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ENERGY SAVING POTENTIAL OF SOCIO-TECHNICAL INTERVENTIONS IN EDUCATIONAL BUILDINGS

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Abstract

Following the geopolitical crisis in fall 2022, a shortfall of fossil fuels was feared, leading many buildings to saved energy by reducing indoor temperatures, disregarding comfort. To address this conflict, we started to analyse the saving potential of socio-technical interventions without major renovation and without comfort reduction. Four educational buildings were selected as pilots due to their great outreach and dissemination potential. This objective requires involvement and participation of the complex chain of all school stakeholders. The proposed strategy combines a participatory energy- and comfort-monitoring approach with analyses of the building specificities, to define reduced operational modus during absence periods.

Introduction

Operations of buildings account for 30% of global final energy consumption (Eurostat, 2023) and 26% of global energy-related carbon emissions (IEA, 2023). In Europe, educational buildings count for 6.5% of the overall floor area and 16% of the non-residential buildings (BSO, 2023). Therefore, schools can contribute significantly to reducing energy consumption of the existing building stock. Furthermore, as stated in the Energy Performance of Buildings Directive (2010) public buildings should set the example due to their great outreach and excellent dissemination potential, which is specially the case for schools where future citizens are educated and thus can serve as multipliers in terms of long-term impacts.

For new buildings norms and standards require high energy performance, while for existing buildings, often incentives are offered to support energetic renovations. Nonetheless, in all cases large discrepancies between predicted and real efficiency can often be detected in field studies, ref. Hoos (2013), Thewes (2014).

Despite efforts to reduce energy consumption in buildings, there remains a significant issue related to the operation of technical installations. This is caused by the different types of buildings, and it is more pronounced in the non-residential domain, where in general users have less influence on operation and maintenance. These buildings are often more complex and have typically facility managers, operating under contracts to maintain the systems working without faults and to minimize complaints from users. Therefore, many operators prioritize avoiding complaints instead of being energy efficient.

According to Techem (2023), monitoring and professional operation can increase the efficiency of conventional heating systems in residential buildings by 15%. Additionally, there is a clear correlation between energy costs and consumption, with higher costs resulting in lower consumption. Felsmann (2020) has shown an average reduction of around 20% of final consumption when energy is individually measured and billed.

Our study intends to finally explore the energy saving potential from the combination of social and technical interventions in schools. It is based on exact understanding of the individual building use and of precise adaption of operational settings to the real needs, while choosing reduced operational modes for all empty periods (night-time, weekends, and holidays). For the identification of saving opportunities and their implementation the involvement of all stakeholders is essential. Prior to the change of operational modes, a deep understanding of technical installations is necessary to give the staff the confidence to try it. Most of the time, the oversized operational modes are defined to avoid complaints from users of this building.

The interdisciplinary approach of combining social and technical interventions to reach energy savings was initiated by the NWE-Interreg ENERGE Project, that stands for “Energizing Education to Reduce Greenhouse gas Emissions”. In this project 13 post-primary schools in 6 countries of North-Western Europe (NWE) worked together to tackle this goal. Brychkov et al. (2023) proposes a systemic framework to improve energy efficiency in schools, while Doherty et al. (2022) explores the concept of learning communities to change energy behaviour.

When discussing energy consumption, very often people relate the age of the building with energy performance. However, for instance Hoos et al. (2016) stated that the final heat energy consumption does not directly correlate with year of construction due to many design and execution issues of new buildings and due to partial renovation over time of older ones. Hoos (2013) studied 60% of the older school building stock in Luxembourg to calculate the average specific yearly consumptions of heat and electricity as presented in Table 1.

Table 1: Summary of calculated mean values referred to gross floor area (GFA) (Hoos, 2013)

	Calculated mean values	Amount of sample buildings
Heated gross area	15,400 ± 4,000 m²	25
End-energy for heat use incl. hot water	161 ± 71 kWh/(m²/y)	26
End-energy for electricity	35 ± 16 kWh/(m²/y)	24

The above classification of buildings allows to evaluate their energy performance and provides an indication of energy savings opportunities. Additionally, it also allows discussions with educational purposes to stimulate and enlarge knowledge of young citizens in this field.

From the identified savings opportunities a tailored strategy to reduce energy consumption without influencing comfort can be deduced, analysed, and implemented. In this phase monitoring is essential to assess the impact of the measures, both on the energy consumption and on the comfort side.

The results should prove the saving potential without renovation while maintaining comfort. It also often shows that there is still space for improvement.

Methodology

The socio-technical energy saving potential of school buildings was analysed in for four pilots in Luxembourg. These buildings represent an older part of the stock, as presented in Table 2, although they have been partly renovated over the years.

Our approach in Figure 1 to save energy is based a 5-step methodology, proposed by the outcomes of the ENERGE project. The methodology aims to raise awareness through educational activities on the energy topic to allow the school communities to identify opportunities, define and implement tailored strategies to reduce their consumption, while keeping comfort.

Table 2: Summary of studied school buildings

School	Gross floor area [m²]	Year of construction
A	16474	1989
B	30865	1974
C	19996	1972
D	25232	1953

Environment readiness and Learning Community

The initial step assesses the readiness of the environment and builds upon the existing framework. This includes the identification of stakeholders, their knowledge, willingness and of the available resources. Meanwhile, a working group in each pilot was established based on a learning community approach. The working group should be composed of at least one representative from each stakeholder group, i.e. of students, teachers, directors, maintenance staff, building owners, and partly parents. It is important to engage all different spheres, but the influence should be adapted to the needs, the competence and activity domain of each group.

Energy Education

During step two, the energy efficiency topic is disseminated within the school environment through educational activities. This is a preparation phase raising awareness to the topic in the school community, allowing further contribution to the following steps.

Energy Audit

The third step is characterized by the energy audit of the school building. It starts with the collection of information about the building envelope, its technical installations and the respective operational modes. From the analysis of the energy consumption in comparison to relevant benchmarks, savings opportunities can be identified. Furthermore, the energy consumption is analysed for different types of use, highlighting big consumers.

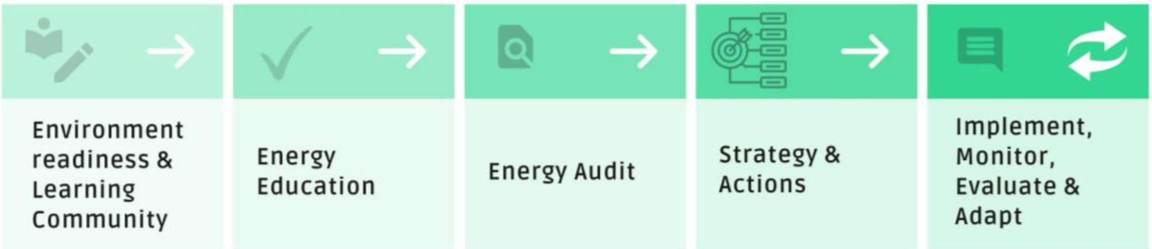

Figure 1: 5-step methodology to reduce energy consumption in school buildings

The school community is involved into this step, both to contribute and specially to benefit from experiential learning. This is also essential for engaging the community in the following steps.

It starts with the analysis of total and specific primary energy consumption relative to comparable buildings. The total yearly consumption of different energy vectors is calculated from real data obtained directly from the monitoring system of the public building owner (Administration des Bâtiments Publics in Luxembourg). From this information it is possible to separate heat and electricity consumptions and divide them by the gross floor area of the building to obtain the specific yearly consumption in kWh/(m^2y). In Luxembourg, these values can be compared to the national benchmarks from Hoos (2013).

Specific yearly energy consumptions that are above the average highlight large saving opportunities. The following step is the distribution of the energy consumption within the building to identify big consumers. The analyses of big consumers themselves and their comparison to references deploys the performance of the specific system and helps to plan adjustments.

To monitor big consumers at least temporary electric meters (clamp-on ammeters) can be installed to measure their consumptions. Whenever this is not possible a simpler and more approximate alternative is to identify the power of the equipment and multiply it with the measured or estimated operational time to approximate their energy consumption.

Strategy and Actions

In step four of the energy audit and especially for the big consumers, it is recommended to define an intervention strategy. A clear saving target should be defined, as well as the necessary actions. The saving measures are specified together with a monitoring plan which allows tracking the savings and the real comfort levels.

Implement, Monitor, Evaluate and Adapt

The fifth step is about implementing the tailored energy saving strategy. Monitoring the measures and comfort levels also allows to evaluate the effectiveness of the strategy, that should be constantly questioned and if needed adapted. Furthermore, schools are also constantly subject to changes, requiring the strategy to adapt. Once again, involving the school community into this step assures being up-to-date and provides important learning outcomes inside and outside the school environment.

By going through this process, it is possible not only to reduce the energy consumption but also to provide knowledge for better adapted future investment decisions in case of later renovation.

Analysis and discussion of the results

The energy savings potential from socio-technical interventions are analysed for the four educational buildings in Luxembourg given in Table 2.

Environment readiness and Learning Community

In Luxembourg, school buildings are owned by “Administration des Bâtiments Publics (ABP)”. The contact points in these schools are volunteering teachers, that are in contact with students, directors, staff, maintenance companies and ABP. These teams were trained and informed in our case by University of Luxembourg. Although parents are listed as stakeholders in the methods, they are not part of this analysis.

Due to the challenge of reducing carbon emissions in the geopolitical situation all involved stakeholders were open and interested to apply the proposed methodology. Hence, our pilot-buildings were accessible, while technical installations and operational information were made available.

This group of stakeholders working as the learning community shared and discussed information about energy savings concepts.

Energy Education

Energy related educational activities were applied to physics lectures in two institutions, while extra curricula workshops were proposed to the broader public in other schools. Some institutions already had this topic integrated in their curricula, while others encountered more barriers to do it.

This type of activity showed the interest of the school community to join discussions, e.g. on energy consumption in schools and at their homes, thus emphasising the dissemination aspect. It also prepared the community to start the energy consumption analysis.

Energy Audit

The comparison between the specific energy consumption of the four studied educational buildings (A, B, C and D) with relevant benchmarks in Figures 2 and 3 shows the saving potential. Specific energy consumptions below the national average as observed in Figure 2, for heat, indicates a better performance. On the other side, the behaviour observed on Figure 3, for the electricity consumption of the same buildings, indicates potential savings. Thus, for the studied buildings, saving energy on the electric side is easier to achieve than on the heat-side.

Hence, a detailed analysis of electricity consumption and its distribution within the building was started. This study presents the results of the energy audit from building B and C only, as building A and D are still under analysis.

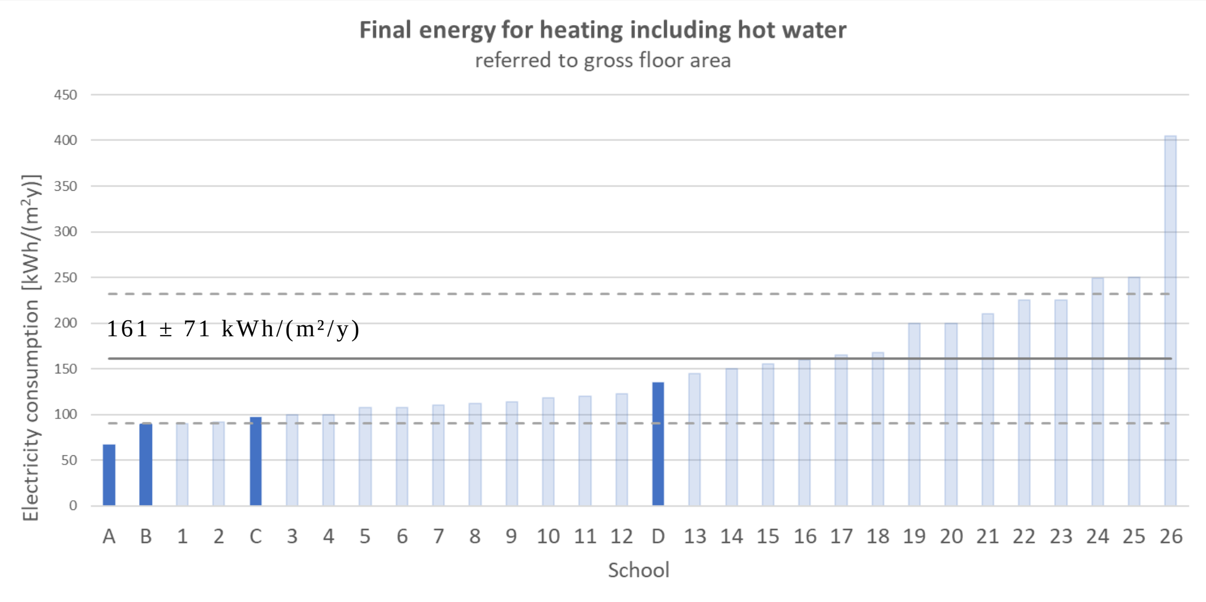

Figure 2: Final energy consumption for heating including hot water, referred to gross floor area. Our 4 pilots of Table 2 are highlighted in dark.

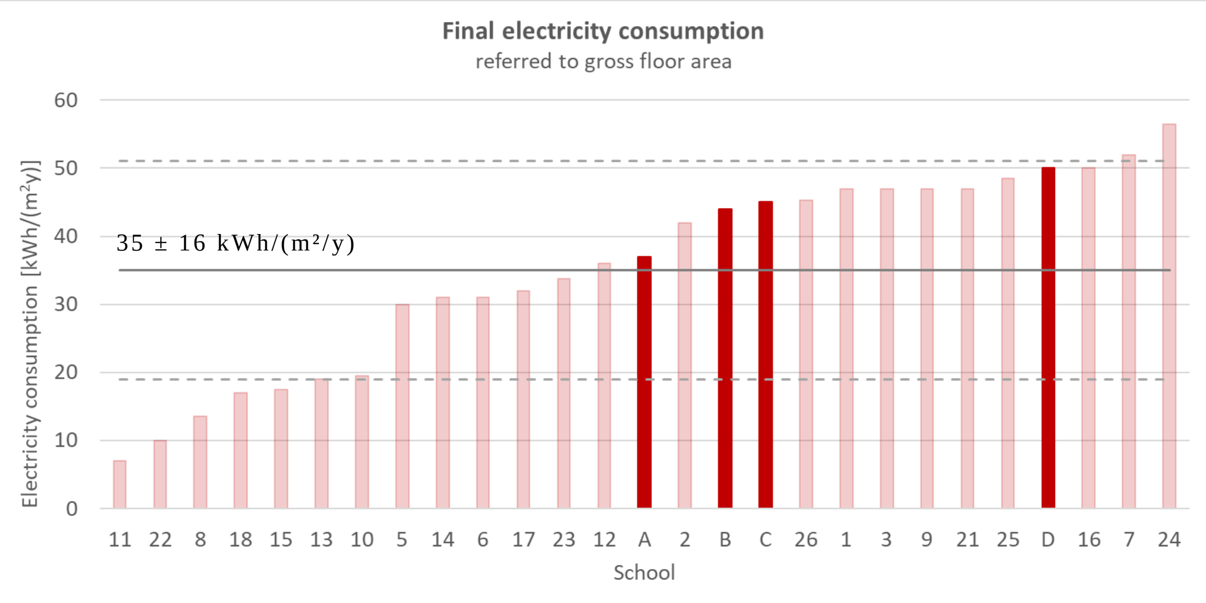

Figure 3: Final electricity consumption, referred to gross floor area. Our 4 pilots of Table 2 are highlighted in dark.

Building B

This is an older building with a façade composed by a big single glazed surface and 6 cm of rockwool insulation layer on the outside of the walls. The complete external wall shows comparatively low thermal resistance and low airtightness of windows and doors leading to high heat losses. However, the consumption is still below the national average for older schools which indicates that heat energy savings probably require more effort.

Nevertheless, radiators and controling valves were checked and the maintenance staff identified that the system needed to be balanced in order to reduce the supply temperature. Besides, various valves of the radiators were either broken and constantly working at full power, or simply not allowing the users to modifiy the reference temperature. This means that it was not possible to adapt the heat flow to the weather conditions, nor to apply reduced operational modus during empty periods. Hence, the building is always fully heated during night time and weekends, although it is not being used.

In another analysis for building B, it was identified that the illuminance at the hallways and corridors was higher than the minimum required 100 lux. Considering the installed older lighting system this represents an opportunity to save energy, while keeping comfort, by simply switching permanently off some lamps.

Building C

The electricity consumption of building C was analysed and then separated into different sub-users in 2022 (ref. to Figure 4). The chart highlights that the swimming pool and the sports hall cause the highest consumptions of this school, contributing to more than one third of the total consumption of electricity. Then the lighting system and the digital consumers (informatics) follow.

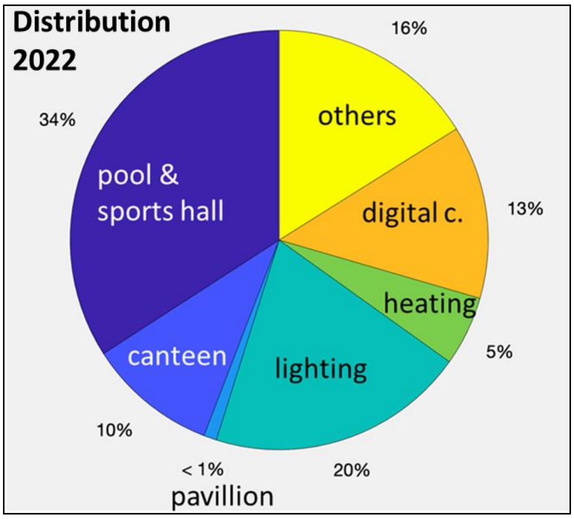

Figure 4: Electricity consumption distribution

Over the years, this school is already replacing the older lighting system by more efficient ones to reduce the consumption. However, the use of more and more electronic devices like computer, notebooks, tablets and servers for educational purposes is increasing the electric consumption.

Furthermore, the information from the distribution of consumption in Figure 4 also indicates that the operation of the swimming pool and the sports hall can has probably a high energy saving potential. It means that a detailed analysis of this part of the building, the technical installations and its operational modes is necessary to indicate where to act.

Every year, the swimming pool is open from mid of of September to mid of July. During the summer break it is cleaned and prepared for the following season. The system includes inter alia three large pumps. Two of them are working simultaneously during the day, from 6h to 22h, while the third one works from 22h until 6h. Besides, the system has a reduced operational mode for Saturdays and Sundays. However, it was also identified that there is no reduced operational mode for holiday periods. The management system of the swimming pool does not allow to change the settings. This means that the staff of the school is not allowed to adapt the operations to the actual use, which is now questioned.

Strategy and Actions

The results from the Energy Audit indicates the following for buildings B and C.

Building B

To reduce the energy consumption for both heat and electricity, two approaches are defined. The first is focused on balancing the heating system and radiators, besides replacing the broken valves to allow users to correctly control the radiators.

The second intervention approach targets the lighting system to meet only the minimum required illuminance in common areas and hallways. Such measures can be taken by disconnecting permanently some lamps.

Building C

The strategy to reduce the energy consumption in this school is based on adopting reduced operational modes for the swimming pool during holiday weeks, and when the pool has less users or none. To enable such intervention, the management system needs to be adapted to allow specific settings, combined with an attentive control of the staff.

Finally, it is also intended to at least discuss and assess savings based on a sufficiency approach with all stakeholders, e.g. the timewise closing of the pool in winter.

Implement, Monitor, Evaluate and Adapt

In this step the intervention measures are or will be implemented and monitored. The monitoring allows the evaluation of the effectiveness of the different interventions. From this analysis it is possible to adapt interventions to reach better results.

Building B

In this phase the heating system and radiators were balanced and calibrated, while broken valves were replaced. However, reduced indoor temperatures have been implemented before to save energy, thus jeopardizing comfort. The overall temperatures are reduced even during the day, when users are present. This measure led to energy savings, but it also led to increasing complaints and reduced comfort.

An adapted intervention plan is currently worked out. Since there are mainly manual systems, it requires the involvement of users in the process. Sensitizing the public for an active role is essential to achieve the defined goal. In a following step the potential of energy savings with reduced operational modes during the empty hours should be quantified and presented to users and compared to the full demand of full operation during working hours. This is necessary to involve users into the saving-process to really operate thermostat-valves once they leave the building. Finally, the cleaning staff need to be informed and better trained to supervise it.

The intervention on the lighting system of common hallway areas led to savings of more than 5% of the overall consumption of electricity. This measure did not lead to any extra investment. It only involved working hours of the maintenance staff and the use of the luxmeter to meet the illuminance requirements. This result achieved so far does not include yet classrooms, offices, and laboratories, showing that there is still an important potential to be explored. Monitoring of the consumption does not only allow assessment of the performance of the individual measure, but also assurance of comfort and good fit of future intervention plans that go beyond.

Building C

The interventions at building C are focused on the swimming pool. The technical staff adapted the real number of users in the pool-management system instead of using overestimated predefined figures. However, the intervention also involved other stakeholders and currently the management system is under revision to allow the staff at site to adopt better and quicker a reduced operational mode whenever possible.

The monitoring of the results from these interventions is part of the optimized control of the electric consumption of the pumping system, together with the control of water quality and the water levels.

The results from monitoring are shared with the school community to engage them even more in the process of identifying new opportunities and savings actions.

Conclusions

The study of the energy saving potential of socio-technical interventions in educational buildings in Luxembourg shows that it is possible to save energy by adapting the consumption to the actual needs. When requirements and operation times are well-known, the technical installations can be better adapted to reduce consumption, while keeping comfort high.

Big consumers of buildings with high energy consumption must first be identified and often offer interesting savings opportunities. Examples are buildings with older and less efficient lighting systems especially in hallways and corridors, where assuring only minimal technical and comfort requirements has proven to save already 5% of the electricity consumption.

The approach proposed for this study focusses on involving the school community to both identify savings opportunities during the analysis of the building, and to engage them later into the implementation, and into the monitoring of comfort and energy characteristics.

Buildings equipped with automated monitoring and operational bus-systems can more easily switch between different operational modes and adapt the indoor conditions easier to the needs of the user, while avoiding energy losses during empty hours. However, these systems also need constant monitoring to ensure that they are working correctly. It shows that the deep knowledge of the building technics, the energy demand and the monitoring of operations are necessary for both older and modern buildings. Therefore, the educational approach to teach the next generations about energy efficiency is essential to reach better performances.

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