The Case for Open Datasets from IoT-connected School Buildings

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Abstract

A lot of activity is being devoted to studying issues related to energy consumption and efficiency in our buildings, and especially on public buildings. In this context, the educational public buildings should be an important part of the equation. At the same time, there is an evident need for open datasets, which should be publicly available for researchers to use. We have implemented a real-world multi-site Internet of Things (IoT) deployment, comprising 25 school buildings across Europe, primarily designed as a foundation for enabling IoT-based energy awareness and sustainability lectures and promoting data-driven energy-saving behaviors. In this work, we present some of the basic aspects to producing datasets from this deployment and discuss its potential uses. We also provide a brief discussion on data derived from a preliminary analysis of thermal comfort-related data produced from this infrastructure.

1 Introduction

The Internet of Things (IoT) and smart cities are currently two of the most popular directions the computer science research community is pursuing very actively. But although we have made great progress in many fields, we are still trying to figure out how we can utilize our smart city and IoT infrastructures, to produce reliable, economically sustainable solutions that create public value, and even more so in the field of education. In this context, the EU considers environmental education one of the most prominent instruments to influence human behavior towards sustainability, while educational buildings (i.e., buildings for primary and secondary schools, high schools and universities, research laboratories, professional training activities) constitute 17% of the EU non-residential building stock (in m^2)[1]. It is thus evident that schools and the educational community could play an important role in our quest for lowering energy consumption as a society in general.

The issue of becoming a more sustainable society as a whole has sparked a general growth of interest towards building energy efficiency, related datasets and benchmarks. In general, there is a lot of research trying to model things like energy consumption patterns, user behavior, etc. At the same time, the relevance of sustainable energy and energy saving behavior is increasingly gaining interest in schools and in educational programs. Just in the last decade, schools have been the target of studies, education initiatives as well as energy efficiency actions

In: Editors of the proceedings (editors): Emilio Calvanese Strinati, Dimitris Charitos, Ioannis Chatzigiannakis, Paolo Ciampolini, Francesca Cuomo, Paolo Di Lorenzo, Damianos Gavalas, Sten Hanke, Andreas Komninos, Georgios Mylonas: Proceeding of the Poster and Workshop Sessions of AmI-2019, the 2019 European Conference on Ambient Intelligence. Rome, Italy, November 2019, published at http://ceur-ws.org

in several countries. Recently, there has also been an increasing interest in the design of energy awareness educational activities centered around IoT-enabled lab approaches. In this work, we argue that producing datasets from public buildings, such as school buildings, has several benefits and such datasets can be used in a number of useful ways.

As our example for realizing such an approach, we base our work on the Green Awareness In Action (GAIA), project. GAIA [3] is a H2020 research project, focused on sustainability and energy awareness. It has built a large-scale IoT deployment across 25 educational buildings in Europe (Greece, Italy and Sweden), with over 1300 sensing endpoints. This infrastructure (see Fig. 1), which comprises mostly open-source hardware, monitors energy consumption in central points in these buildings, along with indoor environmental parameters. The main idea in GAIA is to use the data generated from this infrastructure as an enabler for sustainability and energy-focused activities in the classroom. At the same time, the datasets from these building can allow for many additional aspects, like e.g., thermal comfort studies.

2 Related work

The European Union has been collecting data for several years now from projects related to energy consumption and efficiency and making them public through the BuildUp portal [5]. Another related available source in the US is the Building Performance Database [2]. Building Data Genome is another recent research project [11], [4], that deals with producing datasets from public and non-residential buildings that be can utilized by the research community. Furthermore, a lot of activity has been dedicated to the use of machine learning-based techniques e.g., in the energy disaggregation domain, where the issue is understanding energy consumption patterns by different sources. [6] is a recent survey of this general area. [17] is another recent example of machine learning and specifically of the TensorFlow platform in this context. [15] discussed the general issue of energy benchmarks to compare between different buildings and features that could allow such comparisons. [10] discusses energy benchmarking in educational buildings and the need for datasets belonging to this category to enable such activity. [9] discusses more broadly the use of big data to enable energy management applications inside buildings.

Regarding uses of datasets in an educational setting, there is a growing interest in utilizing such data in recent years, especially in the context of makerspaces, hackerspaces and other similar groups. There are some examples where IoT-driven educational activities have been performed with the additional objective of increasing students' awareness of societal challenges. [14] surveys the area of educational applications in makerspaces. Tziortzioti et al. [16] designed and experimented data-driven educational scenarios for secondary schools to raise students' awareness of water pollution. Mylonas et al. [13] proposed an educational lab kit and a set of educational scenarios primarily targeting primary schools for increasing energy awareness within the GAIA Project. [8] is an example of a recent research project that has produced educational material targeting IoT learning competences. Datasets from IoT-enabled schools could power such activities and also enhance their overall appeal.

Figure 1: Instances from hardware components used in the schools (a), hardware used in lab activities (b), and the exterior of some IoT-enabled schools (c).

3 Benchmarking buildings for energy efficiency and comfort

Thermal comfort is one of the most important parameters for adapting the conditions inside a public building to make it "better" for its everyday users. Especially in school building, where users are mainly children and teenagers, thermal conditions are of utmost importance as they do not only offer comfort to users but affect the performance of students and the educational process itself. Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment and is assessed mainly by subjective evaluation, but can be objectified at some extent. The main factors that influence thermal comfort are those that determine heat gain and loss, namely metabolic rate, clothing insulation, air temperature, radiant temperature, air speed and relative humidity. Psychological parameters, such as individual expectations, also have some effect but cannot and will not be measured in our context.

We focus on a single metric, the PMV model, that was developed by P.O. Fanger [7] using heat-balance equations and empirical studies about skin temperature to define comfort. Fanger's equations are used to calculate the Predicted Mean Vote (PMV) of a group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation in a seven-point scale from cold (-3) to hot ($+3$). A PMV equal to zero represents thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is between -0.5 and $+0.5$.

Based on the data collected from specific school buildings we monitor in GAIA, we present here the calculated PMV value, as well as temperature and relative humidity data from the same building for a typical day. For the rest of the parameters that are not directly monitored we selected and used fixed values (i.e., air speed is 0 since we refer to indoor measurements). The data from a single building are presented in Fig. 2. From the figure, it can be seen that for this specific building PMV is within acceptable limits; going over similar data over greater time periods can provide more useful insights with respect to how conditions inside such a building play out.

Similar data can be extracted from other buildings of our network and the conditions in each of them can be easily evaluated even in real-time. A comparative view of the PMV in two buildings can be seen in Fig. 3 where the PMV value for the morning, working and evening hours is presented for the aforementioned school and another one located in a colder region. Generating such data and exporting them as datasets that can be shared with other researchers can help to identify other approaches, or ideas that can further our understanding and increase the practical usefulness of IoT installations. They can also be used by e.g., local government agencies to detect differences between the way buildings in the same region behave and spot the "weaker" ones, that show greater problems, or spot the best ones that should serve as an example of operation for the rest.

Moving on to more general comparisons between school buildings and detecting overall issues in the way school buildings operate, in Fig. 4 we show the percentage of time during which temperature was outside comfortable levels (i.e., above 25°C or below 19°C) during wintertime. This chart represents the conditions inside 21 school buildings in Europe, and it is interesting that there are big differences in these results. Apart from 3 schools that appear to have essentially 0% time outside of comfortable levels, many schools appear to have serious issues with the handling of indoor temperature during this period of the year.

4 Data-driven education for energy awareness

We now discuss related educational activities that have been proposed targeting schools and integrating with the existing computer science curricula, and that utilize datasets from educational buildings. The pedagogical goals aiming at increasing students' awareness on energy topics, in GAIA, are: awareness, observation, experimentation and action. These goals can be used to inform IoT-enabled education activities, which can focus on helping students and teachers to get a better understanding of the energy-related processes taking place inside their school building, how their actions and routine contribute to their power consumption, or how they compare with other similar schools in the same or other countries.

In Fig. 1, several instances of IoT hardware used in actual hands-on educational activities are shown. Such devices are used inside the school to generate the data that can be then used by students and teachers to provide a better understanding of their natural environment surrounding. They also give students an understanding of the electrical and electronics that are associated with sensing and computers. E.g., they report almost in real time on temperature and humidity inside the class. A key aspect here, and in related datasets, is granularity and responsiveness; in some cases, available datasets focus on datasets with e.g., a granularity of 30 minutes. This does not mix very well with the available time resources in schools, where students would like to see the immediate effect of their actions in some cases.

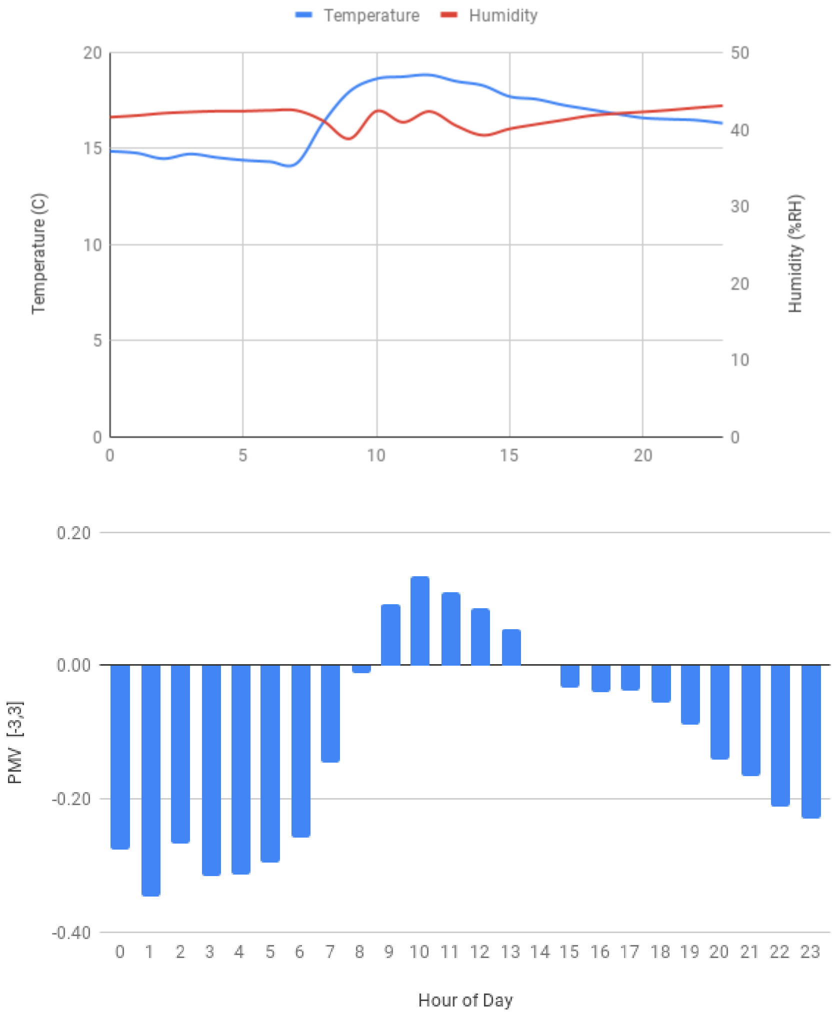

Figure 2: Temperature and Humidity inside a school building (top) and the calculated PMV value (bottom).

Knowledge and experiences gained from these courses, helps students to feel more comfortable with technology and the so called maker movement and build their own projects, either physical, using paper and paint, or more technical, like robotics and DIY both as part of their school curriculum or in their free time. An example of such an outcome can be seen in Fig. 5. It is an interactive installation that uses IoT data from school buildings, like overall power consumption, temperature or noise levels from the classrooms and visualizes it both on the paper-built control panel and on the connected monitor using a simple website. This interactive installation is easy to build and can be fully customized based on the respective school building and available sensors.

Having tools and data available, such as the ones mentioned above, opens up many possibilities for educators. Schools and educators can utilize them in the context of in-class activities according to particularities of their own school environment. Currently, there are few "officially-approved" educational activities focused on sustainability. However, there is always room for inserting such aspects into the context of existing curriculum activities. Furthermore, there is a growing awareness among young people with respect to climate change and the need to act to mitigate its effects, and school environments are a very good candidate for sustainability awareness activities. In the case of the installation depicted in Fig. 5, we have seen that it can be a starting point to make students aware of aspects that did not interest them in practice before, or were completely vague to them.

In this sense, the existence of school building data sets can be utilized in the context of statistics, physics, or natural science classes. Such data series provide the opportunity to study natural phenomena, e.g., the effect of building orientation or materials' use on school building energy consumption behavior, or examine the effect of the presence of students and teachers across different parts of their school and study energy consumption

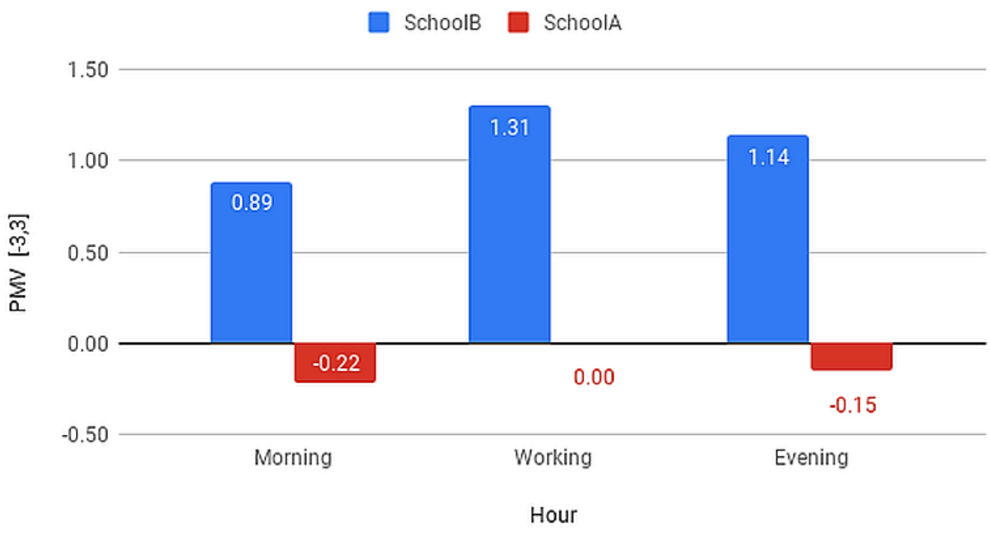

Figure 3: Comparison of PMV values in two distinct buildings located in different geographical regions.

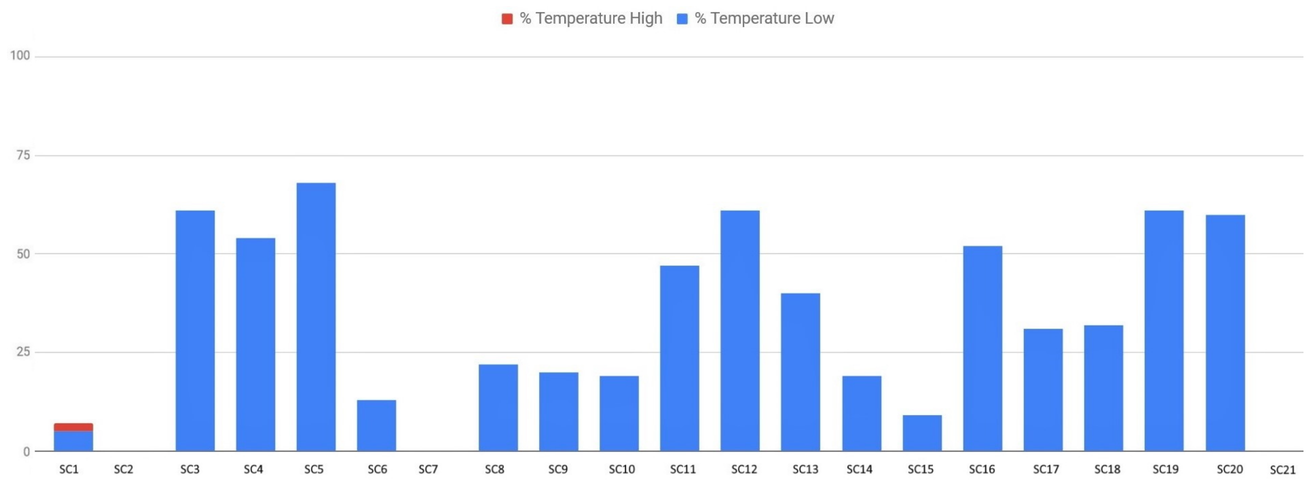

Figure 4: Percentage of time in which temperature was outside of standard levels in 21 school buildings (SC1-SC21) across Europe, during winter 2018-19.

patterns. In practice, we have seen from our experience in the GAIA project educators using such possibilities in various ways; even educators that do not have a technical background can find ways to integrate them into their workflow. The openness and availability of the data in the GAIA provided this kind of flexibility. Essentially, educators can use the available data as the foundation upon which they can work together with their students, serving two aspects at the same time: i) working with data that relate to the students' everyday surroundings, and ii) working in a sustainability-related context. Both have the potential to make in-class activities more engaging and motivate students to become more activated in environmental issues. In [12], a more analytic discussion and some examples are presented in detail, along with some results on raising sustainability awareness and producing energy savings, based on the tools and environment of the GAIA project.

5 Discussion and concluding remarks

Overall, in recent years there has been a lot of interest in terms of producing and utilizing datasets from buildings. This is more or less expected, since you cannot control what you cannot measure, and moreover it is not easy to improve or optimize something for which you do not have a clear picture. In this context, it is a fortunate event that recent advancements in IoT, data analytics, machine learning and cloud computing can help us in understanding processes related to the operation of public buildings, especially given climate change and the

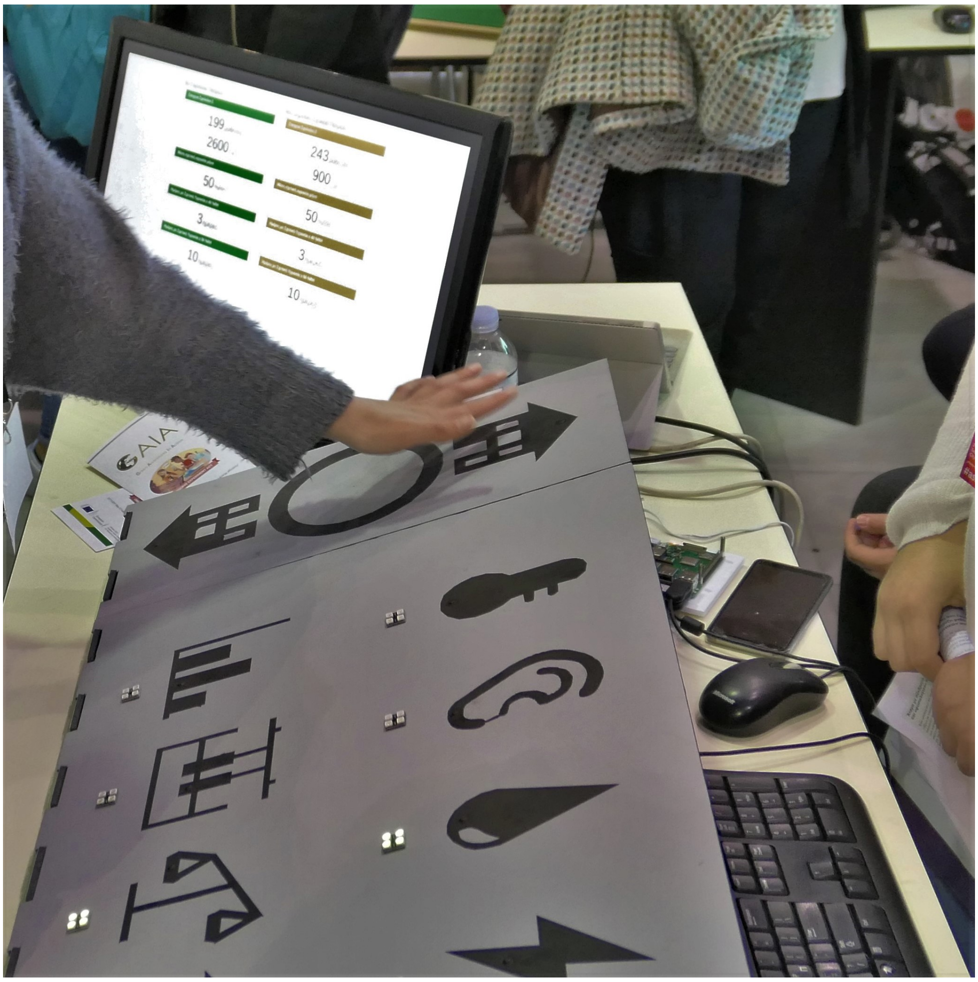

Figure 5: An example of the more “creative” uses of school building datasets. Here, an interactive installation acting as a “control panel” that can be installed at a school corridor, allowing students to “play” with real-time data and statistics related to energy consumption and environmental parameters.

need to become a more sustainable society as soon as possible.

This issue finds a fertile ground in the case of educational buildings: datasets that are produced using e.g., an IoT substrate can find many more uses than those of a typical public, non-residential building. Based on the examples briefly discussed in this paper, we can argument that the existence of open datasets from IoT-enabled school buildings provide plenty of opportunities to work on multiple “fronts”. E.g., they can immediately be utilized in an educational context, providing students with something that relates to their immediate environment, and which can be used as the input in educational activities. We have discussed briefly in this work some existing options and their potential uses. On top of that, they can also be used as input for more generic uses, e.g., understanding energy consumption patterns, testing algorithms for energy disaggregation, etc. We believe that there is a lot of area of potential growth in this domain, and we will be working in the near future to provide more substantial and analytic datasets to the community for such purposes.

Acknowledgements

This work has been partially supported by the “Green Awareness In Action” (GAIA) project, funded by the European Commission and the EASME under H2020 and contract number 696029, and the EU research project “European Extreme Performing Big Data Stacks” (E2Data), funded by the European Commission under H2020 and contract number 780245. This document reflects only the authors views and the EC and EASME are not responsible for any use that may be made of the information it contains.

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