Reducing energy demand in existing buildings as a tool to reduce air pollution

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Abstract. Buildings, on average, account for approximately 41% of total energy consumption in the European Union. This energy consumption also translates into hundreds of millions of tonnes of emitted CO2 and other air pollutants. Due to a large share in the total energy consumption, the buildings sector has a significant potential to reduce the energy intensity of building operation, increase the share of renewable energy sources (RES), and thus significantly reduce emission of air pollutants. Existing buildings in Poland, both residential and public, are characterized by high potential in terms of energy and environment. One way to improve the energy efficiency of existing buildings and reduce emissions (in particular greenhouse gases) is through thermos modernization which adapts existing buildings to current and future energy demand requirements. The paper presents the expected environmental effects of measures which adjust the existing residential buildings to the requirements in force in Poland since 2021. It has been assumed that the energy demand for heating buildings will be limited to 55-60 (kWh/(m²year)). The calculations show that such measures will result in a reduction of total air pollutant emissions from households due to the reduction of energy demand for heating of dwellings from about 30% to about 67%, depending on the type of pollution.

1. Introduction
Given the high dependence of the modern world on various forms of energy, the depletion of conventional energy resources and the environmental impact of their processing, the efficient use of energy should be the subject of special measures.

In the European Union, legislative foundations have already been created to take appropriate actions in the form of binding provisions on the need to achieve, by 2020, all EU countries, objectives that are conventionally 3 x 20.

These goals were agreed at the European Council summit in March 2007 and they are:
- reducing CO2 emissions by 20%,
- increasing the share of energy from renewable sources to 20%,
- increasing energy efficiency by 20%.

Recent years have seen two dominant and interdependent trends in the discussion of economic development problems:
- increase in demand for energy resulting from development with simultaneous depletion of non-renewable fuels and searching for sources to meet the growing needs,
- emission of pollutants and their impact on climate change.
The presence of these thematic currents in a broad debate led the author to carry out considerations and author’s simplified quantitative analyses, limited to residential buildings and households. The quantitative analysis was made on the basis of GUS statistical data referring to 2011, when the last National Census was conducted, which were subject to transformations to the form desired by the author. Their partial results in terms of reducing the emission of pollutants into the air as a result of a possible reduction of energy consumption for heating buildings are presented in this paper.

2. Emission of pollutants into the air
Another important aspect of the production of energy from non-renewable fuels using conventional energy technologies is also related to the subject of improving energy efficiency. This aspect is the emission of pollutants into the air. The issue sometimes even seems to dominate over energy efficiency, which is not fully justified in the context of a very broad interdependency.

In the EU, ambitious rules have been set to reduce pollutant emissions. This situation, due to the monoculture of coal in the Polish economy, sets additional difficult goals and tasks for our country. According to the author, these targets are too high in terms of the time of implementation due to the economic and technical tasks necessary to reduce \( \text{CO}_2 \) emissions into the air which is maintained in Poland at the level of 300 million tones / year (GUS. Information Portal. State and protection of the environment 2016) [1].

There is no doubt that efforts should be made in this direction. However, it is important to quantitative and qualitative manner determine the scope of activities undertaken this route. According to the author, the set emission limits will probably not be met by the use of eco-efficient energy technologies alone, and some opportunities in this respect arise while saving energy and reducing energy consumption (fig. 1 and 2).

![Figure 1. Carbon dioxide \( \text{CO}_2 \) reduction potentials [2]](image-url)
3. Energy consumptions in buildings

The search for the largest opportunities in the use of energy efficient and effective should focus where there is the highest energy consumption. The subsector of buildings with the majority share of residential buildings plays the dominant role here. It is one of the main consumers of energy in the modern economies of developed countries, and above all in the operation phase of these facilities. On average, buildings account for approximately 41% of the total energy consumption in the European Union, which also translates into the emission of hundreds of millions of tons of CO2 [3,4].

Due to a large share in the total energy consumption, the buildings sub-sector has a significant potential to reduce the energy intensity of building operation, increase the share of RES, and thus significantly reduce emission of, inter alia, CO2 (Fig. 3).

The quoted data only strengthen the thesis that reducing energy consumption in buildings is very important for rational energy management and reducing emissions of pollutants into the air. Residential buildings (the largest functional group of buildings) play a dominant role in this process and have therefore been the subject of particular attention by the author of this publication. Considerations and analyses carried out later in this paper refer to the year 2011 due to the fact that in that year the National Census (abbreviated to NSP 2011) was conducted.
4. Energy consumption in households

In 2011, there were 12,060,000 dwellings in occupied residential buildings (Table 1) which were used by 13,568,000 households [6,7].

Energy consumption in households (including passenger cars in operation) reached the level of 1117 PJ [8] and constituted about 27% of the national energy supply with the dominant share of heating amounting to 68.8% (Fig. 4) [8].

“In terms of volume, solid coal fuels and district heating, which is also produced from these fuels in approx. 75%, played a leading role in space heating” [8]. It should be added that the production of network heat is based in about 75% also on solid coal fuels [8]. Natural gas was the third most used energy carrier. However, only 9.2% of households used this more environmentally friendly fuel than coal as their primary carrier [8].

Figure 3. Potential possibilities to reduce CO₂ emissions resulting from the exploitation of buildings [5]

Figure 4. Structure of household energy consumption by purpose [8]
5. Energy efficiency of residential buildings and reduction of air pollutant emissions

The analysis of the possibilities to reduce the energy consumption for heating residential buildings and pollutant emissions inherent thereto in relation to the energy use objectives of buildings clearly shows the greatest potential for measures taken in the scope of space heating.

**Table 1.** Reduction of energy consumption for heating buildings and flats built in Poland at various times as a result of reduced unit energy demand for heating up to: 60 kWh/(m²·year) for single family buildings, 55 kWh/(m²·year) for multi-family buildings (own elaboration based on [6,7,8,10]).

| The construction period | Energy demand for heating before reduction (kWh/(m²·year)) | Energy demand for heating after reduction (kWh/(m²·year)) | Reduction of energy demand for heating (kWh/(m²·year)) |
|------------------------|----------------------------------------------------------|----------------------------------------------------------|------------------------------------------------------|
|                        | in single-family buildings | in multi-family buildings | in single-family buildings | in multi-family buildings | in single-family buildings | in multi-family buildings |
| before 1918            | 367.66                     | 264.31                    | 60                         | 55                       | 307.66                     | 209.31                    |
| 1918-1944             | 306.10                     | 191.31                    | 60                         | 55                       | 246.10                     | 136.31                    |
| 1945-1970             | 265.22                     | 172.74                    | 60                         | 55                       | 205.22                     | 117.74                    |
| 1971-1988             | 230.25                     | 156.52                    | 60                         | 55                       | 170.25                     | 101.52                    |
| 1989-2010             | 183.36                     | 125.67                    | 60                         | 55                       | 123.36                     | 70.67                     |

Such measures in existing housing may be carried out:
- in terms of (“quantitative”) reduction of energy demand for space heating by adjusting it to future heat and energy requirements,
- in the scope of (“qualitative”) reduction or elimination of emissivity of sources of power generation for heating. This can be achieved by using appropriately cleaner technologies and fuels or by introducing on a large scale renewable energy sources which can be used in our climatic conditions to heat buildings. Such activities contribute to the reduction of the emission of pollutants into the air while limiting the consumption of primary energy for heating. However, they do not affect the final energy consumption
- by optimally combining the activities mentioned above in an optimal way.

In the following, the results of the quantitative analysis of the potential to reduce the energy demand for heating residential buildings are presented by their adaptation to the level 60 kWh/(m²·year) and 55kWh/m²·year), respectively for multi-family and single-family buildings used in Poland in 2011 (Table 1).

In the next step, a percentage reduction of the total energy demand for heating of the buildings under consideration was assumed at the calculated average level of 72.29% (Table 2). This value allowed for a simplified calculation of the reduction of emissions of selected pollutants to the air as a result of the reduction of energy demand for heating buildings by raising their energy standard. For the calculations, a simplified assumption was made that the percentage reductions in energy demand and pollutant emissions were equal. The calculations were carried out starting from the elaboration of the obtained data concerning the emission of selected pollutants to the air from heating and total in households, and ending with their percentage reduction resulting from the previously calculated reduction of energy demand for heating. Due to editorial limitations, Table 3 and 4 presents only the results of the last stage of calculations for households in 2011 in the form of reduction of the types of emissions to the air considered in the work as a result of reduction of energy demand for heating.
Table 2. Reduction of energy consumption for heating buildings and flats built in Poland at various times as a result of reduced unit energy demand for heating up to: 60 kWh/(m²/year) for single family buildings, 55 kWh/(m²/year) for multi-family buildings (own elaboration based on [6,7,8,10]).

| The construction period | Reduction of total energy consumption for heating (TWh/year) | Reduction of total energy consumption for heating (%/year) |
|-------------------------|-------------------------------------------------------------|----------------------------------------------------------|
|                         | Reduction in single-family buildings | Reduction in multi-family buildings | Reduction in single-family buildings | Reduction in multi-family buildings | Reduction in single-family buildings | Reduction in multi-family buildings |
| before 1918              | 11.72 | 6.34 | 18.05 | 83.7 | 79.2 | 82.05 |
| 1918-1944               | 12.86 | 5.70 | 18.56 | 80.4 | 71.3 | 77.35 |
| 1945-1970               | 20.89 | 9.54 | 30.43 | 77.4 | 68.2 | 74.23 |
| 1971-1988               | 27.36 | 12.97 | 40.33 | 73.9 | 64.9 | 70.76 |
| 1989-2011               | 16.15 | 7.31 | 23.46 | 67.3 | 56.2 | 63.40 |
| TOTAL (AVERAGE)         | 88.98 | 41.86 | 130.84 | (75.4) | (66.4) | (72.29) |

Table 3. Annual air pollutant emissions from the heating and the total in households (own elaboration based on [11,12])

| Specification of emission | Air pollutant emissions from household heating (thousand tons) | Air pollutant emissions from household (thousand tons) | Total air pollutant emissions in Poland (thousand tons) |
|--------------------------|---------------------------------------------------------------|------------------------------------------------------|-------------------------------------------------------|
| AIR EMISSIONS FOR GREENHOUSE GAS EXPRESSED CARBON DIOXIDE EQUIVALENT | | | |
| Emission of carbon dioxide CO₂ | 49440.568 | 62566.758 | 330309 |
| Emissions of nitrous oxide | 280.575 | 435.758 | 27241 |
| Emissions of methane | 2538.768 | 2572.661 | 35538 |

AIR EMISSION OF SELECTED POLLUTANTS

| Emissions of nitrogen oxides NOₓ | 67.506 | 117.448 | 851 |
| Emission of sulfur oxides SOₓ | 219.180 | 219.180 | 910 |
| Emissions of ammonia NH₃ | 0.510 | 0.819 | 270 |
| Emission of non-methane volatile organic compounds | 102.769 | 229.456 | 652 |
| Emission of carbon monoxide CO | 1622.308 | 1873.686 | 2916 |
| Dust emission PM₁₀ | 103.756 | 109.877 | 245 |
| Dust emission PM₂,₅ | 61.348 | 66.813 | 151 |
| Emission of total suspended dust | 141.360 | x | 414 |
| Emission of dioxins and furans, i-TEQ | 134.9 | x | 269 |
| Emissions of hexachlorobenzene (HCB) | 2.8 | x | 14 |
| Emission of polychlorinated biphenyls (PCB) | 0.0004353 | x | 0.0007246 |
| Emission of polycyclic aromatic hydrocarbons | 0.1230266 | x | 0.1437719 |
Table 4. Annual reduction of air pollutant emissions from the heating and the total in households (own elaboration based on [11,12])

| Specification of emission                                      | Reduction of air pollutant emissions from household due to reduction of energy demand for heating in households (thousand tons) | Reduction of air pollutant emissions from household due to reduction of energy demand in relation to air pollutant emissions from household (%) | Reduction of air pollutant emissions from household due to reduction of energy demand for heating in relation to total air pollutant emissions in Poland (%) |
|---------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| AIR EMISSIONS FOR GREENHOUSE GAS EXPRESSED CARBON DIOXIDE EQUIVALENT |                                                                                                                                 |                                                                                                                                 |                                                                                                                                 |
| Emission of carbon dioxide CO$_2$                            | 35738.35                                                                                                           | 53.33                                                                                                                                 | 10.82                                                                                                                                 |
| Emissions of nitrous oxide                                    | 202.81                                                                                                             | 43.45                                                                                                                                 | 0.74                                                                                                                                 |
| Emissions of methane                                          | 1835.16                                                                                                             | 66.60                                                                                                                                 | 5.16                                                                                                                                 |
| TOTAL                                                         | 37776.33                                                                                                             | x                                                                                                                                 | x                                                                                                                                 |
| AIR EMISSION OF SELECTED POLLUTANTS                          |                                                                                                                                 |                                                                                                                                 |                                                                                                                                 |
| Emissions of nitrogen oxides NO$_x$                          | 45.56                                                                                                               | 41.55                                                                                                                                 | 5.74                                                                                                                                 |
| Emission of sulfur oxides SO$_x$                              | 147.92                                                                                                               | 72.29                                                                                                                                 | 17.41                                                                                                                                 |
| Emissions of ammonia NH$_3$                                   | 0.34                                                                                                                 | 45.03                                                                                                                                 | 0.14                                                                                                                                 |
| Emission of non-methane volatile organic compounds            | 69.36                                                                                                               | 32.38                                                                                                                                 | 11.39                                                                                                                                 |
| Emission of carbon monoxide CO                                | 1094.89                                                                                                              | 62.59                                                                                                                                 | 40.22                                                                                                                                 |
| Dust emission PM$_{10}$                                      | 70.02                                                                                                                | 68.26                                                                                                                                 | 30.58                                                                                                                                 |
| Dust emission PM$_{2,5}$                                     | 41.40                                                                                                                | 66.37                                                                                                                                 | 29.29                                                                                                                                 |
| Emission of total suspended dust                              | 95.40                                                                                                                | x                                                                                                                                 | 24.69                                                                                                                                 |
| Emission of dioxins and furans, i-TEQ                         | 91.04                                                                                                                | x                                                                                                                                 | 36.25                                                                                                                                 |
| Emis. of hexachlorobenzene (HCB)                             | 1.89                                                                                                                 | x                                                                                                                                 | 14.88                                                                                                                                 |
| Emis. of polychlorinated biphenyls (PCB)                      | 0.000315                                                                                                             | x                                                                                                                                 | 43.43                                                                                                                                 |
| Emission of polycyclic aromatic hydrocarbons                  | 0.08                                                                                                                 | x                                                                                                                                 | 61.86                                                                                                                                 |
| TOTAL                                                         | 1775.74                                                                                                              | x                                                                                                                                 | x                                                                                                                                 |

6. Summary
The potential for energy savings in buildings (mainly residential) is estimated at: 33-60% for improving thermal insulation of walls, 16-21% for modernizing ventilation system, 14-20% for improving thermal insulation of transparent partitions, 10-12% for regular inspection and repairs of central heating boilers, 50-80% for modernizing hot water production system with the use of RES [13]. The calculations show that as a result of adjusting the energy demand for heating in residential buildings to the level of 50-60 kWh (m$^2$/a year) (based on the requirements in force in Poland since 2021), the demand in existing residential buildings may be reduced by an average of approx. 67% as compared to the situation in 2011.

At the same time, such measures will reduce the overall emissions of air pollutants from households due to the reduction of energy demand for heating of dwellings from about 30% to about 67% (Table 3 and 4), depending on the type of pollutant. In the scale of the whole country, this will
reduce the air pollutant emissions considered in this paper from about 0.7% to about 62% (Table 3 and 4) in comparison to the national emissions of these pollutants in 2011. It should also be noted that the low percentage reduction for domestic emissions is mainly due to the low share of these household emissions in the total Polish air emissions account.

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