Environmental and Social monitoring in existing building structures – results of a case study within several historical buildings

Alexander Redlein
TU Wien
IFM – Real Estate and Facility Management
Vienna, Austria
redlein@tuwien.ac.at

Lisa Thrainer
TU Wien
IFM – Real Estate and Facility Management
Vienna, Austria
lisa.thrainer@tuwien.ac.at

2022 15th International Conference on Human System Interaction (HSI) | 978-1-6654-6822-0/22/$31.00 ©2022 IEEE | DOI: 10.1109/HSI55341.2022.9869468

***Abstract*—One year ago the European Union defined the Environmental, Social and Governance (ESG) directive to foster investment in sustainability. This directive asks for energy monitoring / optimization and actions to foster human well-being. To cover that demand especially historical buildings in Europe need solutions in these respects, to be more energy efficient and at the same time to safeguard the well-being of its users. These buildings have almost no building automation installed. So, the basic prerequisite to identify high energy consumers valid usage data is not available. For that, the following research questions have to be answered: Which data is necessary to reach both, the environmental and social goals? How can data be captured in a valid and efficient way? How can data be made available to optimize energy usage and well-being? To answer these questions, a literature research was executed to define the relevant parameters. Firstly, based on the results of that step and a previous mixed-methods-research project, the relevant tools and the IT architecture were defined. Secondly, based on the ESG-reporting demands, data structure and relevant building structures were defined. Thirdly, a case study was conducted, which is based on the previously defined IT architecture, using IoT measuring devices, two different databases and two analytic tools. As a result, this paper presents the final decision on the database and the analytics tool, based on the users' interaction and feedback of the case study.**

Keywords—ESG, Sustainability reporting and real-time monitoring, Technology platforms for optimal energy management, Human-centric Internet of Things solutions, Internet of Things, Big Data, Analytics, Artificial Intelligence

I. Introduction

The "EU REGULATION (EU) 2020/852 of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088" puts a focus on sustainability as it asks in Article 8 for "Transparency of undertakings in non-financial statements". According to that article all companies of a specific type and size specified in Directive 2013/34/EU have to publish "(a) the proportion of their turnover derived from products or services associated with economic activities that qualify as environmentally sustainable […] and (b) the proportion of their capital expenditure and the proportion of their operating expenditure related to assets or processes associated with economic activities that qualify as environmentally sustainable […]" in their non-financial reporting. This additional reporting demand and the Green deal of the EU with the goal to improve the flow of money towards sustainable activities across the European Union increases the importance of sustainable actions of companies. As the real estate sector is responsible for around 40% of the CO2 emissions (cmp. [1]) and further requires much energy during the utilization phase, the developers and investors within the real estate industry have to focus on the "Environment, Sustainability and Governance" (ESG) criteria and carry out additional sustainability reporting, real time monitoring and optimization activities. Most of them concentrate on energy- and CO2-monitoring and reduction, but ESG is much more. The 17 sustainability development goals (SDG) of the United Nations give a perfect overview of the related topics. Of these seventeen (17), three are particularly important to the real estate industry:

- goal #7 Energy efficiency
- goal #3 Good health and well-being
- goal #8 Decent work environment

The goal of the paper is to provide an innovative, efficient solution for an IT support to automatize the new tasks necessary to fulfill the EU regulation and SDGs. The solution focuses on historic buildings. Within this project historical buildings are seen as buildings that are constructed before 1945. This bases upon an official Austrian differentiation of buildings built before and after the End of the 2nd World War [2]. This type of buildings was selected as their degree of building automation is normally very low. Therefore reporting, monitoring and optimization is done manually and causes a lot of effort. The solution is to close this gap and enable efficient, automated optimization of energy consumption and safeguard well-being of the tenants. In order to set up the solution, the following research questions have to be answered:

1. What are the relevant wellbeing and energy usage parameters and key performance indicators (KPIs) to be measured to fulfill the new ESG regulations and SDGs?
2. Which technologies can be used to capture the necessary real time data in a valid and efficient way focusing especially on existing historic buildings with a currently low level of automation? How can the technology platform, combining the single technologies, look like?
3. Which kind of tools can be used to store and analyze the data, in order to set further steps to decrease energy consumption and safeguard well-being?

In the following, the methodology applied to answer these research questions, is described. The chapter "results" will give an overview of the relevant technologies, that can be used to support the necessary processes of data capturing and analysis to be able to define valid steps for optimization. It analyzes how and which technologies work together to create a functioning ecosystem.

II. Methodology

In a first step a literature research was carried out to define the relevant parameters and KPIs that have to be measured to fulfill the new ESG regulation and the SDGs. To answer the questions 2 to 4, the results of a research project about the availability, usage and interrelation of emerging technologies conducted via mixed methods research (see [3] – [5]) was used. The research project consisted of the following steps: Based on a preliminary literature review, emerging technologies that were considered to be already in usage within the building industry were defined. Then expert interviews with 50 German speaking facility managers were conducted to define the technologies in focus of the further analysis. That qualitative step was used to gather as much information as possible. Therefore, unstructured interviews were used to give the participants room for their input.

Based on the results of this first qualitative phase, the quantitative part of the research started. The researchers collected international use cases in the chosen emerging technologies. Use cases were primarily found in publications like IEEE spectrum, MIT technology review, Harvard Business Review, Google Scholar, ResearchGate and strategy documents of well-established consultancies like McKinsey, CBRE, JLL, Gartner Group, EY, PwC and Deloitte. Many of these publications referenced scientific journal articles, which were used as further input. Overall, 986 use cases were collected since 2017. These cases were primarily published in the years from 2015 to May 2022.

The published use cases were analyzed using grounded theory methodology to ensure that the results were replicable and meaningful [6]. The written descriptions of the use cases were analyzed for two types of anchors for coding and conceptualization:

- the emerging technologies applied
- the facility services they were applied in.

For the categorization of the emerging technologies on the top level called "Class Level" (see table "Category" in fig. 1), in the first step the listing of [7] and the input of the qualitative phase (literature review and expert interviews) were used. Examples of the entries at the "Class Level" are Artificial Intelligence (AI), Internet of Things (IoT), Big Data etc. In addition, the explicit technologies named in the article were also coded and gathered in the table technology case as the "Base Technology". In this way a distinction between Deep Learning, Machine Learning (ML) Voice Recognition etc. in the area of AI was made. The entries of the list were enlarged, based on the literature analyzed. Each new base technology was subsumed to a technology of the top level.

To better analyze the data, a middle level called "Category" was created, where individual base technologies, having made an extensive contribution to their class, were singled out (e.g. ML). This allowed a more detailed analysis of the emerging technologies, applied by the use cases without overextending the level of detail. For the analysis in this paper the researchers primarily used the "Category level".

For the categorization of the services, the definition of the individual services given in [8] was used. The application of grounded theory ensured that the coding and categorization of the services and technologies was consistent for all individual use cases.

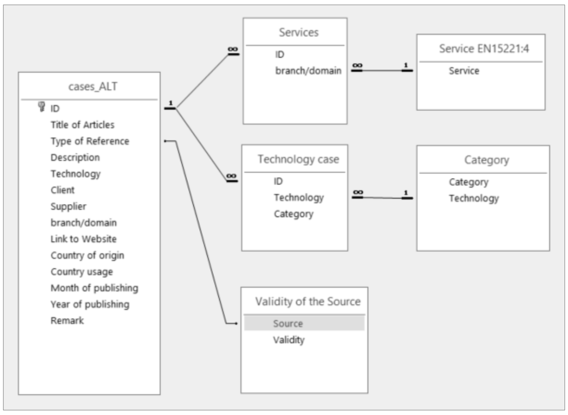

Fig. 1. Data entities, attributes and relations of the use case database

The use cases were entered into a Microsoft Access Structured Query Language (SQL) database. The structure of this database and the type of data collected can be seen in fig. 1. In order to ensure the results' validity, the type of source for the individual use cases was also recorded. We assigned grades based on significance and ensured that less creditable sources like newspaper articles or companies' press reports were not overrepresented compared to peer reviewed scientific reports and articles. For a more detailed description of the methodology used and the architecture of the database see reference [3].

Using the described methodology and this database, the emerging technologies applied in the use cases and the Facility Services in which they were applied, were analyzed. The 986 use cases analyzed in that way provide a valid overview of the status quo of the utilization of emerging technologies in the facility services industry. Based on the best practice described in the relevant use cases, the applicable technologies and tools were identified and a suitable IT architecture combining the tools was defined.

To validate the approach two prototypes using different databases and analytic tools were implemented and tested in real life. The databases and the analytic tools were selected based on their usage according to the best practices use cases analyzed and on the costs related to the usage. In that way, the license costs and the needed hardware were taken into consideration within the selection process. Finally, expert interviews with 10 key users were conducted to include the user feedback about the usability of the proposed prototypes. In this qualitative step the interviewer went through the process steps carried out by the key users and notated the feedback for each task regarding functionality in general, user interface design and performance. The semi structured interviews were used to give the participants room for their input. Based on this feedback on the usability of the prototypes, the database and the analytic tool were selected.

III. Results

A. *Relevant Parameters to be measured*

As a first step, the parameters influencing the well-being of users in buildings were analyzed by carrying out a literature research using the keywords room climate, well-being, user-building interaction, temperature, humidity and CO2. In total, 35 studies on the impact of temperature on the well-being and on the performance of users were analysed.

Studies [9] – [16] state that temperature has an influence on the productivity of employees and should be in a specific range between 22,6 and 26,5 degrees Celsius to safeguard the concentration capability and to reduce fatigue.

In total, 30 studies on the impact of humidity on well-being and the performance of users were analyzed: According to [17] – [21], humidity has an influence on the possibility of getting a flu or a cold. According to [22], [23] and [24] there is also an influence on dry eye syndrome. According to [25] and [26] this syndrome can be reduced if humidity is in a range between 26% and 33%. These two parameters are put in relation by [27] (see fig. 2), which define an area of comfort and an area of still comfort and the corresponding relationship between temperature and humidity. These areas are the constraint for the optimization.

In total, 40 studies about CO2 and its impact were analyzed. CO2 above 1000 ppm and especially between 1500 to 4000 ppm reduce the performance and even impact the health of the users of buildings (cmp. [28] – [31]). Especially the Sick-Building-Syndrome is associated with the CO2 concentration. Consequently, the optimisation of the air quality leads to an improvement of the performance of employees [32]. Especially illness and absence of employees is influenced by the CO2 concentration [30]. Therefore, we use the value of 1500 ppm as upper constraint for our optimization. There are other well-being parameters like acoustics, but they are not influenced by the building equipment or the tasks of energy optimisation and therefore were not included in the selection.

Based on this literature research the room climate parameters namely temperature, humidity and CO2 are selected to measure well-being. In addition, these parameters are also influenced to a large degree by the heating, ventilation and air conditioning (HVAC) systems, which represent 40% of the energy usage of a building [33]. The relevant forms of energy are electrical power, gas, oil, district heating and water.

In the next step technologies to measure, store the data and to provide the necessary analytics are defined.

B. Technologies

If we concentrate on the use cases with the goal to optimize energy usage we find the following picture (see fig. 3). IoT is applied in 83% of the analyzed use cases as technology to gather the relevant data. Sensors can automatically gather data and trigger certain actions, like measuring energy usage and room climate (cmp. [35] and [36]), as well as adjusting thermostats, which make our lives more comfortable and in the same way more energy efficient (cmp. [37] and [38]).

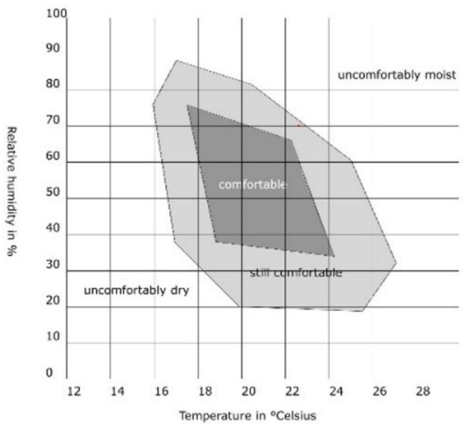

Fig. 2. Comfort in practical use [27]

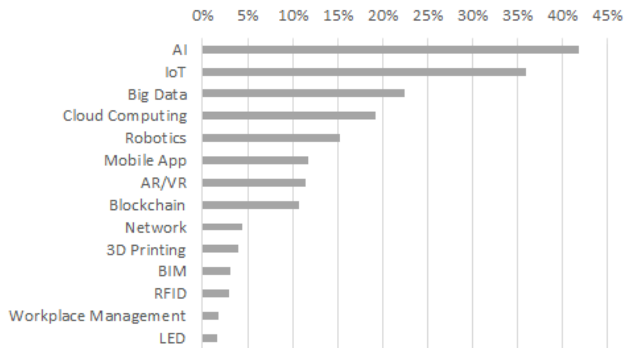

Fig. 3. Relevant Technologies for Energy Optimiziation as percentage of energy optimisation use cases, cmp. [34]

Data gathered from smart devices gives valuable insights into the building usage and operation. IoT enabled sensors help to improve operations by providing solid data for decisions and even enables forecasting machine failures [39]. Sensors can provide information on how we use space [40], which is the basis for space optimization. They can help us to lead healthier lives [41]. These examples should give an overview on how far reaching IoT technology has become over the last years.

Fig. 3 also includes some enablers, technologies which enable the use of other technologies like IoT and AI. Cloud Computing and Software-as-a-Service (SaaS) are these enablers. They make the application of the other technologies easy and cost efficient. Both service models do not ask for great investment into hard-and software by the final users as they are centrally provided and hosted. Providers like Amazon Web Services and Microsoft Azure provide computing and storage as a cloud service. Using these offerings, hard- and software can be employed on a pay-per-use model. This means, for instance companies can rent out 15 Terabyte of Memory for one day and have to pay only for this usage, which is much cheaper than buying the hard- and software as well as setting up the environment as a whole. These services also provide IoT interfaces, Big Data systems and AI tools, which only need to be customized to the requirements of the use case. In some cases, even pre-configured solutions are offered. These offers make a feasibility test and also operation much easier and cost efficient. That is the reason, why we call these two approaches enablers for the other emerging technologies.

The in-depth analysis showed that 84% of the IoT use cases apply at least on one other form of technology. This is to be expected since IoT technology, especially in regard to sensors, is used as part of an IoT ecosystem, consisting of many layers. IoT sensors create huge amounts of data, which have to be transmitted, analyzed and in some form made available to the end user. IoT is most powerful when embedded in a well-designed system. In this eco-system Big Data is applied as fast storage and to enable analytics. AI is used to analyze the data automatically and to derive algorithms to optimize the utilization [41].

Over the last years, several attempts have been made to standardize layers used for IoT architecture. In its most basic form IoT architecture consists of three levels: hardware to collect data, middleware for storage and analysis and finally a presentation layer with visualization tools to present the data to the end user [42].

Fig. 4 shows these layers in a typical workflow, described several times in the analyzed use cases. Out of this layer

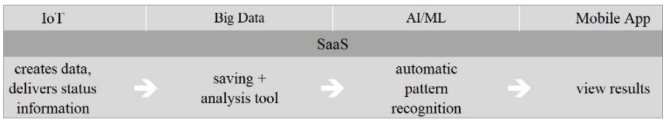

Fig. 4. Typical IoT use case workflow (cmp. [4], based on [43])

suggestion and the results of the use case analysis we see a flow from data generation and collection to data storage and to manual or automated analytics.

C. *Prototype*

Out of these theoretical results we set up a prototype to test technical feasibility, the technology platform, user interaction and acceptance (for the setup see fig. 5).

The architecture and its parts are based on fig. 5. The prototype consists of

1. different IoT devices measuring the relevant data,
2. a Message Queuing Telemetry Transport (MQTT) broker as technology platform that gathers data from the different IoT devices, standardizes it and sends the data to a central server.
3. a server component which stores data from different sources and enables further big data analysis.
4. a web-based dashboarding tool to provide the necessary information for reporting and to define actions for optimization.

Based on former studies (cmp. [44] and [45]) MQTT was selected as technology platform. "It is an OASIS standard messaging protocol for the IoT, designed for extremely lightweight publish/subscribe messaging transport. MQTT is ideal for connecting remote devices with a small code footprint, requiring minimal network bandwidth" [46], but safeguarding complete data exchange with the service quality level 1 and 2. "MQTT today is used in a wide variety of industries, such as automotive, manufacturing, telecommunications" [46]. In the prototype, the Quality of Service (QoS) level set to 1 to safeguard a complete data collection.

The IoT sensors selected measure real time data of:

- Electricity usage
- Gas, oil or district heating consumption
- Room climate (temperature, humidity and CO2)

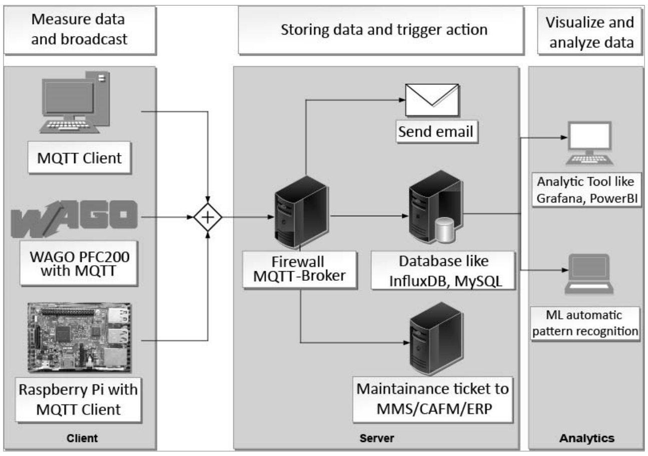

Fig. 5. Setup for ESG monitoring prototype (cmp. [47], [8] and [36])

The first two parameters were selected to cover the ESG reporting demand regarding "energy usage", the third one to cover the Social perspective of "well-being" and "decent workplace" according to the literature review described above.

The energy measurement was done by programmable logic controllers (PLC)) that were already available in some of the buildings. Then only the energy measurement units had to be added. These PLCs also act as local MQTT broker/bridge gathering the data, manipulating it and sending it in a standardized structure and procedure to a central server with database. If no PLC was available a Raspberry-PI (RPi) was used as a broker. Both systems, the PLC and the RPi, have enough computing power for these tasks. All data exchange is done over the local WLAN or internet cables in an encrypted way to secure data security and safety.

The used room climate IoT sensors are mainly self-sufficient. They produce the energy necessary for their operation by themselves, using photovoltaic panels and are connected to the local WLAN. In this way no additional cabling is necessary. In many buildings, intelligent lighting systems with IoT room climate sensors are already available, alternatively existing systems can be upgraded at almost no cost. As an alternative solution, other existing MQTT-clients are used, providing the relevant data. All these sensors send the data via MQTT to the PLC- or RPi-broker. The WLAN used for data communication was set up as a non-trusted WLAN. As only measured data was exchanged and no actions were triggered over that network, this level of security was determined as sufficient for this prototype.

Within the prototype two different databases were applied: an InfluxDB and a MySQL database (cmp. [48]). Both databases are available as an open source software. The InfluxDB has the advantage that it is optimized to store timeseries (cmp. [49]). For an analytic tool, the prototype applied the software PowerBI in the first version. It is a common analytic tool and widely spread in the real estate industry. After using the system for several months, the users were asked about their experience using the two prototypes to safeguard a human centric solution. Therefore, interviews were carried out with the key users documenting their feedback for each of the tasks supported by the prototypes. Regarding the database, they did not recognize any differences. As InfluxDB is optimized for time series data this database was selected for further usage.

Regarding the data granularity, in a first step the sample rate was 5 minutes for all devices as this was expected to be precise enough for usage and sustainability reporting as well as the real time monitoring. After the test phase the key users stated that they need more granular real time data to be able to analyze the reason for over- but also for under-energy usage. As they found out, they can use the data in addition to recognize upcoming failures and if no energy is used, to identify existing failure of a device. According to the demand of the key users on data granularity the sampling rate was set to one minute for the energy measurement and to five minutes for the room climate parameters.

Regarding the analytic tool, they mentioned that the user interface of PowerBI was familiar to them as they have used it already for other tasks. As this tool is quite widely spread, the time to train people was rather short. The users were capable to adapt the reports and generate additional ones in a short time frame. But the amount of data generated by the IoT devices was so large, that this analytic tool came to its limits. The time to start the application was more than 30 seconds. To overcome this shortcoming in the next version Grafana (version v8.4.4, OSS edition) was used, which showed a much better performance with less hardware resources needed.

Based on the feedback and the additional requirements of the key users, the concept was enlarged to directly interact with the service staff either via email or by triggering an event in the existing Maintenance Management System (MMS), the Computer Aided Facility Management (CAFM) or the Enterprise Resource Planning (ERP) system (cmp. [47]).

- Email information: It immediately alerts the personnel and gives information about which parameter is too high or too low at which sensor. Based on this information the recipient can easily identify where an action has taken place.
- Triggering and existing MMS/CAFM/ERP system: In this case, a ticket is created with the information described above.

Based on the results of this first prototype the described setup was tested in several other historical buildings to gain more insights.

The application of MQTT as messaging protocol and platform technology fulfilling the sustainability reporting requirements regarding data completeness was proven by an analysis of the database on the completeness of data. Based on the analysis, the sensor and MQTT software was optimized, to be able to store locally more data in the case of the internet not being available. The accuracy of the IoT enabled energy measuring sensors was validated by comparing the prototype usage data with the data of the calibrated measuring devices. As the analysis of the deviation of the measured data was very low, the setup of the prototype was approved in respect of accuracy. Regarding usability of the user interface the key users carrying out the maintenance of the buildings were questioned using semi structured interviews and the feedback validated that the prototype provides the necessary data, analytics features as well as an easy to use human system interface and optimized the human system interaction.

IV. Conclusion and Discussion

The new EU directive on ESG asks for an elaborated reporting of the energy usage within buildings and a permanent optimization of the consumption. Based on an extensive literature research the relevant parameters to monitor ESG were defined. Using the results of a research project about availability of emerging technologies, the usage fields of these technologies and their interrelation, the authors developed an IT architecture and a prototype to cover the new demands of the EU taxonometry directive especially in existing and historical buildings. The prototype consists of:

1. IoT enabled sensors capturing the data,
2. a MQTT-broker that gathers data from the IoT devices, standardizes it and sends the data to
3. a central database system to store and analytic tools to analyze the data to set actions for optimization.

IoT devices capture the necessary data of energy usage and the room climate in a valid, efficient way. The usage of cheap, self-sufficient IoT sensors that can easily be installed as an add-on to the existing environment, reduces cost and time of implementation within the building. The reuse of already implemented PLC devices that act as MQTT broker makes the approach even more efficient. So, this solution asks on the hardware side only for small “upgrades” in the switchboards of the existing buildings and the installation of self-sufficient IoT sensors and therefore accomplishes a very cost-effective implementation.

Big Data systems, either on premise or in the cloud, store the data, merge it and put it into relation. Using this data, analytic or dashboarding tools like PowerBI or Grafana can provide aggregated information at low cost, which enable the identification of the main energy consumers and to identify actions to reduce the energy consumption in existing buildings. The application of cloud-based software tools which are already configured asks for no or only small license fees, make the implementation of further Big Data tools and analysis very effective. The availability of the room climate data helps us to safeguard the well-being and prevents overshooting action through a single focus on energy consumption. In addition, the solution enables the technicians to identify the reasons for the misusage of energy and to set steps for an optimal space utilization. Both analytic tools provide a convenient user interface and human system interaction.

Based on the results of the usage of the prototypes, further research and prototyping are necessary in the following areas. The first question is, what granularity of data is necessary to enable in-depth analysis in the area of optimization and to use the data also for preventive maintenance. The second question deals with the analysis of the gathered data. The amount of data generated points in the direction of ML as a tool for automatic analysis. The next area for further research is how the current usage data, existing building automation and smart building technologies can automatically optimize the operation and energy usage while safeguarding the well-being. The last area is the change of the user behavior. During the tests it was realized that the users’ behavior has a very large influence on the energy demand. Therefore, the question arises, how a user interface giving feedback on the current energy consumption and suggestions for optimization has to be designed to influence the users’ behavior in the long run.

References

[1] UN Environment and International Energy Agency, “Towards a zero-emission, efficient, and resilient buildings and construction sector. Global Status Report 2017”, p. 13, 2017.

[2] E.-M. Asamer, N. Bachholz, A. Bauer, I. Bettel, S. Blauensteiner, J. Einfalt et al., “Census 2011 Austria – Results of the registerbased Census”, S. Blauensteiner (ed), Vienna, p. 59.

[3] A. Redlein and L. Grasl, “Impact of emerging technologies on facility services – a mixed-methodic approach on smart building technologies”, IECON 2018, 44th Annual Conference of the IEEE Industrial Electronics Society IEEE, pp. 807, 2018.

[4] A. Redlein and C. Höhenberger, “The prevalence of IoT in the facility services industry”, Journal of Facility Management Education and Research, p. 5, 2020.

[5] R. B. Johnson, A. Onwuebguzie and L. A. Turner, “Toward a definition of Mixed Methods Research”, 2007.

[6] B. Glaser and A. Strauss, “The Discovery of Grounded Theory: Strategies for Qualitative Research”, Sociology Press (Mill Valley CA), 1967.

[7] K. Schwab, “The Fourth Industrial Revolution”, World Economic Forum (Geneva), p. 184, 2016.

[8] Austrian Standards, „ÖNORM EN 15221-4 -Facility Management – Teil 4: Taxonomie, Klassifikation und Strukturen im Facility Management“, 2012.

[9] R. D. Pepler, “Psychological effects of heat”, in C.S. Leithead and A. R. Lind (eds.) *Heat stress and heat disorders*, London: Cassell, pp. 237-271, 1964.

[10] R. D. Pepler and R. E. Warner, “Temperature and learning: an experimental study”, ASHRAE Transactions, 74: pp. 211-219, 1968.

[11] D. P. Wyon, I. B. Andersen and G. R. Lundqvist, “The effects of moderate heat stress on mental performance”, Scand J Work, Environment & Health, 5: pp. 352-361, 1979.

[12] D. P. Wyon, “Human responses to cyclic changes in the thermal environment”, Editions INSERM, 75: pp. 153-161, 1979.

[13] G. Langkilde, “The influence of the thermal environment on office work”, in: P. O. Fanger, O. Valbjörn (eds.) *Indoor Climate*, Kopenhagen: Byggeforksningsinstitut, 1978.

[14] G. Langkilde, K. Alexandersen, D. P. Wyon and P. O. Fanger, “Mental performance during slight cool or warm discomfort”, Archives des Sciences Physiologiques 27, A pp. 511-518, 1973.

[15] G. Schrader, W. Bischof and H. Horn, „Mentale Leistung unter variierten Raumklimabedingungen“. Stadt- und Gebäudetechnik, 37, 7, pp. 212-214, 1983.

[16] P. Wargocki, D. P. Wyon, “Research report on effects of HVAC on student performance”, ASHRAE Journal, Oktober 2006, p. 2, 2006.

[17] C. S. Sale, “Humidification during the cold weather to assist perennial allergic rhinitis patients”, Ann. Allergy 29, pp. 356-357, 1971.

[18] A. Gelperin, “Humidification and upper respiratory infection incidence”, Heat. Pip. Air ,Condit. 45, pp. 77-78, 1973.

[19] G. H. Green, “The effect of indoor relative humidity on absenteeism and colds in schools”, ASHRAE Trans. 80, pp. 131-141, 1974.

[20] G. H. Green, “Indoor relative humidities in winter and the related absenteeism”, ASHRAE Trans. 91, pp. 643-653, 1985.

[21] K. Fiedler, H. Hoyer, „Logistische Regressionsanalysen zum Einfluss von Wohnumwelt, Wohnhygiene und Lebensweise auf die Häufigkeit und Dauer akuter respiratorischer Erkrankungen bei Kleinkindern“, Zbl. Hyg. 198, pp. 204-214, 1996.

[22] J. E. Laviana, F. H. Rohles, P. E. Bullock, “Humidity, comfort and contact lenses”, ASHRAE Trans. 94, pp. 3-11, 1988.

[23] H. Sommer, J. Johnen, P. Schongen and H. Stolze, “Adaptation of the tear film to work in air-conditioned rooms (office-eye syndrome”, Ger. J. Ophthalmol. 3, pp. 406-408, 1994.

[24] M. Sato, S. Fukayo and E. Yano, “Adverse environmental health effects of ultra-low relative humidity indoor air”, J. Occup. Health 45, pp. 133-136, 2003.

[25] L. M. Reinikainen, J. J. K. Jaakkola and O. Seppänen,“The effect of air humidification on symptoms and perception of indoor air quality in office workers – A six-period cross-over trial”, Arch. Environm. Health 47, pp. 8-15, 1992.

[26] L. M. Reinikainen, L. Aunela-Tapola and J. J. K. Jaakkola, “Humidification and perceived indoor air quality in the office environment”, Occup. Environm. Med. 54, pp. 322-327, 1997.

[27] F. Leusden and H. Freymark 1951, „Darstellungen der Raumbehaglichkeit für den einfachen praktischen Gebrauch“,: Gesundheitsingenieur 72 Heft 16, pp. 271–273, 1951.

[28] M. G. Apte, W. J. Fisk and J. M. Daisey, “Associations between indoor CO2 concentrations and sick building syndrome symptoms in U.S. office buildings: An analysis of the 1994–,1996 BASE study data”, Indoor Air 10, pp. 246-257, 2000.

[29] A. N. Myhrvold, E. Olsen and Ø. Lauridsen, “Indoor environment in schools – Pupils’ health and performancein regard to CO2concentration”, In: S. Yoshizawa, K. Kimura, K. Ikeda, S. Tanabe, and T. Iwata (eds) *Proceedings of Indoor Air ’96: The 7th International Conference on Indoor Air Quality and Climate*, Nagoya, Vol. 4, pp. 369–374, 1996.

[30] D. Shendell, R. Prill, W. J. Fisk, M. G. Apte, D. Blake and D. Faulkner, “Associations between classroom CO2 concentrations and student attendance in Washington and Idaho”, Indoor Air, 14, pp. 333-341, 2004.

[31] R. Shaughnessy, U. Haverinen-Shaughnessy, A. Nevalainen, and D. Moschandreas, “Carbon dioxide concentrations in classrooms and association with student performance: a preliminary study”, In: *Indoor Air ‘05 – Proc. 10th Internat. Conference On Indoor Air Quality and Climate*, Beijing, China, Vol. 1, pp. 373– 376, 2005.

[32] O. A. Seppänen, W. J. Fisk, M. J. Mendell, “Association of ventilation rates and CO2 concentrations with health and other responses in commercial and institutional buildings”, Indoor Air 9, pp. 226-252, 1999.

[33] Y. Peng, L. Fan, W. Jin, Y. Ye, Z. Huang, S. Zhai et al., “Coloured low-emissivity films for building envelopes for year-round energy savings”, Nat Sustain 5, 339–347 (2022). https://doi.org/10.1038/s41893-021-00836-x

[34] A. Redlein, “Modern Facility and Workplace Management”, Cham: Springer, p. 145, 2020.

[35] F.-J. Ferrández-Pastor, H. Mora, A. Jimeno-Morenilla and B. Volckaert, “Deployment of IoT edge and fog computing technologies to develop smart building services”, Sustainability vol 10(11), p. 3832, 2018.

[36] J. Rothweiler, “Using IoT to do away with stuffy air”, *www.swisscom.ch.* [Online]. Available: https://www.swisscom.ch/en /business/enterprise/themen/iot/iot-climate-monitoring-decentlab.html #:~:text=New%20IoT%20system%20monitors%20indoor%20climate %20conditions%20The,CO2%20and%20VOCs%2C%20temperature %2C%20humidity%20and%20barometric%20pressure. [Accessed: Apr. 28, 2022]

[37] Tado GmbH, “The smart thermostat for you”, *www.tado.com*, 2016 [Online]. Available: https://www.tado.com/gb/thermostat-heating [Accessed: Apr. 28, 2022]

[38] M.-C. Dubois and Å. Blomsterberg, “Energy saving potential and strategies for electric lighting in future North European, low energy office buildings: A literature review”, Energy and Buildings, vol. 43, no. 10, pp. 2572–2582, 2011, doi: 10.1016/j.enbuild.2011.07.001.

[39] KONE Corp., “Improving “people flow” in 1.1 million elevators globally with IBM watson IoT and IBM cloud”, *www.ibm.com*, 2016. [Online]. Available: https://www.ibm.com/case-studies/kone-corp [Accessed: Apr. 28, 2022]

[40] L. Cozza, “Intellithings announces roomme, the first solution to enable person-specific, room-level presence-based operation of smart home devices”, *www.globenewswire.com*, 2019. [Online]. Available: https://www.globenewswire.com/news-release/2019/01/06/1680907/0/en/Intellithings-Announces-RoomMe-the-First-Solution-to-Enable-Person-Specific-Room-Level-Presence-Based-Operation-of-Smart-Home-Devices.html [Accessed: Apr. 28, 2022]

[41] SAP SE, “SAP leonardo digital innovation system capabilities & success stories”, SAP Leonardo, 2017.

[42] D.R.P. Patnaikuni, S.N. Chamatagoudar, “A Model for Predictive and Prescriptive Analysis for Internet of Things Edge Devices with Artificial Intelligence”, in S. Smys, R. Bestak, R. Palanisamy, I. Kotuliak (eds), *Computer Networks and Inventive Communication Technologies . Lecture Notes on Data Engineering and Communications Technologies*, vol 75. Springer, Singapore, 2022. https://doi.org/10.1007/978-981-16-3728-5_25.

[43] K. Shafique, B. A. Khawaja, F. Sabir, S. Qazi and M. Mustaqim, “Internet of things (IoT) for next-generation smart systems: a review of current challenges, future trends and prospects for emerging 5G-IoT scenarios”, IEEE Access vol 8, pp. 23022–40, 2020.

[44] C. Baretschneider, „Entwicklung eines IoT bis Analytics Lernszenarios und der SAP-Umsetzung für das österreichische Schulwesen“, Masterthesis, TU Wien, Vienna, 2018.

[45] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari and M. Ayyash, “Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications,” in *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347-2376, Fourthquarter 2015. Doi: 10.1109/COMST.2015.2444095

[46] MQTT, “MQTT: The Standard for IoT Messaging”, *www.mqtt.org*, 2022. [Online]. Available: https://mqtt.org/ [Accessed: Apr. 28, 2022]

[47] A. Redlein, C. Baretschneider, C. Höhenberger, “Practical applications of emerging technologies in the FM sector”, in *The 19th EuroFM Research Symp*, Tuuli J, Ed., The Hague: EuroFM, pp 35–41, 2020.

[48] R. Han, L. Kurian John, J. Zhan, “Benchmarking Big Data Systems: A Review” in *IEEE Transactions On Services Computing,* vol. 11, no. 3, pp. 580-597. Doi: 10.1109/TSC.2017.2730882.

[49] P. Krivic, E. Gruberovic, I. Podnar Zanko, I. Cavrak, “Evaluation of Selected Technologies for the Implementation of Meter Data Management System” in *10th International Conference on the Internet of Things (IoT ’20)*, October 6–9, 2020, Malmö, Sweden. ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3410992.3410999