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Abstract. Schools are learning communities where multiple stakeholders can collaborate to learn about energy efficiency, including via formal curricula, non-formal learning and day-to-day practices. Furthermore, by improving energy literacy among building occupants, the energy efficiency of schools can be improved. However, turning schools into learning communities rather than learning organizations is still problematic. This article details a case study realised in the form of the ENERGE project, which integrates technological, educational and practical activities in 13 post-primary schools from 6 European countries. Owing to an extensive collaboration of diverse stakeholders, the ENERGE project resulted in the origination of a learning community around energy efficiency in the schools. The outcomes of building a learning community within the ENERGE project included: capacity building (in the form of the ENERGE Committees and Teacher Network), the introduction of digital education (via the ENERGE digital platform), development of curriculum-based modules to raise energy literacy, and the establishment of a viable model for expanding ENERGE experience to other schools. The article concludes by explaining the benefits of the ENERGE approach for stakeholders.

Keywords. Business model, energy, energy literacy, digital platform, learning community
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1. Introduction

The transition to nearly zero-energy buildings (NZEB) requires holistic efforts in all segments of energy generation and usage, as well as active engagement of multiple stakeholders, including, policy and decision makers, engineers, architects and designers, academia representatives, building owners, energy-related product/service suppliers, and last, but not least, building occupants [1]. As part of these holistic efforts, educational opportunities for building occupants regarding energy and the implications of its use should be developed. This can help create energy-centred learning communities to enable communities to take action to reduce energy consumption or advocate for changes that can do so. Energy-centred learning communities are places of extensive interpersonal collaboration between different stakeholders (e.g. educators, students, engineers, sociologists, businesses etc.) that can drive responsible energy use learning, teaching and practicing. The implementation of a learning community approach can turn schools, (regarded as primary educational units and key staging points for promoting responsible energy use in public and private environments), into leaning communities, rather than learning organizations, thus prioritising collaborative forms of learning for personal development [2].

There are various projects and programmes aimed at improving energy efficiency in schools [3-5]. However, such projects can underperform with respect to several important elements of building energy efficiency learning communities in schools [4]. These elements include the following:

(a) extensive multi-stakeholder collaboration (e.g. via energy efficiency-focused intra-school and inter-school groups),

(b) introduction of multi-purpose digital platforms (e.g. where energy-monitoring technology can be combined with educational activities),

(c) development of curriculum-based modules to raise energy literacy (e.g. via systemic and collaborative approach to energy module development), and

(d) the establishment of a viable business model to expand knowledge and experience obtained in such projects to other schools.

Thus, an interdisciplinary and longitudinal study within the Interreg ENERGE project, which stands for "Energizing education to reduce greenhouse gas emissions", is being undertaken to address these elements using 13 post-primary schools in 6 countries of North-Western Europe (France, Germany, Luxembourg Ireland, Northern Ireland, and The Netherlands) as pilot schools. The project follows a multiphase mixed methods research design. This article describes the ENERGE project as a case study to present its vision of building a learning community with the aim of improving energy efficiency in the schools, and also in their private homes from the lessons learned.

2. Research methods

2.1 Context analysis

In order to realise the learning community approach, the ENERGE project recruited diverse partners from various domains, including professional engineers and sociologists, energy service contractors, business innovators, decision makers, etc. These partners selected 13 post-primary schools in various North-Western European locations to be part of the learning community. **Appendix A** (**Tab. 1 to Tab. 4**) contains the profiles of the ENERGE project schools, including information on school location (with some climatic conditions), school type, construction/extension years, school building ownership, curriculum orientation, student/staff numbers and space heating fuel type. The appendix demonstrates a certain level of diversity of the project schools. The diversity of the partners and the schools is vital to build a rich and vibrant learning community, in which all entities could share varied knowledge, skills and experience.

2.2 Capacity building and social networking

Two key methodological tools of building an effective learning community included the formation of the school-based ENERGE Committees and Teacher Network [6]. The ENERGE Committees were formed in all project schools (one per project school) by attracting those students and staff that were primarily interested in energy saving and sustainability. Each committee comprised several students headed by a teacher. The committees served as testing grounds for various ENERGE-related activities, including, for instance, piloting energy literacy modules (see below in this section). An "ENERGE Teacher Network" (19 teachers from 11 project schools) was established to serve as a platform for sharing ideas, knowledge, skills and experience related to teaching and learning about energy and its saving. The prime concern of the Teacher Network was to develop and pilot energy literacy modules.

2.3 Energy literacy modules

As part of forming an effective learning community, the ENERGE project aimed to collaboratively create proprietary energy literacy content in the form of energy-related modules, (represented via separate units and activities). The methodology of this element of building a learning community was as follows. The partners developed an ENERGE energy literacy framework, which contained basic parameters of energy literacy [7]. Then, the partners, via a systematic literature review [8] (full specification of the literature review is provided in the Supporting Materials), created a shared database of energy-related teaching/learning modules. Each unit is divided into topic units with a range of 5-10 activities in each module. Furthermore, in cooperation with the members of the Teacher Network, the partners developed the ENERGE module design process and uploaded relevant energy literacy modules into this database. Specifically, the members of the Teachers Network provided their feedback on the compatibility of the designed modules with existing school curricula. After the design and content of the modules was agreed, the members of the Teacher Network piloted these modules among their students, including members of the ENERGE Committees. Following piloting, and further collaboration with all 13 project schools, the design and content of modules was finalised, while further suggestions on their compatibility with the school curricula were made.

2.4 ENERGE digital platform

Another vital tool for creating an innovative learning community was the development of an "ENERGE digital platform". The ENERGE Digital Platform was developed to monitor electrical energy consumption and indoor climate quality (specifically, temperature, humidity, carbon dioxide, lighting and noise levels) at specific locations in each of the 13 project schools. The platform included: (a) devices for energy use monitoring, i.e. nine-channel electrical meters and a Sigfox Modbus data collector; and (b) devices for indoor climate monitoring, i.e. Elsys wireless sensor boxes, together with a LoRa gateway and a router (the specifications of the installed devices are available upon request). The selection of relevant sensor/meter installation points was guided by the following considerations: (1) identification of significant energy users and/or energy/comfort-related issues; (2) occupancy levels in the monitored areas; (3) the capacity of these points to be subject to energy-related interventions (e.g. behaviour change, etc.) that might lead to tangible energy-saving outcomes; and (4) the feasibility of installing monitoring equipment at these specific locations.

From the time the devices started to generate datasets on energy consumption and indoor climate conditions, the data has been processed and monitored via user-friendly proprietary interfaces. The available datasets are employed as a tool of collaborative learning by all stakeholders to monitor energy usage and comfort parameters to understand and implement various interventions and behaviour change measures. Collaborative learning opportunities have been harnessed in workshops in addition to the ENERGE Digital Platform co-design sessions, which were carried out with multiple stakeholders, including the members of the ENERGE Committees and Teacher Network in each of the project schools. Therefore, the ENERGE Digital Platform performs two roles: (a) it acts as a data hub, with a user-friendly interface, for analysing school built environment via a network of electrical energy meters and indoor climate sensors installed in the project schools, and (b) it acts as a teaching/learning tool to educate school stakeholders in energy-related interactions and strategies. Since the ENERGE project is a long-lasting initiative, which is intended to continue even after project finalization, the development of the Digital Platform is an ongoing process, subject to its adaptation for stakeholder needs based on received feedback.

2.5 ENERGE business model

The actions and outputs of the ENERGE project are somewhat wasted without a means of ensuring that the methodology in the project can be applied long after the project itself has ended. To ensure this, an ENERGE business model is being developed that allows for the exploitation of the ENERGE results across the six target countries in a viable manner. An important element of the ENERGE business model is that it should overcome differences in governance, administrative and financial structures for post primary schools in the different countries. The relevant business model for the ENERGE project is being developed with the help of a business model canvas, value network and five-stage business model generation process [9]. This work includes the following stages:

1) Mobilise: This meant mobilizing key ENERGE stakeholders to define the initial business model.

2) Understand: This included a good understanding of the context in which the business model will evolve (by preparing a special report on the project schools and running several surveys among the school population) and the collection of ideas of relevant stakeholders on the development of business model workshops.

3) Design: This included the exploration of the business model options. To select the most promising business model, a workshop among the project partners was carried out. This was enhanced by a series of key informant interviews with the project school administration and teachers. The key objective of the interviews was to clarify the focus of the project and expectations related to it.

4) Implement: The ENERGE business model will be implemented and executed first at the project schools. Based on the results and experiences from the project schools, the ENERGE business model will be adapted or adjusted. Once finalised, the ENERGE business model will be made available for implementation in a broader context.

5) Manage: Once implemented, the performance of the ENERGE business model will be monitored. If needed, the business model will be modified (the last two stages will be realised in the future as the ENERGE project is ongoing).

3. Results and Discussion

3.1 Establishment of the ENERGE Committees and the Teacher Network

The ENERGE Committees formed in each project school and the Teacher Network established a community of like-minded and active students and staff that are interested to learn how they can assist in improving energy efficiency in their schools. To some extent, these groups can be viewed as drivers of change and the project ambassadors, but they also can act as voluntary participants in multiple activities related to raising energy efficiency in the schools. They demonstrated their readiness to learn and share their own knowledge and experience, thus creating a much-needed atmosphere of reciprocity and collaboration. In general, joining the ENERGE Committee is an instrument of behaviour change in itself [10], as in accordance with self-perception theory, our attitudes, including pro-environmental, are formed when we observe our own overt behaviours and the circumstances in which these behaviours occur [11]. To this extent, the ENERGE Committee membership can be regarded as a commitment to community-based behaviour change [12]. In addition, the linking of the ENERGE Committees from different countries brings a cross-country element to the learning community and creates transnational cooperation between students when sharing ideas and experiences.

In a similar fashion, the work of the established Teacher Network resulted in extensive collaboration between the project school teachers engaged in the exchange of their knowledge, skills and experiences with respect to energy-related issues and initiatives, including teaching energy-related topics and piloting energy literacy modules. All members of the Teacher Network stressed a current lack of energy-related curriculum-supporting classroom modules (including activities). They also suggested that there is a need for a series of activity-based modules on energy themes. As for energy literacy, low levels of energy literacy was also indicated by the Teacher Network members, which is substantiated by various studies looking at both student populations as well as the wider public [13,14].

3.2 Improvement of Energy Literacy

As a working definition of energy literacy, the members of the Teacher Network, in cooperation with the project partners, adopted the characteristics of an energy literate student defined by DeWaters and Powers [7]. These are as follows: (a) a basic understanding of energy science and its usage in everyday life; (b) understanding of how energy production and consumption affects environment; (c) recognition of the need to conserve energy to develop alternatives to fossil fuels; (d) recognition that personal energy-related decisions and actions matter; and (e) efforts to make pro-environmental choices and decisions with respect to energy consumption. As such, the concept of energy literacy has three interlinked dimensions – cognitive (skills and knowledge), affective (e.g. attitudes, commitments, motivations, responsibility, values etc.) and behavioural (e.g. participation, consumer actions, legal actions etc.). These dimensions are all reflected in the ENERGE energy literacy framework created by the project partners in cooperation with the Teacher Network members.

While co-developing energy literacy modules, the teachers, who represented different disciplines (geography, physics, information technology/ computer science and social sciences), expressed their views on the characteristics and the potential of these modules. In general, all teachers shared the view that, despite the fact that energy is taught as an interdisciplinary topic across various STEM and non-STEM disciplines, there is a lack of cohesion across the formal curricula. In addition, the teachers believe that the strongest benefit of the ENERGE educational materials is their alignment with the existing curricula. Geography teachers reported that energy literacy themes are present in the social and ecological dimensions of the subject. ENERGE-based modules are designed to support existing geography curricula by developing practical activities and lesson plans that are relevant to the modern students and able to stimulate behaviour change. The incorporation of local case studies based on geographic information system (GIS) technology would be beneficial. Physics teachers argued that current curricula in this discipline could offer little room for the affective and behavioural dimensions of energy literacy. To account for this, ENERGE modules can supplement the existing curricula by balancing the present tilt towards the cognitive dimension of energy literacy. Disciplines focusing on IT and data analytics could significantly benefit from the ENERGE modules that rely on the use of smart metering systems that monitor energy consumption and indoor climate quality (e.g. the ENERGE Digital Platform). Social science teachers also expressed their enthusiasm about the supplementary character of the ENERGE modules, which could provide depth to the existing curricula.

The profound collaborative efforts undertaken by the project partners, members of the Teacher Network and students who participated in the module piloting, resulted in the preparation of the final list of the selected designed modules. This list is available online for the open access (link: https://cutt.ly/3U6Vm0G) and the authors of this publication welcome any contribution from all interested parties/schools to review the presented modules. The piloting stage also resulted in several recommendations regarding the applicability of these modules. Firstly, the application of these modules should take into consideration interregional differences that exist between educational models of different countries (e.g. countries with common-core curricula vs. countries with highly differentiated curricula; [15]). Secondly, the module application should take into consideration variability of students between 12 and 18 years with respect to cognitive, affective and behavioural capacities. Thirdly, language may be a significant barrier so the modules need to consider the linguistic capacity of the targeted audience. Fourthly, informal opportunities for teaching energy literacy modules are underrepresented in the curriculum but can potentially offer the teachers the flexibility they need to accommodate for the needs of all students.

3.3 Origination of the ENERGE Digital Platform

Digital learning tools use a combination of text, graphics, simulation and multimedia to enhance the learning process [16]. In the context of energy education, digital learning has been used to present instructional materials as well as to monitor the learning that takes place. Numerous programmes report about the application of different digital learning tools. For example, computer-assisted instructional materials in the teaching of the process of photosynthesis can be employed [16]. Researchers can use simulations as tools for students in physics education to investigate energy concepts such as energy forms, transformation and conservation [17]. Digital game-based learning is widely used by educators in different fields [18]. Petra et al. [19] utilised Web-based Inquiry Science Environment (WISE) as a teaching aid on energy topics in biology. In their totality, digital learning tools engage students and develop knowledge as well as a variety of skills, including problem solving, inquiry, reasoning, argumentation, communication, and collaboration. The latter is a particularly important outcome of the digital tool application. To this extent, the ENERGE Digital Platform is key to building a collaborative learning community by incorporating such elements as data-based analysis, environment simulations, and decision-making processes.

The ENERGE Digital Platform is an interactive interface, which displays the information on energy consumption and indoor climate quality in the project schools. As alluded before, the platform allows occupants to be involved in two interlinked tasks: energy management and energy-related learning (Fig. 1). Such diverse functionality was welcomed by all personnel of the project schools, which was confirmed by the key informant interviews.

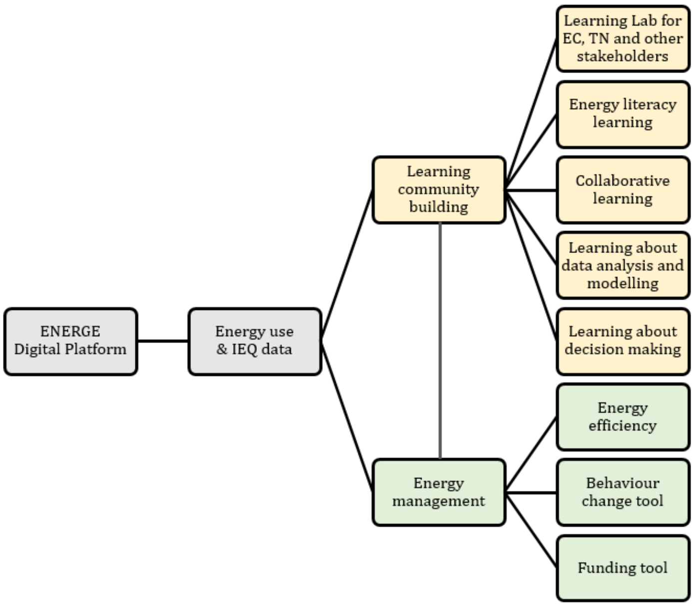

Fig. 1 - Energy Digital Platform multi-functionality. IEQ = indoor environmental quality, EC = ENERGE Committee, TN = Teacher Network.

The role of the ENERGE Digital Platform (**Fig. 2**) in building learning communities is clear. By using this tool, students, teachers and other stakeholders were able to collaboratively analyse data on the built environment, execute exercises in modelling and make certain decisions on the basis of the obtained energy/comfort data. It may serve as a learning lab for members of the ENERGE Committees, the Teacher Network and all other interested stakeholders. A "learning lab" metaphor here means that the interested persons could understand the essence of various parameters of their built environment, identify interdependences about these parameters and potentially be more driven to address challenges related to their environment. Of course, the ENERGE Digital Platform can also assist in energy management of the project schools, by acting as a tool for monitoring and displaying energy efficiency and changes in behaviour.

Fig. 2 - ENERGE Digital Platform mock-up

It is interesting to note that the platform could be also an instrument for attracting financial resources for the schools since it could provide substantiation for allocating funds to the schools, since the platform can generate data on energy usage and indoor environmental quality. One of the participants of the key informant interviews mentioned that "Funding [for energy efficiency] can be sought from a minor works application, but these are generally focused on Health and Safety (H&S) needs rather than energy etc., as H&S is the best way to try to get funding." The ability to link energy usage and the health of occupants due to indoor environmental quality offers a new perspective on seeking funding for projects such as lighting and building fabric upgrades, which are known to result in significant energy savings whilst also improving comfort levels for building occupants.

3.4 Formulation of the ENERGE business model

It was a consensus among all the ENERGE stakeholders (incl. the project partners, school personnel and students) that the best way to develop the ENERGE business model is to merge educational aspects of the ENERGE Project with its objectives to improve energy efficiency and energy management of educational facilities. As such, the core value proposition of the ENERGE project is twofold, i.e. (a) to build learning community around the issue of energy efficiency in the schools and (b) to improve their energy and indoor environmental quality. This duality of the business model is evident in its multiple dimensions, including key partners, activities, or resources, targeted customer segments, distribution channels and financials.

It is important to mention that the design of the ENERGE products and services needs to consider the context in which the ENERGE business model will be deployed. Three important factors that define how to shape the ENERGE value proposition are:

(1) The character of the targeted schools in terms of a region and type: general or vocational education and lower or upper secondary education;
(2) The level of digitalization of the ENERGE proposition: available infrastructure at the schools and digital literacy of teachers and

students; and

(3) The scope of the educational materials: Focus on energy efficiency only or the inclusion of other sustainability-related topics.

It is obvious that educational materials need to match the skills and competences of each specific age group. In addition to age, the education level needs to be taken into account when designing the ENERGE proposition. General education and vocational education have different needs in educational materials. In addition, the ENERGE proposition needs to be in line with the national curriculum. For the level of digitalization, two elements are relevant for the ENERGE proposition: the level of school building automation and the use of digital material and devices in lessons. Differences in degree of autonomy to schools for managing financial resources impacts the financial structure of the ENERGE business model. Schools in Ireland, U and the Netherlands generally have more autonomy for managing their financial resources, while schools in Germany, France and Luxembourg have very limited or no freedom in this area [20], while school budgets for educational materials and sensors and building automation are often allocated at different levels of authorities. The ENERGE project primarily focusses on energy efficiency and indoor climate quality. However, the key informant interviews with the project schools' principals and teachers showed that there is a preference for bundling multiple related topics. The overarching theme could be "sustainability", which is broader than energy and health.

3.5 General framework for the ENERGE learning community building

To summarise the above-mentioned contributions, **Fig. 3** provides a general framework for building a learning community around the issue of energy efficiency in schools, which is addressed in the course of the ENERGE project.

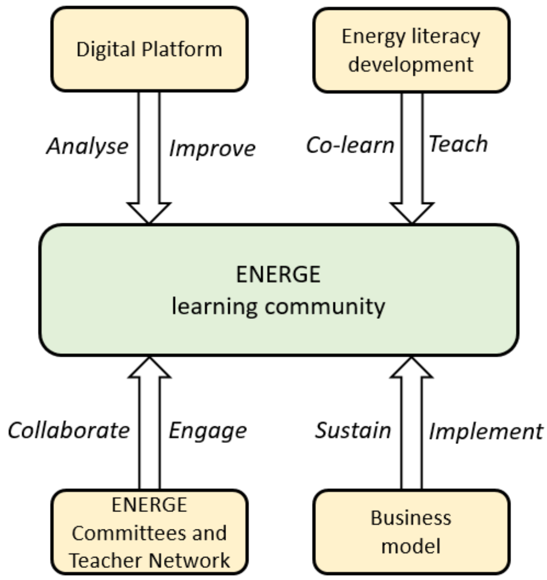

Fig. 3 - General ENERGE framework for learning community building.

The framework's four key components, i.e. the multi-functional Digital Platform, curriculum-based energy literacy development programme, networking opportunities (in the form of the ENERGE Committees and the Teacher Network), and a viable business model for the post-project exploitation of the ENERGE solutions, integrate both technological and educational approaches, which can be put into practice.

Within these four contributions, the realization of the ENERGE framework can lead to improved energy-efficient behaviours in schools **(Fig. 2**). The Digital Platform may stimulate data analysis-based improvement of energy management in schools. The suggested form of energy literacy development is a way to organise co-learning practices. Networking and collaboration, involving the ENERGE Committees, the Teacher Network and other stakeholders, are instrumental in originating a co-designed behavioural change, while an effective business model can help in implementing and sustaining energy efficiency activities in schools.

4. Conclusions

The suggested ENERGE framework for building a learning community can offer tangible benefits to various stakeholders, including school personnel, students, educators, policymakers, to name only a few. By educating young adults about energy-efficiency in their own school environment, we can influence their behaviours in school, but also their behaviours at home, and their behaviours as they move through life.

From an engineering perspective, building occupants who are aware of their energy-related behaviours can positively impact a building's energy consumption via their day-to-day actions. The ENERGE framework enables building occupants, in this instance school students, to gain a better understanding of how they actions can affect the energy-efficiency of a building and work together as part of a learning community to improve sustainability.

5. Acknowledgement

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6. Appendices

Appendix A

Tab. 1 – Profile of the ENERGE project schools (France and Germany).

School	France 1	France 2	Germany 1	Germany 2
Location	Orléans	Centre-Val de Loire region	Trier	Prüm (Trier)
School Type	Professional training	Agro college	Post-primary	Rural, vocational
Year of construction (extensions)	1953 (1960 / 1996)	2009	1914 (1965 / 2002)	1954 (1966 / 1974)
Building ownership	Regional Council	Regional Council	City of Trier	District admin.
Curriculum orientation	Engineering, crafts	Agricultural	Science and Maths	Technical
Student / staff number	791 / 150	493 / 90	1027 / 90	950 / 75
Space heating fuel type	Natural gas	Woodchips / natural gas (80/20%)	Natural gas	Natural gas
*Av. monthly temperature in Jan/Jul, °C **	5 / 19	5 / 19	2 / 18	0 / 17
*Av. monthly rainfall in Jan/Jul, mm **	52 / 59	52 / 59	79 / 70	79 / 70

Tab. 2 – Profile of the ENERGE project schools (Ireland and Northern Ireland).

School	Ireland 1	Ireland 2	Northern Ireland 1	Northern Ireland 2
Location	Galway	Galway region	Down Co.	Tyrone Co.
School Type	Post-primary	Rural, post-primary	Post-primary	Post-primary
Year of construction (extensions)	1919 (2009)	1830 (1930 / 1960 / 2013)	1970 (2015)	1954
Building ownership	Diocese of Galway	Dept. of Education	Dept. of Education	Dept. of Education
Curriculum orientation	General / classic	General / classic	General / classic	General / classic
Student / staff number	780 / 80	490 / 44	876 / 85	796 / 65
Space heating fuel type	Natural gas	Kerosene	Natural gas	Natural gas
*Av. monthly temperature in Jan/Jul, °C **	6 / 16	6 / 16	4 / 15	4 / 15
*Av. monthly rainfall in Jan/Jul, mm **	84 / 71	84 / 71	109 / 75	80 / 71

Tab. 3 – Profile of the ENERGE project schools (Luxembourg).

School	Luxembourg 1	Luxembourg 2	Luxembourg 3
Location	Luxembourg city	Luxembourg city	Luxembourg city
School Type	Post-primary, vocational	Post-primary	General secondary and vocational school
Year of construction (extensions)	1965 (1985)	1989	1972 (1998)
Building ownership	Public building administrat	Public building administrat	Public building administrat
Curriculum orientation	Technical	Technical	Technical
Student / staff number	4400 / 340	2500 / 200	1400/140
Space heating fuel type	Natural gas	Natural gas	Local district heating (gas-fired CHP) plant
*Av. monthly temperature in Jan/Jul, °C **	2 / 18	2 / 18	2 / 18
*Av. monthly rainfall in Jan/Jul, mm **	77 / 71	77 / 71	77 / 71

Tab. 4 – Profile of the ENERGE project schools (The Netherlands).

School	Netherlands 1	Netherlands 2
Location	Hague	Rotterdam
School Type	Gymnasium	Post-primary
Year of construction (extensions)	1907 (2011)	1950 (1999)
Building ownership	Secondary edu. office of Hague district	Edu. office & Municipaplity of Rotterdam
Curriculum orientation	General / classic	General / classic
Student / staff number	810 / 75	724 / 70
Space heating fuel type	Natural gas	Natural gas
*Av. monthly temperature in Jan/Jul, °C **	4 / 17	4 / 16
*Av. monthly rainfall in Jan/Jul, mm **	68 / 73	69 / 74

* Note: 2019 was used as a reference year

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