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Carbon dioxide emission while heating in selected European countries

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ABSTRACT

Carbon dioxide emissions during the application of the heat pump in selected European countries for one hundred years are estimated. These emissions were calculated including the source of the electrical energy. The highest emissions are in Macedonia and Poland, where coal and lignite are the major sources of electrical energy. The lowest emissions are in Norway, where the major portion of the electricity is produced from renewable resources. The highest emissions are forty times higher than the lowest emissions, so the heat pump can be named a "green" heat source only in those countries where electrical energy is produced from hydropower or nuclear power plants. The methodology to calculate the critical value of the average generation factor for power plants, from which the heat pump causes lower carbon dioxide emissions, was developed. As an example, the calculations were performed for the ground heat pump, gas condensing boiler, and the oil boiler. In conclusion, for the countries where solid fuel is major source of electricity, heat pumps should not be applied. Instead, condensing gas boilers should be used.

1. Introduction

A rise in the average temperature has been observed since the midpoint of the twentieth century. Greenhouses gases (methane, carbon dioxide, water vapour, ozone, nitrous oxide, halogenated hydrocarbons, etc.) are suspected to be the source of this effect (named global warming). These gases are emitted from natural or anthropogenic sources. Common natural sources are biological flora and fauna activity, volcano eruptions, and forests fires. Anthropogenic sources are fossil fuel combustion, deforestation, cement production, and other processes involving carbonates.

According to actual hypothesis, 9–26% of the greenhouse effect is caused by carbon dioxide. The Keeling Curve shows the amount of carbon dioxide measured at Mauna Loa Observatory (Hawaii). The concentration of this carbon dioxide gas grows continuously (from 313 ppm in 1960 to 385 ppm in 2010) [1].

In Kyoto, on 11 December, 1997, thirty-seven countries adopted a protocol to limit the greenhouse effect (the protocol was ratified by Poland on 2 December 2002). These thirty-seven countries committed themselves to reduce emissions of six of the greenhouse gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. Following this agreement, internal actions were taken in these countries.

The Chinese State Council determined 10% to be the target reduction in gaseous contaminants in years 2007–2010. In particular, Ding et al. [2] determined that finding new schemes and retrofits for air-conditioning systems in industry can redound to emission reduction. Then, Ye et al. [3] examined the impact of different types of buildings on carbon dioxide emissions caused by energy consumption in urban homes. They claimed that using suitable material for walls and windows can reduce energy consumption. Older buildings have greater UHEUCE (urban home energy usage carbon emission) because they have poorer thermal insulation than younger ones. In places where summers are hot and sunny, buildings with external transparent windows also have larger UHEUCE caused by using large quantities of energy for cooling [3]. Efforts to reduce this emission were made in Korea. Energy consumption in shopping mall complexes can be reduced by applying the economiser in the air handling unit and in the heating, ventilation, and air conditioning systems. They can also be reduced by using condensing boilers and an optimal range for external lighting, cf. Park and Hong [4].

As Suzuki and Tatsuo [5] showed, varying stages of housing construction redound to carbon dioxide emissions. For example, in Japan, carbon dioxide emissions equal 850 kg/m^2 for an SRC multi-family house, 400 kg/m^2 for a lightweight steel-structure single-family house and 250 kg/m^2 for a wooden single-family house. Office buildings also share in this phenomenon. Based on calculations made for Japanese office buildings, Suzuki et al. [6]

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estimated carbon dioxide emissions for the entire life cycle (including construction, operation, maintenance, renovation). These emissions are equal to 4430 kg/m^2. As Rosas-Flores et al. [7] calculated, replacing refrigerators and air conditioners will reduce energy consumption, which consequently leads to cuts in carbon dioxide emissions by 15,087 Tg CO_2.

The European Union decided to cut greenhouse gas emissions by at least 20% of the 1990 levels by the year 2020. Jenkins et al. [8] analysed the decrease in CO_2 emissions caused by office buildings in the UK. This lower emission was caused by refurbishment of electrical equipment and lighting. The predicted climate change would cause unnoticeably lower carbon dioxide emissions. Thermo-modernisation would cause another decrease in these emissions. These changes should be followed by ventilation heat recovery. This modernisation of the facilities could be extended by an empirical formula for thermal comfort, which would decrease the demand for cooling energy. The formula for thermal comfort (cf. Eq. (1) in the work [8]) is based on outside temperature. Gladyszewska-Fiedoruk [9] claims energy consumption can be reduced by modernisation and proper usage of stack ventilation. Ferrantea and Cascella [10] concluded that it is possible to achieve a zero energy balance and zero on-site CO_2 emissions from houses in the Mediterranean climate. However, the unit total real heat consumption, calculated for heating demand only, equals 30.6 kWh/(m^2 a) in Greece and other countries in southern Europe and 621.4 kWh/(m^2 a) in Poland and other countries in the northern part of the continent (cf. Wichowski [11]). Because the unit heat consumption in Mediterranean regions is over 20 times lower than in countries with a more severe climate, the zero energy balance for buildings could not be achieved in the northern countries. Moreover, the heat transfer through the walls is much lower than the heat demand for heat-ventilated air in well-insulated buildings (cf. Romanowicz [12]).

For that reason, other ways to reduce carbon dioxide emissions by 20% should be found. To fulfil the Kyoto Protocol as well as "Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings", the National Fund for Environmental Protection and Water Management in Poland (NFOSiGW abbr. in Polish) implemented the GIS Programme [13], the source of the funds for thermal modernisation. These financial resources can also be expended for the use of technology for renewable energy sources, e.g. particularly heat pump installation or solar systems [14]. However, this directive (in Article 5) ensures that the technical, environmental, and economic feasibility of heat pump installation should be considered before construction starts. Moreover, Directive 2009/28/EC promotes only those heat pumps that provide that the final energy output significantly exceeds the primary energy input required to drive the heat pumps (cf. Article 5).

Heat pump seems to be a "green" heat generator because it uses mainly renewable sources of heat or even waste heat and it produces no the carbon dioxide directly. However, heat pump needs electrical energy which production causes carbon dioxide emissions. Ossebaard et al. [15] analysed six different sources of electricity and heat (including domestic water heat). Four parameters were calculated: exergy, costs, NO_x emissions, and CO_2 emissions avoided. Avoided CO_2 emissions were calculated in comparison with separate production for heat and electricity supplied by the reference system. This system consisted of a condensing boiler for heat production and large-scale combined cycle for electricity production. Avoided CO_2 emissions were calculated at 12.6% in 1993, 13.8% in 2010 and 15.6% in 2030.

Brenn et al. [16] analysed carbon dioxide emissions from heat pumps in Switzerland driven specifically by natural gas or electricity. If the electrical grid in the Swiss Confederation is the source of electrical energy, the electricity-driven heat pump will emit the lowest amount of CO_2. If the energy was imported, better solution could be a natural gas-driven heat pump or an electricity-driven heat pump powered from a combined plant cycle where natural gas is the primary fuel.

Soimakallio et al. [17] analysed greenhouse gas emissions in life cycle assessment in detail. The analysis of this subject was divided into two categories: attributional and consequential. The paper showed the method of analysis and indicated the uncertainties associated with the analysis. The authors claimed that not only did the technology applied in power plants and primary fuels used in power plants has an important influence on CO_2 emission, but they also said that other factors (e.g. fuel transport or production of the infrastructure) must be considered. This upstream emission share can be up to 20% of the greenhouse gas emissions. Monahan and Powell [18] concluded that heat pumps in the UK are not the best solution for carbon dioxide emission reduction because of electricity. They claimed that electrical energy consumption in heating systems must be reduced. In this aspect, the best technologies are solar. Johnson [19] studied heat pumps in terms of carbon footprints. Heat pumps can be considered green heat sources if their carbon footprints are below a certain threshold. This paper claims that the use of electricity is crucial as is the type of refrigerant and its leakage. This author concludes that heat pumps are at the same level as or worse than gas boilers and better than oil and solid fuel boilers in terms of CO_2 emissions. If the refrigerant fluid R404A is used, the carbon footprint is higher than in the case if a gas boiler. Moreover, R404A is not used as a refrigerant in the heat pumps in Europe. However, R134a contributes to the reduction of carbon footprints. The paper also shows that the production and sale of heat pump equipment is not important in the carbon footprints mentioned. In opposition, Self and colleagues [20] conclude that the geothermal heat pump emits less carbon dioxide than gas boilers in Canada.

The aim of this paper is to extend the discussion about CO_2 emissions to the selection of heat generator in a synthetic presentation. Temperature in the heating system is changed and its value depends on outdoor temperature which varies with geographical conditions, season, a time of the day, or weather. A heat pump in the investigated case needs the low voltage electrical energy. The efficiency of electrical energy transport for the low voltage supply system differs from the general efficiency of electrical energy transport published by IEA (cf. Ciura's data [37] in Section 2.2 and IEA data for Poland in Table 4). The general efficiency is greater because the efficiency of electrical energy transport for the high voltage electrical energy is greater than in the low voltage system (cf. Ciura [37]). For those reasons, the analytical attitude requires detailed information for each country. Temperature distribution in heating system and efficiency of electrical energy transport are only examples of the complexity of the investigated issue.

In this paper, the emissions will be estimated for some European countries. The estimation includes the direct emissions as well as emissions caused by production of electrical energy that is supporting the heat source. The emissions depend on both the heat source and the type of fuel burnt in the power plants.

2. Calculations and discussion

The selected countries range in latitude approximately from 35° N (Greece) to 71° N (Norway). There are therefore significant differences in climate. For that reason, the heat sources should be selected separately for each country. However, if this approach were chosen, the effects on carbon dioxide emissions could not be compared, and general conclusions could not be obtained from those calculations. Another approach is the selection of one heat source for the average conditions and comparison of the