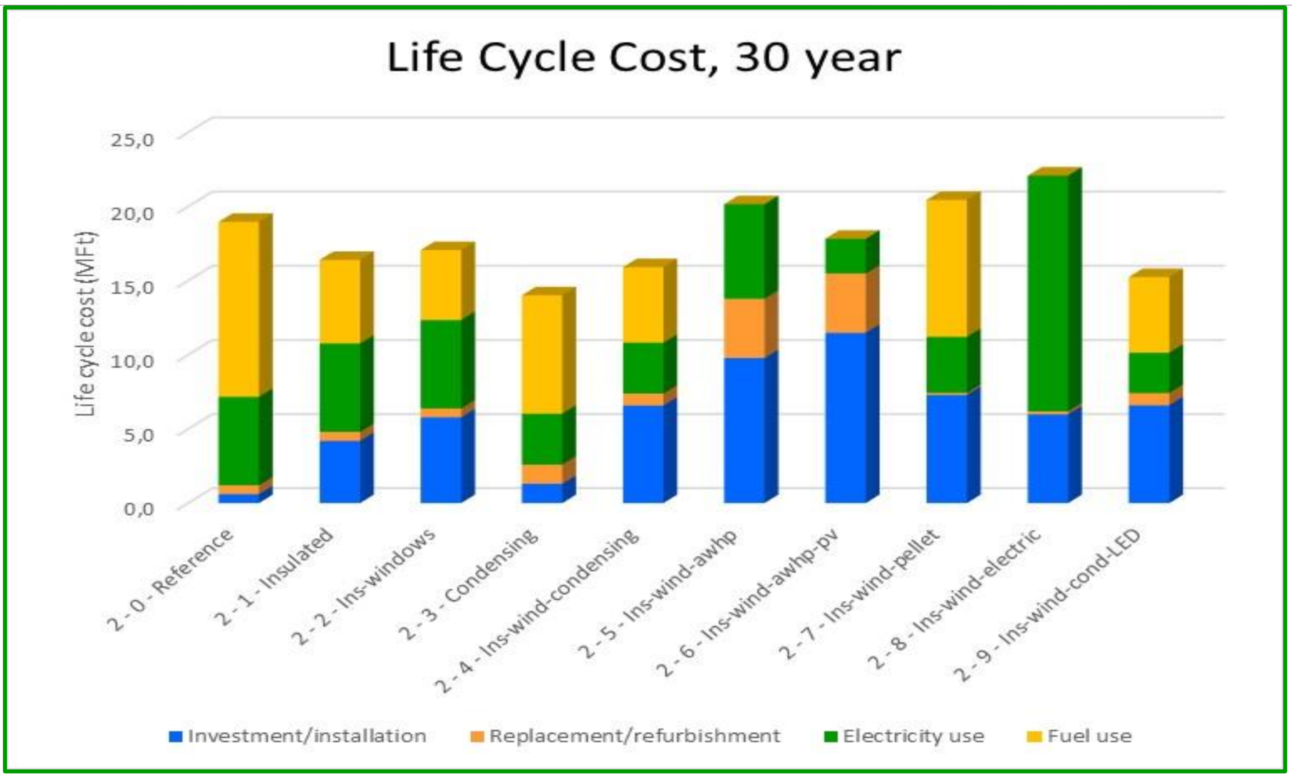
5. RESULTS

5.1. LIFE CYCLE COSTS (DISCOUNTED) (LCC)

The life cycle costs are the total discounted costs for 30 years, including investment, replacement and operation. Insulation (v1), window exchange (v2) and condensing gas boiler (v3) are all worthwhile investments and reduce the global costs with 7-10% compared to the reference case (v0). The investment cost of insulation and window exchange are much higher than that of the condensing boiler, but the achieved energy saving is also higher and finally the total costs are similar. As the life time of condensing gas boiler was set to 20 years, one replacement will be necessary, while the insulation and windows do not need to be exchanged.

We can compare the different heating systems in v4-v8. The investment cost of the heat pump is much higher compared to the condensing gas boiler and it also needs to be exchanged after 20 years. On the contrary, the investment cost of the pellet boiler is similar to the condensing gas boiler but the operation cost is high due to the price of the pellets and hence the total costs are higher than for the reference case. The installation of PV (v6) is worthwhile and reduces LCC, as this option has the lowest operational costs. The investment cost of the electric heater (v8) is the lowest from all the options, but if we add up the operation costs for 30 years, this alternative has the overall highest LCC, as the price of electricity is the highest from all energy sources.

The effect of the lighting system is visible if we compare v4 and v9. The installation of LED pays back as the investment cost is relatively low, the life time of LED is high and there is a reduction in the operation costs.



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5.2. GLOBAL WARMING POTENTIAL (GWP)

The GWP figures show very different results compared to the LCC figures. From an environmental point of view, the reference case (v0) proves to be the worst among all the options. While in LCC, investment costs dominated in many options, material input has a negligible contribution in GWP. This means that from an environmental point of view, all retrofit options are worthwhile. Insulation (v1) and window exchange (v2) pay back very quickly in CO_2 and a complex retrofit including insulation, windows and condensing gas boiler (v4) performs even better.

When we compare the different heating systems (v4-v8), electric heaters have the highest GWP, followed by the condensing gas boiler, then heat pumps, while pellet boiler has the lowest GWP. Heat pumps perform well, even though some refrigerant leakage was considered during the use. Heat pump combined with PV is as low as the pellet boiler option. Lighting with LED reduces the total impact (compare v4 with v9), although the saving is only 3%.

Do not forget that we can use the current Hungarian energy mix in our calculations (nearly 50% of all energy is nuclear, a significant portion is fossil and a small portion comes from renewable sources), and we set a significant improvement in this, in the 30-year perspective in which we also calculate the effects of the renovation. So we can rightly hope that in the diagrams below, the environmental impact from energy consumption will be significantly lower. (Unfortunately, we cannot promise that the same trend will be true for life cycle costs).

The environmental impact of building materials and energy supply systems is less than one tenth of the load caused by 30 years of energy consumption. To see the former in more detail, we separated the energy use data (this is followed when discussing further impact categories). Most striking here is the installation of a solar system that emits about the same amount of greenhouse gases as the complete insulation of the house along with the windows. As a reassurance, let's look at the figure above, which shows that the solar cell no longer causes any environmental impact during the use phase. We can also see the opposite case, the consequence of the smallest investment is very high CO_2 emissions.

The biggest contribution to GWP is caused by the leakage of the heat pump refrigerant. These substances no longer deplete the ozone layer as previously freons, but have a similarly high GWP, over 10,000 CO_2 equivalents. In the figure above, we can also see that, at the same time, an even higher emission, from fuel use, has been eliminated.

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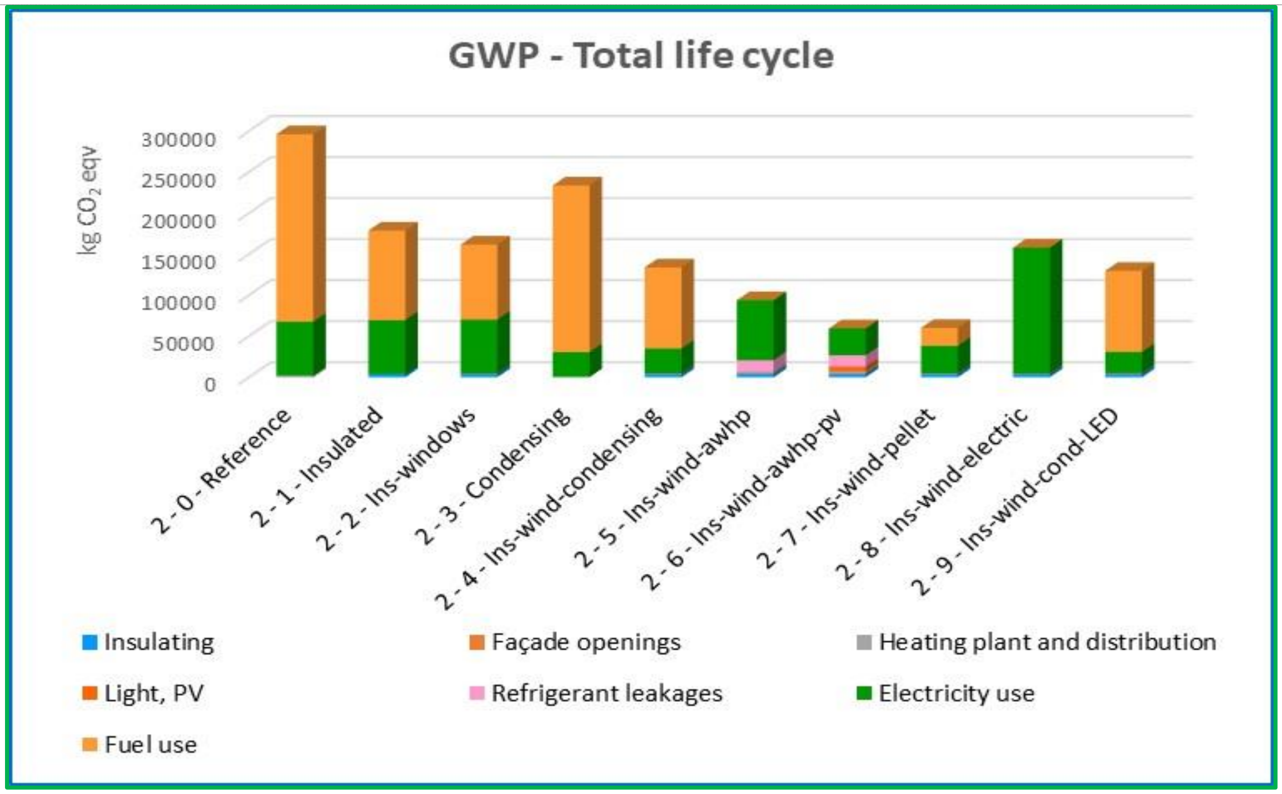

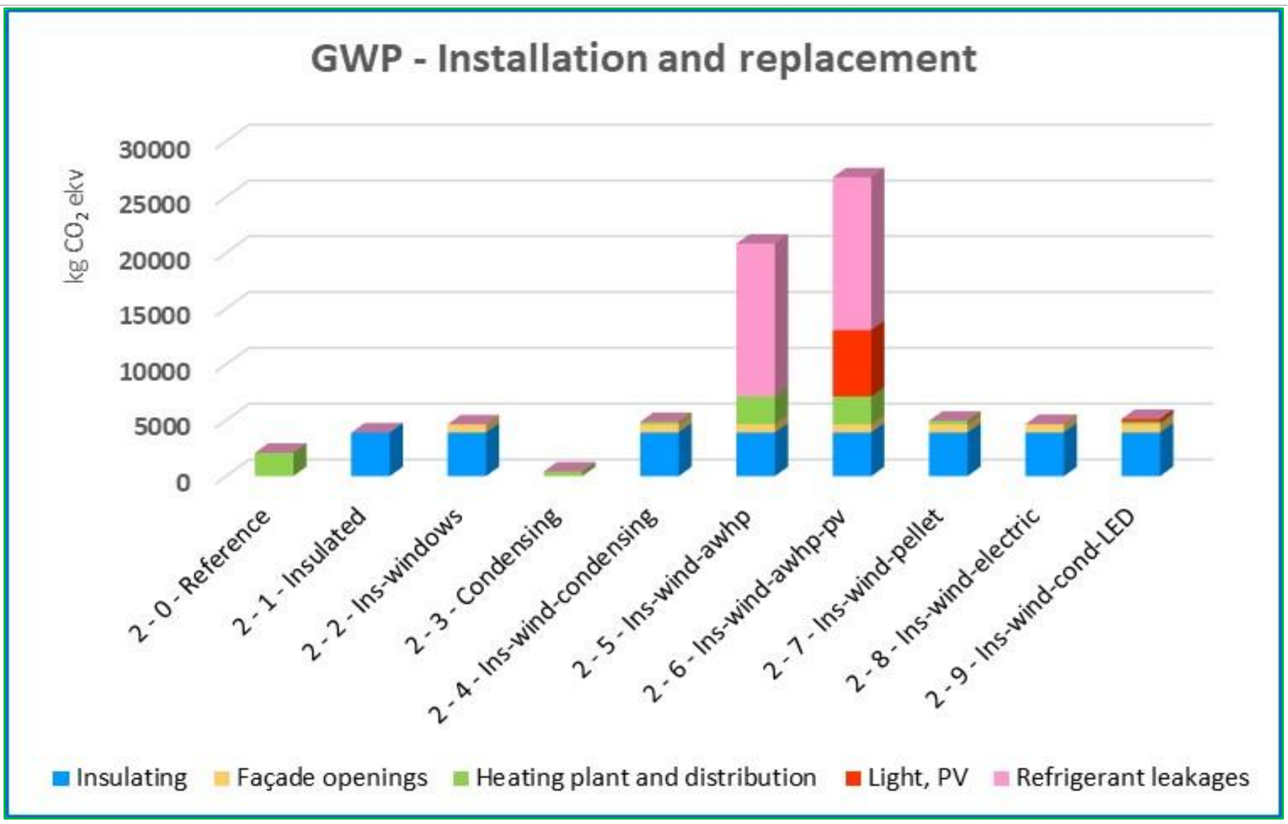

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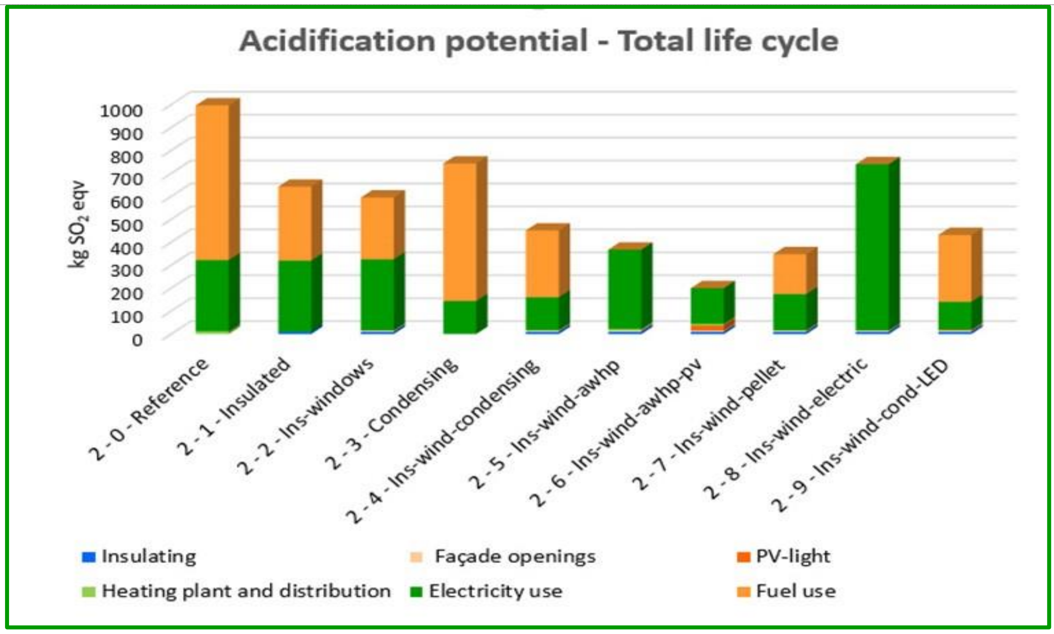
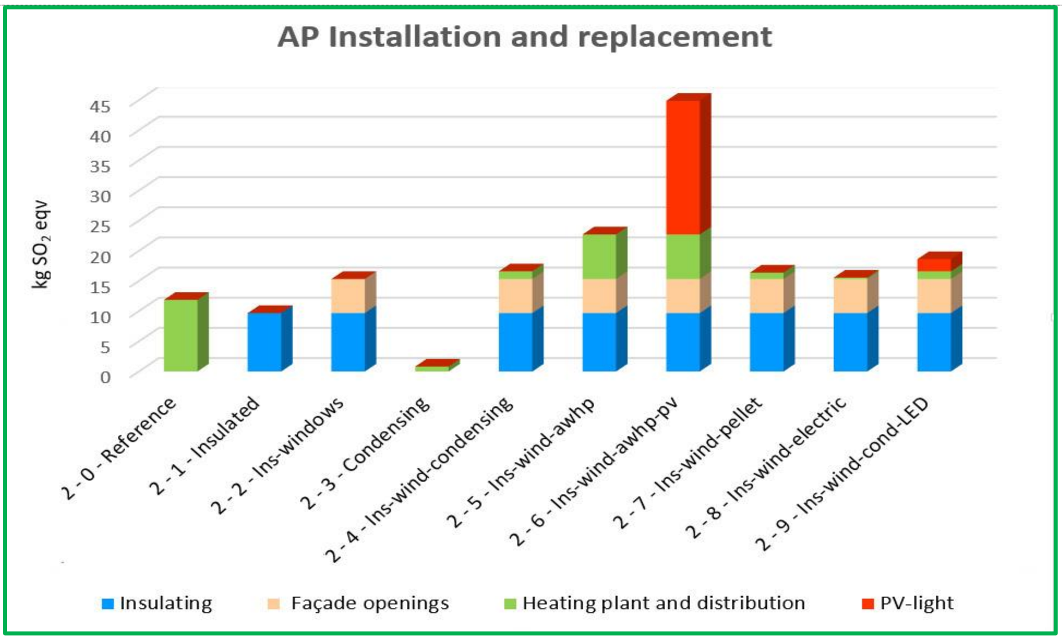
5.3. ACIDIFICATION POTENTIAL (AP)

Acidification is caused by sulfur and nitrogen oxides released into the air during various technological processes. Sulfur is released into the atmosphere primarily from the burning of fuels or naturally from volcanic eruptions. The source of nitrogen can be topsoil, high temperature combustion, exhaust gas or lightning. So the energy consumption of our house also comes with emissions that cause acid deposition, whether we use mains electricity or a home boiler. It's no coincidence that the chart is very similar in nature to the GWP chart. The emissions of building materials and energy production equipment are about one twentieth of the total lifetime operating emissions, and the explanation is similar to that of the materials that cause climate change.





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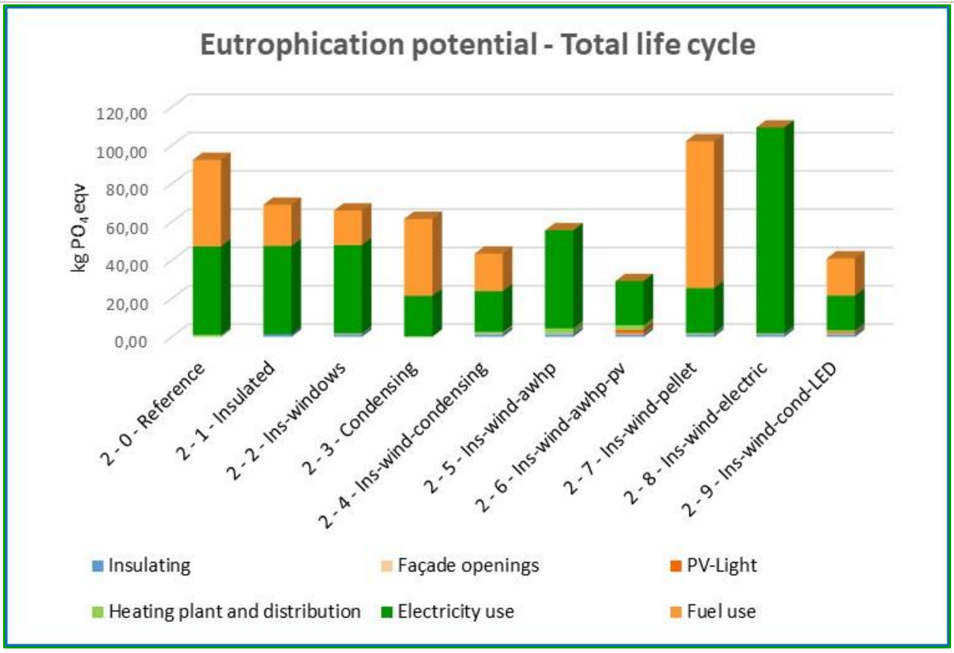
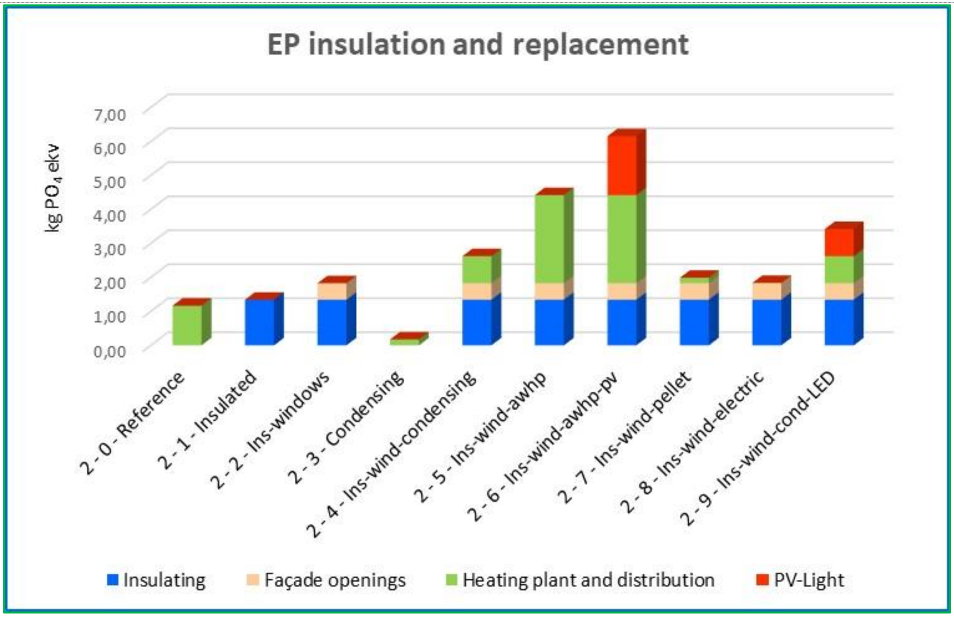
5.4. EUTROPHICATION POTENTIAL (EP)

The phenomenon results from the overfeeding of natural waters, caused by phosphate and nitrate compounds entering the soil and groundwater. As we can see, energy consumption plays a dominant role here as well, so nitrogen oxides formed during energy production also cause this environmental load, phosphate compounds hardly occur here. The high value of the pellet boiler is striking. This is caused by nitrogen oxides formed during combustion. The effect of materials and equipment here is only a fraction of the use phase. Phosphates also appear in small amounts here, between emissions from iron and steel production.





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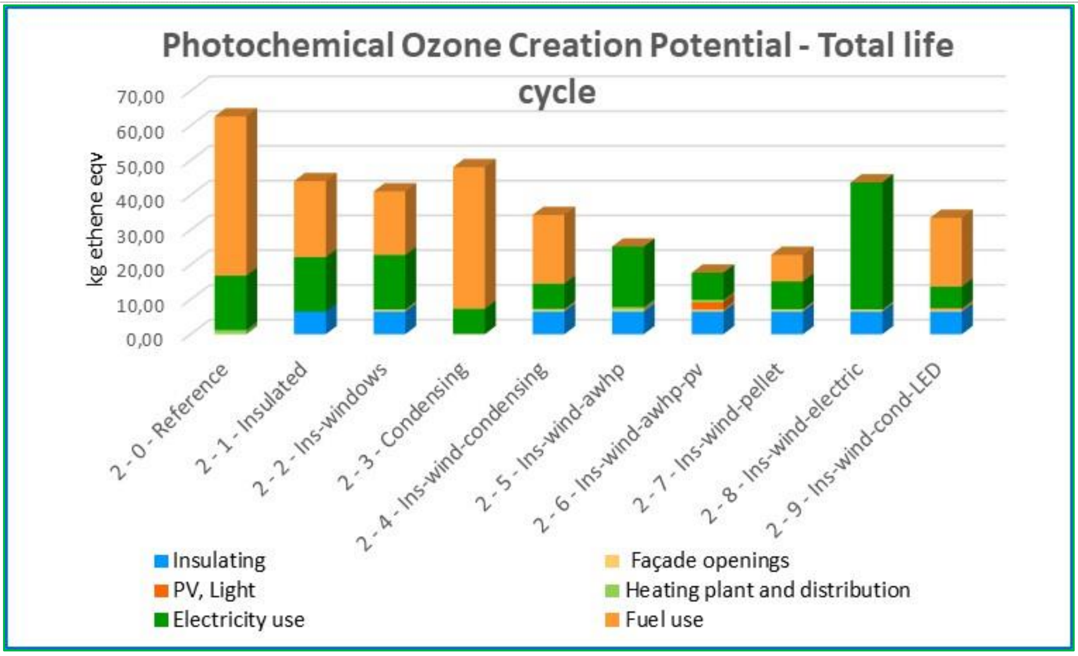
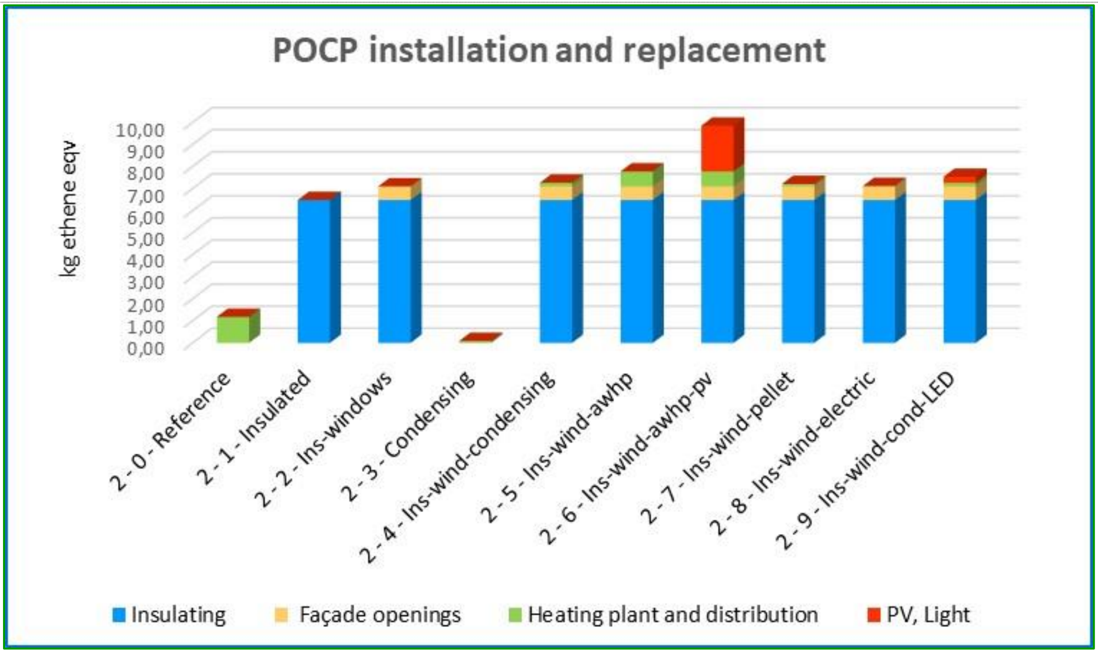
5.5. PHOTOCHEMICAL OZONE CREATION POTENTIAL, (POCP)

Ozone, which is harmful to health, is formed in complex photochemical reactions near the earth. The condition is the combined presence of summer solar radiation, volatile organic compounds (VOCs) and nitrogen oxides (NO_x). Typically, loads from urban traffic, but these materials can also come from imperfect combustion. Thus, in the case of the house, transportation and burning of fuels causes this load. In the case of materials, volatile organic compounds are clearly released into the air during the production and foaming of the XPS insulation layer.





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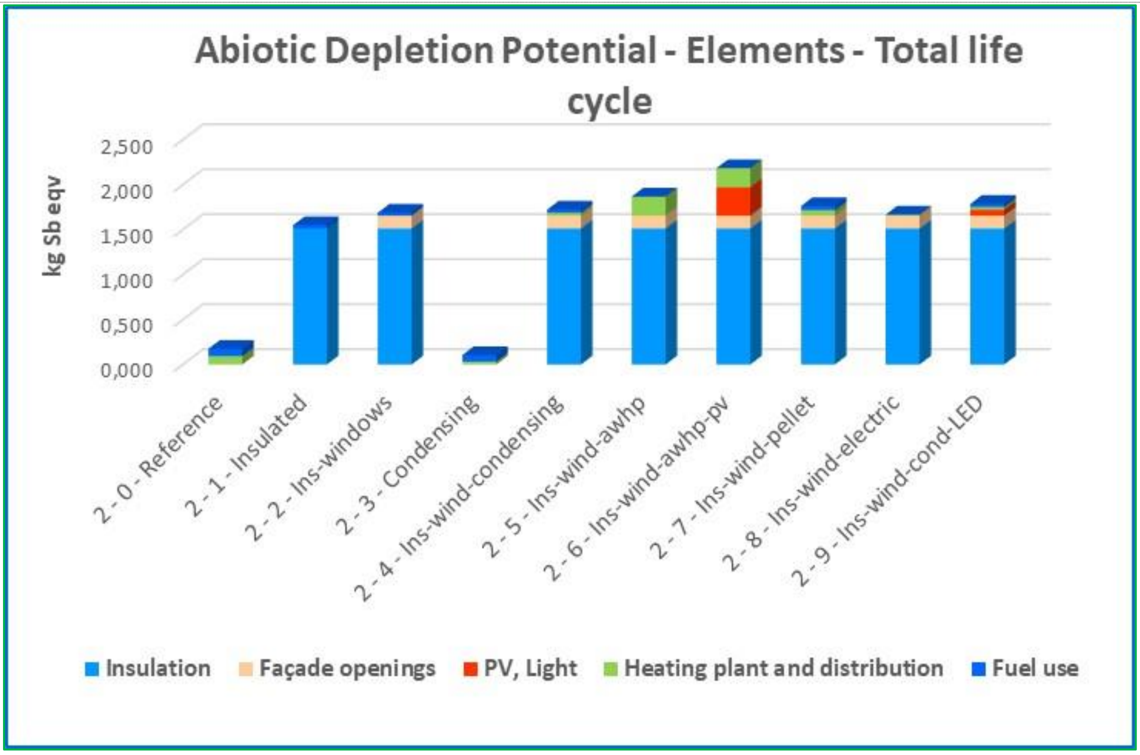
5.6. ABIOTIC DEPLETION POTENTIAL – ELEMENTS (ADP-E)

This impact category indicates the consumption of natural resources, including raw materials. It is higher when the Earth's supply of any of the materials used is depleted. Apparently, such materials are not needed for house building and equipment. This consumption, equivalent to a maximum of 2 kg of antimony, does not pose a serious burden on the environment. We can also read from the diagram that energy consumption does not play a role in this impact category. An indicator of energy depletion is calculated separately, but it provides only minimal additional information compared to GWP. Therefore, we do not show this separately. Only PS foam shows a noticeable value because its raw materials are petroleum and natural gas.



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