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Field study on the energy consumption of school buildings in Luxembourg

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ABSTRACT

Buildings account for 40% of total energy consumption and 35% of the total CO_2 emitted in the EU. In consequence, there is an enormous energy saving potential and the European Union requires from all EU member states to save energy in this sector. Hence, reducing the energy consumption of buildings represents an essential component of environmental protection efforts. Furthermore, the new European directive 2010/31/EU requires that the member states tighten national standards and draw up national plans to increase the number of “nearly zero-energy buildings”. Well-planned energy-saving strategies presume knowledge of specific characteristics of the current national building stock. Therefore, the implementation of a process to support systematic data collection, classification and analysis of the energy consumption of buildings will become increasingly important during the coming years.

In the field study described below we analyzed the energy consumption of 68 school buildings in Luxembourg. A separate collation of electricity and heat energy consumptions allowed to make a detailed analysis of specific energy parameters. Clustered according to energy sources, the new buildings were analyzed from a statistical point of view. We defined the energy relevant parameters such as energy standards, the purpose of use of the buildings or whether they had canteens.

1. Introduction

The Kyoto protocol adopted in 1997 [1] was aimed at fighting the constant increase in worldwide energy consumption and, as a result, the increase in greenhouse gas emissions. The leading industrial countries committed to reduce their annual greenhouse gas emissions by an average of 5% for the period 2008–2010. As buildings account for more than one third of total energy consumption in the European Union and have an enormous energy-saving potential, the EU directive [2] sets national binding targets for CO_2 reductions. Saving energy in the building sector is therefore a central key-point with regard to climate protection.

During recent years the distribution per sector of Luxembourg’s energy consumption shifted noticeably in favor of the building sector. In 1990, 71% of the total domestic end energy consumption was ascribed to the industrial sector and only 20% to the building sector. The distribution has changed significantly since then and in 2005 the industrial sector contributed only 44% to the national energy consumption while transport and the tertiary sector (incl. private and public households as well as non-residential buildings) accounted for 25% and 31% [3], respectively.

Hence, a non-existent database with the most important benchmarks of the various building types is necessary to define the exact saving potential of the whole Luxembourg building sector. So, the aim and most important research activity were to collect energy values of buildings in order to compile a representative database and make a statistical evaluation. This paper presents the results of the benchmark study for newer schools in Luxembourg and illustrates that, contrary to common expectations, the primary energy consumption of new buildings has increased in recent years as a result of the increased electricity consumption.

2. Energy benchmarks of schools in European countries

In order to rate the energy performance of a building, it must be compared to many other same-category buildings. Therefore, the first step is to establish a database. Many countries already have such benchmark studies of school buildings [17–25].

The deviations between countries are mostly not significant as they are used for the same purpose, i.e. education. In most cases,

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the average heat consumption is about 100 kWh/(m^2a). Santamouris [25] analyzed 320 school buildings from different regions in Greece, concluding that the average heating energy consumption is of 68 kWh/(m^2a) and that 25% of all Greek school buildings boasting the lowest values consume less than 32 kWh/(m^2a). However, a study by the German Fraunhofer Institute [18] determined a maximum average value of 211 kWh/(m^2a). In contrast, another German study [17] provided very different results. This can be explained, on the one hand, with the sample size ([17] is higher by a factor of ten than the sample size of the Fraunhofer study [18]), and, on the other, with the selection of the buildings (only energy-efficient buildings or a large range of building types). This example shows that many conclusions on energy consumption need to be regarded with caution. Therefore, benchmark analysis is always necessary in order to know which types of buildings and which boundary conditions (heating degree days, floor area, etc.) were used.

According to the existing European benchmark studies [17–25], the electricity consumption values of schools vary from 10 to 30 kWh/(m^2a). The minimum value of 10 kWh/(m^2a) found in German primary schools [17] can be explained by the very low level of technical equipment and the fact that here artificial light uses the majority of the energy.

With regard to energy consumption in schools, British studies analyzed the dependence of special-use areas (e.g. cafeteria) and found that consumption increases by up to 7–10%. Energy consumption is likely to increase by even as much as 20% if a gym is taken into consideration when calculating a building's energy consumption [10].

Finally, the various European countries show no significant differences regarding average thermal as well as electricity consumption. Thus, it will be interesting to see how the energy consumption of new Luxembourg schools fit into this set of benchmarks.

3. Analysis of the buildings included in the sample

3.1. Description of the building sample

The following sample includes educational buildings that were constructed, extended or completely renovated after 1996. This year was defined as a threshold because at that time the first thermal insulation regulation in Luxembourg, based on limited *U*-values, came into effect. This remained to be the reference regulation in Luxembourg until the new energy-efficiency regulation for non-residential buildings [4] came into effect on January 1st, 2011. The sampled objects have a total heated gross area of approximately 400,000 m^2. The buildings were classified into four different groups depending on the type of use (see Fig. 1):

- preschools including daycare centers
- primary schools
- secondary schools (high schools)
- gyms

There are 49 secondary schools in Luxembourg. However, this number does not reveal the actual total quantity of existing buildings as some schools have more than one building. Buildings classified as "new" were constructed or renovated after 1996, resulting in 16 "new" secondary school buildings in Luxembourg. Twelve of these buildings were analyzed for this field study, representing 75% of the total population and allowing significant conclusions to be drawn.

The primary and pre-school buildings are similar with respect to the nature of their use and represent the second largest group of educational buildings. In a study [5] conducted by the

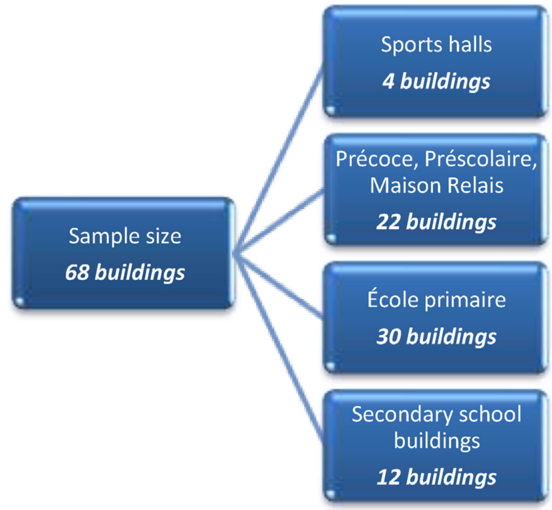

Fig. 1. Quantities of school buildings collected in Luxembourg.

Ministry of Education in 2008/2009, there was a total of 452 school buildings falling into this category in Luxembourg. Based on information received from the relevant municipalities in Luxembourg, 91 of these buildings can be classified as new objects (year of construction after 1996). Of these 91 school buildings we analyzed the energy consumption of 52 buildings in this study. These represented 55% of the population and consequently provided a representative sample.

3.2. Definition of the reference values

To compare the energy consumptions measured in the various buildings, the most common benchmarking metric used in the energy sector is based on the gross heated floor area (including the exterior walls) [17,26,27]. Furthermore, the climatic boundaries must be specified to neutralize the effect of weather conditions. The thermal end energy consumption of each building collected during this study was altered, based on the average climatic conditions in Luxembourg. In doing so, the portion of thermal end energy, which is dependent on weather conditions, was adjusted to the average climate conditions in Luxembourg with the help of $HDD_{20/15}$:

$$E_{Vhb} = E_{hb} \times \frac{HDD_{20/15\mathrm{m}}}{HDD_{20/15\mathrm{m}}} \quad (1)$$

where E_{Vhb} is the normalized thermal end energy consumption of a building relative to average climate conditions, E_{hb} is the measured thermal end energy consumption of a building, $HDD_{20/15\mathrm{m}}$ is the average heating degree days in Luxembourg for the period 1995–2009 (3560 Kd/a) and $HDD_{20/15}$ is the heating degree days of the period analyzed.

3.3. Thermal end energy consumption

The thermal end energy consumption will become less important in the coming years when compared to the total primary energy consumption of a building. Fig. 2 shows the heating consumption, including the domestic hot water supply, of 68 objects with reference to the heated gross area. The different colors represent the various energy sources used to heat the building. The mean value is 93 kWh/(m^2a) and therefore significantly lower than the energy consumption of single family houses (131 kWh/(m^2a)) [6]. Some of the buildings analyzed use district heat as an energy source. Thus, the generation and storage losses are not included in the measured energy consumptions of these school buildings. The