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Energy consumption of non-retrofitted institutional building stock in Luxembourg and the potential for a cost-efficient retrofit

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ABSTRACT

The public building stock of a country, consisting of schools, offices, accommodation facilities, single- and multi-family homes, accounts for a high consumption of electrical and heat energy. Therefore, this stock is often subject to actions with the goal of lowering this energy usage by increasing the efficiency of those buildings. This is usually done by applying measures to the building envelope like insulation and/or new windows and by using a more efficient HVAC technology. But often, in the initial state, the current energy consumption of such a stock is unknown or only known for single buildings. In this case, the calculation of energy and cost savings is either impossible or not exact. This paper shows a way to quantify and categorize the end-energy for heat use of the public building stock in Luxembourg, which consists of a gross area of 1.744 million m^2. This analysis was carried out in cooperation with the national administration of public buildings.

A certain amount of sample buildings was analyzed and then separated into three groups of low, normal and high end-energy use. The boundaries of these groups were chosen according to literature values, derived from European retrofit projects, which also served as the source for possible renovation costs. This data was extrapolated to the whole stock. This information serves as a basis for future decisions concerning the retrofit of those buildings and makes a calculation of costs possible.

As a result, the type of buildings with the highest potential for retrofit measures was identified. Schools, offices and accommodation facilities with a "high" consumption of more than 190 kWh/(m^2a) show the highest economic potential with retrofit costs of 0.04–0.08 €/kWh if their energy consumption is lowered to values of around 90–100 kWh. Other groups of buildings show higher costs of around 0.07–0.19 €/kWh.

1. Introduction

In the national energy efficiency plan of Luxembourg [1], the retrofitting of old buildings plays an important role. Especially the big stock of institutional buildings, built before the first national energy regulation for buildings in 1995 [2], shows a big potential to lower its energy consumption. The stock consists of single- and multi-family homes, schools, commercial buildings and accommodation facilities. In order to develop retrofit strategies, the end-energy consumption has to be determined and interpreted in reference to the heated gross area. Since for those buildings there was no data available concerning the heated gross area, the building age distribution and the energy demand, the analysis is based on a number of sample buildings, for which these parameters were either known or measured on site. With this data, an extrapolation to the totality of the public buildings is achieved and an estimation of the condition of the public building stock in Luxembourg becomes possible. These values are compared to the results of a literature study of different European publications, in which the end-energy use of different building types and stocks are presented. Hereinafter, all mentioned area data is defined as gross area (external). If there was another reference area used in the European studies, the values were translated according to the geometrical data available in those studies. If only the net area was known, a factor of 1.25 was used to calculate the gross area.

2. Literature study

2.1. Single- and multi-family homes

In a data collection of [3] it is shown, that in the class of buildings constructed in Germany between 1919 an 1978, the end-energy use of non-retrofitted single-family homes is more or less identical and the average value is 195 kWh/(m^2a). After the

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oil crisis and the new German thermal insulation regulation in 1977, the average value decreased to 144 kWh/(m^{2}a) in the period between 1979 and 1987, while newer buildings after 2002 consume only 78 kWh/(m^{2}a). The same situation applies to Luxembourg, where buildings built before the year 1970 show an average value between 185 kWh/(m^{2}a) [4] and 195 kWh/(m^{2}a) [5]. Newer buildings after 2000 show lower values between 95 kWh/(m^{2}a) [5] and 122 kWh/(m^{2}a) [4]. Buildings, built after 2000 with focus on energy efficiency showed even lower average values of 73 kWh/(m^{2}a) [6]. Thus, by retrofitting, the saving potential for old buildings lies between 60 and 120 kWh/(m^{2}a). For multi-family homes the situation is similar. According to [3], buildings before 1978 which haven't been retrofitted show an average end-energy consumption of 158 kWh/(m^{2}a). Residences in Slovenia [7], Switzerland and Denmark [8] show similar energy consumptions. Old buildings in France and the Netherlands show slightly higher average values of around 210 kWh/(m^{2}a). In Luxembourg, multi-family homes until 1970 show values between 140 kWh/(m^{2}a) [5] and 151 kWh/(m^{2}a) [4]. Again, old buildings until 1970 did not show any decreases of the end-energy consumption throughout the construction years from 1918 to 1970. Newer buildings after the year 2000 show average values between 100 kWh/(m^{2}a) [4] and 128 kWh/(m^{2}a) [5]. In Germany, new multi-family homes after 2002 show even lower values with an average of 82 kWh/(m^{2}a) [3].

2.2. Commercial buildings

There exist several databases in Germany about the end-energy use of commercial buildings, but without distinguishing between the construction years. According to [9], the average value across all building ages is 128 kWh/(m^{2}a) which corresponds to the average value of the category of "low-technological buildings" of another German study [10]. Bulgarian and Luxembourgish buildings show similar average values of around 130 kWh/(m^{2}a) [7], while the average value for "low-technological buildings" in Luxembourg is 56 kWh/(m^{2}a) [11]. The more complex the technology in a building, the more likely is a consumption of electrical end-energy of more than 100 kWh/(m^{2}a) [12]. To lower the end-energy use of commercial buildings, it seems, that it is crucial to lower heating and cooling loads while keeping the complexity of the technology of the building as low as possible to avoid a replacement of heating energy with electrical energy, resulting in high primary energy values [10].

2.3. Schools

Like for commercial buildings, there exist several studies for the end-energy use of schools in Europe, unfortunately again not distinguishing between the construction years. The average values of three studies in Germany vary widely. While the schools in [9] show an average end-energy use for heating of 120 kWh/(m^{2}a), which is close to the average values of new Luxembourgish schools of 113 kWh/(m^{2}a) [11,13] calculates a value of 211 kWh/(m^{2}a) and [10] calculates a value of 160 kWh/(m^{2}a). A British study showed an average value of 175 kWh/(m^{2}a) [14]. Even if those values are average values across all building ages, a saving potential between 45 and 100 kWh/(m^{2}a) compared to the level of new Luxembourgish schools can be assumed. Luxembourgish schools which were built according to the low-energy standard show an even lower average value of 72 kWh/(m^{2}a) [10]. The end-energy consumption of electricity is fairly low compared to those of commercial buildings with values between 14 and 30 kWh/(m^{2}a) across all studies. Nonetheless, in the case of retrofitting it is recommended to keep the complexity of technology rather low in order to avoid such effects as encountered in commercial buildings.

2.4. Accommodation facilities

According to five studies which include facilities like day-cares, nursing homes, dormitories and kindergartens, the average value lies between 160 and 220 kWh/(m^{2}a) [13,15,16]. Again, no difference was made between older and newer facilities. In more recent studies [17], the Hereinafter value decreases to about 125 kWh/(m^{2}a), which is due to the higher share of modern buildings in the sample. The end-energy use of electricity was between 20 and 30 kWh/(m^{2}a) and is only small, compared to the end-energy for heating.

2.5. Costs for retrofit

If possible, the costs for a retrofit should be refinanced by the savings of energy costs. One way to lower the heat demand of a building, is to lower the transmission losses by applying an insulation to the building envelope. The optimal thickness of this insulation layer depends on assumptions and the current state of the building. When short calculation times are assumed, the optimum lies between 6 and 9 cm [17–19]. When longer time periods are considered, the optimum is between 10 and 20 cm. If there are any actions to be taken anyhow, like a retrofit of the plaster, an insulation of the envelope becomes more attractive and an insulation thickness of over 20 cm is economically valuable [19]. Unfortunately, other construction parts have longer lifetimes than plaster, so not every retrofit can be coupled with other actions. Nonetheless, the insulation of the upper floor ceiling and basement ceiling in most cases is economically worthwhile, even if full costs are considered [17,20]. Other possible actions are the renewal of the heating system, e.g. the replacement of old boilers with condensing boilers, or the replacement of old single-glazed windows with multiple-glazed windows, whose frames are also more airtight. According to a study by [21], the retrofit of single-family homes with an end-energy demand of 230 kWh/(m^{2}a) to a demand of 85 kWh/(m^{2}a) can be economically feasible. This retrofit includes the insulation of the facade, the upper floor ceiling and basement ceiling, as well as the replacement of the old boiler with a condensing one. A change of windows, even if a replacement of windows is necessary because of other reasons, is almost never worthwhile [21,22]. In a Belgian study, the insulation of the upper floor ceiling is considered to be the most economical action, followed by the insulation of the basement ceiling and a replacement of the boiler, while the insulation of the facade and the change of windows do not show any economical potential [23]. The reason for this contradictory statement concerning the insulation of the facade could be, that [21] combined the action and costs with a renewal of the plaster, while [23] considered full costs for the insulation. In a study of [24], single-family homes were retrofitted. Starting with an end-energy use of 199 kWh/(m^{2}a) for all buildings, a reduction to 46 kWh/(m^{2}a) for a cost of 245 €/m^2 (standard insulation, double-glazed windows, no mechanical ventilation), a reduction to 47 kWh/(m^{2}a) for a cost of 288 €/m^2 (thicker insulation, exhaust ventilation system) and a reduction to 36 kWh/(m^{2}a) for a cost of 334 €/m^2 (thicker insulation, triple-glazed windows, ventilation system with heat recovery) were achieved. As for the primary energy, the buildings are on the same level, due to the electricity use of the ventilation system in the third building. Despite different efforts to retrofit, the result was more or less the same. Of course, the influence of the user has to be considered, which can be assumed as about one third of the possible deviation from the average value [5]. [25] takes a look on multi-family buildings, which were retrofitted between 1995 and 1997. The actions included 12 cm of insulation of the facades, 8–16 cm of insulation of the upper floor ceilings and double-glazed windows. By these actions, the initial end-energy use between 140 and 173 kWh/(m^{2}a)