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Building management system based on brain computer interface. Review

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Abstract: The article provides an overview of Brain Computer Interface (BCI) solutions for intelligent buildings. A significant topic from the smart cities point of view. That solution could be implemented as one of the human-building interfaces. The authors presented an analysis of the use of BCI in specific building systems. The article presents an analysis of BCI solutions in the context of controlling devices/systems included in the Building Management System (BMS). The Article confirms the possibility of using this method of communication between the user and the building's central unit. Despite many confirmations of repeatable device inspections, the article presents the challenges faced by the commercialization of the solution in buildings.

Key words: BCI, BCI challenges, BMS, intelligent building, review

1. Introduction

A trend that has been developing for several years in building control systems is to increase the level of automation and integrity with people. Modern buildings themselves should be able to take care of the most efficient energy consumption combined with the highest possible quality of life indoors [1]. User as an element of the building system is not only the element on which the control status depends, but also the system manager. Each user should be able to easily control the building to the best possible degree. It should be easy from both points of view: user and system. The system user can communicate with the building automation system using many interfaces, one of them being brain waves. Researchers and companies describing the development of technology indicate this interface as a special one, thanks to which we will soon be able to communicate in the same way as with the use of others, e.g., voice [2]. The way of controlling with the use of brain waves is not new in the world of science [3–11]. For several years, there has been a significant increase in the number of articles related to the use of this interface in helping paralysed people who are unable to issue commands in any other way [12–14]. From the point of view of building control, the use of this interface by people with disabilities is significant because this method becomes very universal. We will have some special cases when BCI will not be able to process information from the brain to the building. Every human being generates a series of signals produced directly by the brain. The current interfaces, e.g., voice, exclude people with a defect and speech problems from controlling. Similar issue we can have in the other interfaces. In this publication, the possibility to use Brain Computer Interface (BCI) in the context of smart buildings is presented. The aim of the review is to check in which elements of the Building Management System (BMS) can and in which cannot BCI be implemented. The current state of the art in control devices by BCI is considered. The concept of what the control could look like is presented and will be examined in future work. During current research certain obstacles that may affect the transition from the incubation period of the solution in laboratory conditions to the acceleration and dissemination stage were encountered. The solution analysis indicated which Electroencephalography (EEG) devices should be used in the context of buildings.

The concept of intelligent buildings and the fight against the reduction of energy used by buildings is analysed on a global level. The European Union in the commission to monitor the digital transformation issued a document describing the problem of buildings, and thus the challenges faced by modern systems [15,16]. The brain-machine interface can improve the quality of building control, and thus reduce energy consumption. To achieve that goal, BCI should move from research and development (R&D) to production.

2. Building management system

The current building management systems have an extensive structure and communication systems [17]. Many systems that make up the entire BMS, most often consist of a central system that plays the role of a supervisor and a control and information exchange centre [18]. All systems performing specific tasks in the building communicate with the central unit to obtain specific information or inform about the actions performed. Often, the central system also plays the role of servers or databases to which the user can connect through numerous graphical interfaces or mobile applications. We can distinguish two main groups of systems in terms of the control unit:

– central unit responsible for control;
– located in the building [19];
– cloud-based [20];
– distributed across all devices [21];
– no central unit – devices/systems control with their algorithms.

The central unit located in the building is a common solution. Thanks to it, we can reduce the distance between devices and the central unit. The level of security in systems of this type is much higher because communication often does not go outside of the building. Central units of this type allow for communication with wired systems, such as serial connections, Controller Area Network bus (CAN) and Logical Channel number standard (LCN) interfaces, as well as other wireless devices with a relatively low range, such as Bluetooth, Zigbee, and radio waves of control devices. Profit from moving the central unit to the cloud allows you to use learning algorithms. The algorithm can increase their precision by learning in many buildings with different environmental conditions, making access to data easier. Unfortunately, it may be less secure for building management data. Lack of connection to the cloud may mean the building does not perform an action, e.g., access is denied. Modern units can protect themselves against such problems and pass some algorithms directly to the devices. Moving the central unit closer to specific systems or devices leads to a distributed control system in which data circulates from system to system. It is a very fascinating concept that reduces the number of necessary systems to a minimum but increases the demand for algorithms and the amount of data. It is difficult to say what is better and what is worse, most often the selection of the appropriate system depends on the needs of the building and the complexity of the systems used. Systems in which we do not have one centralized unit may have better control devices/buildings, e.g., better neural networks that train on many control objects and the update is done in real time. There are also building systems in which we do not have a central unit and each system works separately. In this case, according to many scientists, we do not talk about intelligent buildings because each system creates its system, but about system integrity. These systems most often use built-in control algorithms as well as their interface with the user, that unfortunately each system has its own. The system makes it difficult for users to control building values in an easy and friendly way.

In each building system, a level of interaction between the building and the user is specified. Several degrees of integrity are listed below:

1. The user makes decisions responsible for the performance of actions by a given building system.
2. The user issues commands influencing the system decisions, but the system can make the decision automatically.
3. The user does not issue commands, however, the system monitors the behaviour and intent of the user and makes automatic decisions on this basis.
4. The user is not associated with the control system.

The analysis shows what factors form an individual building automation systems and what ways of interaction with the user may occur in them. This analysis shows where the human-BMS interfaces occur.

A full building management system can consist of many subsystems that perform a specific role, nowadays, the trend is scalability or the possibility of using an increasing number of systems connected to the central unit. However, we can list groups of systems with which we will surely meet intelligent building control systems:

– **Heating, Ventilation and Air-Conditioning (HVAC) control** – this system is responsible for moving air between rooms in the building including outdoor air, along with cooling and heating. This system is also responsible for keeping the best air quality in the rooms by controlling CO_2, PMs, humidity and temperature. Optimal comfort level for users is essential for that part of the BMS [22, 23].
– **Lighting Control** – this control system is responsible for indoor and outdoor lights. The system includes actuators and sensors that allow to manage the lighting in the best possible way, to keep comfort of users and care of energy consumption. It is also responsible for correct lighting during emergencies [24].

- **Device Control** – this sub-system manages the devices across of building. It can be connected by many protocols and interfaces, for example: ZigBee, Modbus, CAN, LCN, KNX standard. The aim of that system is helping users to control devices as TV, blinds, audio, oven, microwave, fridge. This system can be very helpful for disabled users [25].
- **Fire Protection and Alarm (FPA) system** – it is a critical sub-system of the BMS due to the impact on human life. The real-time FPA monitors by sensors' smog, fire, gas, and other factors which act on human life. The system can be directly connected to the fire brigade system [26].
- **Security system** – that system is mandatory in the intelligent building to protect home and people. The system can detect danger via sensors and turn on alarm and can connect with security guards. This system includes devices which control access to the building or special rooms [27].
- **CCTV system** – it is a system for transferring images from cameras across the building. The system can record and transfer data to increase the security level and help users. Users can monitor events at any time with the use of various types of devices via that system.
- **Energy system** – this system is responsible for monitoring the energy consumption from smart meters. It is also a part of the energy safety system in the building. The part of that system can be responsible for renewable energy sources [28, 29].
- **Water system** – this system is crucial from a green building perspective. It is responsible for providing the information about consumption and share data from water meters. That system is also responsible for turning off the water source during the emergency.
- **User interface system** – that system is responsible for communication with user via interfaces. That system collect data from users via sensors.
- **Data Centre as optimal management** – that system is usually handled by the software part of the BMS. It is responsible for collecting data and using that to learn artificial intelligence, fuzzy logic or other.

Each of the above types of systems found in buildings may have a different scope, among others. We are focusing on communication between the BMS and users. Table 1 presents integrity level via human interface of each of the building automation systems. The available system on the market and solutions described by the researches [30–39] are presented. The user can now communicate through various interfaces with which he can influence the operation of the system in a greater or lesser way. These interfaces are shown in Fig. 1.

So far, we can distinguish several ways. The user communicates with the building through the management system: **Manual interface** – performed by physical control devices, e.g., switches, dimmers, regulators; **Wire-operated** – connected directly to the system using the building automation interface, e.g., KNX [40]; **Working/Operating wirelessly** – connected with the use of wireless communication, e.g., Wi-Fi, Bluetooth; **Sensory interfaces** – making measurements, e.g., motion detection, window opening; **User peaking (identification) interfaces** – fingerprints, face, and eye lens; **Voice interfaces** – supporting voice commands issued by the user; **Gesture interfaces** – detecting and responding to gestures; **Measurement interfaces of user's physical properties** – body temperature, pressure, weight; **Intelligent control** – modes of automatic work with the use of logic based on advanced technical solutions, e.g., neural networks [41]; **Brain waves interface** – new interface in the building control, we think, this interface should be available in production soon.

Table 1. Table of human integrity of individual building sub-systems

	Integrity Communication Level			
System name	**1 (User's action)**	**2 (User interact with building)**	**3 (Building monitor user)**	**4 (Autonomous building)**
HVAC	×	×		
Lighting control	×	×	×	
Device control	×		×	×
FPA			×	×
Security system		×	×	×
CCTV			×	×
Energy system			×	×
Water system			×	×

× – The building system communicates on a given level with the user

Figure 1 shows how the system user can influence the operation of the entire building system. Using these interfaces, we can influence the behaviour of the building through appropriate actuators. Building systems are often based on a few of the interfaces mentioned, or even one. And here the question arises, whether the BCI interface will be sufficiently reliable, easy, and accessible during control? Unfortunately, now it is still difficult to clearly answer this question. It requires a lot of research on the real object for quite a long period of time, at least a year, to be able to compare technical aspects and user opinions. This is undoubtedly an interesting direction in the method of building control.

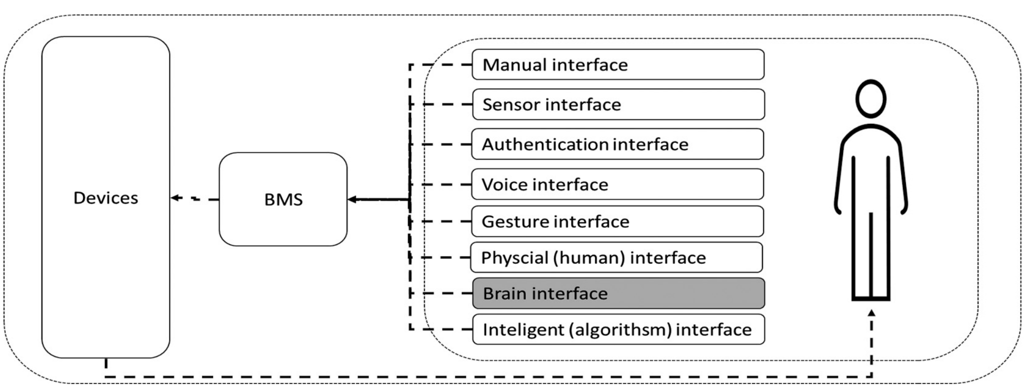

Fig. 1. Interfaces between human and building

Another question that is closely related to the BCI interface is what we can control, what commands to issue. In the case of this question asked in this way, we have many examples of use in publications: lighting control, device management. In many of them, it all depends on the equipment used and the method of learning. The accuracy of the equipment is significant in this case because it determines the number of readable commands and the quality of their collection. The method of learning that we will use in buildings should be strictly matched to a specific building because a person may have different associations, emotions and brain waves.

3. Brain computer interface

In many publications we can find many descriptions of what BCI is and how it works [42–48]. BCI can be defined as the entire process of obtaining information from the brain through classification, analysis, to the result and feedback about the action performed, or it lack. The general measurement process using BCI is shown in Fig. 2.

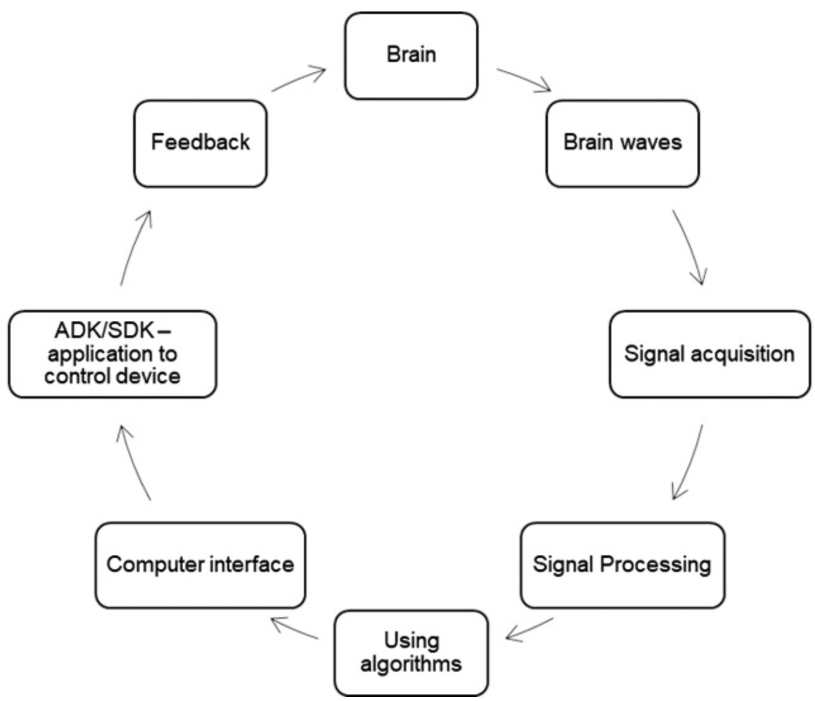

Fig. 2. Block diagram of process measurement brain activities

We could recreate the process presented in Fig. 2 based on the analysis of many publications. The starting point is, of course, the brain from which we collect/read brain waves. We carry out the process through special electrodes. These signals go to the Hardware (HW) which reads and then processes the data further by specialized signal detection algorithms. These signals are most often transferred to the central unit, e.g., in the form of a computer/server/cloud, where subsequent calculations are performed, and commands are issued for objects. Feedback returns with or without a control effect.

Current BCI solutions allow us to download data from different places, which means that we are a better understand the functionality of our neurons. There are different methods of measurement: EEG, electrocardiography (ECoG), magneto encephalography (MEG), electrical signal acquisition, functional magnetic resonance and near infrared spectroscopy [6]. Current devices focus on EEG, therefore, from the perspective of available technologies in terms of buildings, we focused precisely on this measurement method. Before creating a building management system, based on BCI, we need to know what we measure and how.

In controlling buildings with the use of brain waves, it is best to use information collected from as many points as possible located on the skull, thanks to which we increase the precision of measurements, of course, the number of measurement points is proportional to the price of the device, but we will return to this in further sections describing the devices available on the market. An issue related directly to the device is the choice of waves that we will test, in many devices available on the market we focus on EEG waves because we can easily read the necessary data for the control process. In EEG waves, from the point of view of intelligent buildings, waves above 7 Hz are interesting because we can detect the focus and intentions of the user. Since the signals collected from the brain are of incredibly low voltage values, the systems needed for the measurement must be of incredibly good quality, also in this case the price is at stake, but also the mobility of the device [49–51].

When measuring data using electrodes, the measuring system receives physical signals in the form of the brain's voltage potential. These signals can be classified and divided, some of them are difficult to measure, which means that measurement systems often ignore them. We can list the types: **Steady State Visually Evoked Potentials (SSVEPs)** – generated during stimulation in the form of an image, sound, vibration (touch); **P300** – a signal occurring approx. 300 ms from the external factor action; **Slow Cortical Potentials (SCPs)** – these signals can be trained by a human; **(Non) Motor Signals (Sensorimotors)** – signals related to the movement or the lack of it; **Hybrid Signals** – which are a combination of the above two types [7].

A summary of classifications is presented in Table 2 when we have a column with a possibility to adapt in the building each type of classification. SCP is a slow signal that requires training obtaining satisfactory repeatability. This signal is used to control devices. Of course, the mea-

Table 2. Summary of classifications of potential signals with the use of the BMS

Signal	**Additional information about signal**	**Count of choices**	**Training**	**Using in BMS**
SSVEP	Measure from visual cortex	High	No	High
SCP	Slow voltages from the brain signals	Low	Yes	Low
P300	Measure infrequent stimulations	High	No	Medium
Sensorimotor	Modulation from sensorimotor activities	Low	Yes	Medium

surement can be influenced in the same way as in other types of signals: psychophysical aspects, mental state, motivation, and many others [52].

Some of BCI systems are based on neural networks which help classify signals from EEG devices. Ortiz and Tapia used the estimation algorithm represented in the below equation [53].

$$\frac{\mathrm{d}}{\mathrm{d}t}\hat{x}_t = \boldsymbol{A}\hat{x}_t + W_{1,t}\boldsymbol{\sigma}(\hat{x}_t) + W_{2,t}\boldsymbol{\varphi}(\hat{x}_t)\,u_t + \boldsymbol{K_1}e_t + \boldsymbol{K_2}e_t, \tag{1}$$

$$\hat{y}_t = \boldsymbol{C}\hat{x}_t.$$

$\hat{x}_t$ is the state vector of brain signals; $\hat{y}_t$ is the output of the neural network; $\boldsymbol{A}$, $\boldsymbol{K_1}$, $\boldsymbol{K_2}$ are the constant matrices of appropriate dimensions which are adjusted during training; σ and φ are the vector functions; $\boldsymbol{C}$ is the matrix output, it is assumed previously known; the parameters W are the weights.

3.1. BCI devices for BMS

To be able to perform measurements and thus control the system, we need appropriate devices. These devices have many features. Many devices on the market are adapted to medicine, where we need high precision, and therefore the cost of a single device is expensive, for building applications we would need devices with satisfactory precision, but also at an affordable price and easy to use. By measuring a (technological) system we understand a complete system that allows the transformation of brain waves into control instructions, and thus both HW and Software (SW). In the HW device overview, we focused on the following device features:

- the way of communication,
- number of measurement channels,
- dedicated software (SW) is needed,
- type of measured waves.

The best-suited system for integration with the BMS is presented in Table 3. Most of the devices described in Table 3 use wireless connectivity. One wired communication system has been considered (6) as an example, there are many more wired solutions, however, from the building management point of view, only wireless solutions may be of interest.

Emotiv company (1) has a few types of HW. The features of that platform are: good balance between the count of EEG sensors and performance; maximized wearability; good Application Programming Interface (API) for communication with our applications; additional motion sensors. Emotiv uses Bluetooth connection as wireless in 5.1 versions. Neurosky has in the store MindWave headset (2). MindWave is an elementary device with limited EEG sensors. A big benefit of that solution is its availability for other applications. We do not need any additional SW to connect directly with a headset. Muse (3) produces headbands. This solution is rather used to sleep tracking and meditation but in the control system we can use signals from the Muse SW to create a system based on BCI. OpenBCI (4) delivers open-source hardware which is compatible with popular microcontroller platforms. The main part of that system is Cyton Board. The headset is more of a prototype than in other vendors. Wearable Sensing creates more professional devices (5). DSI series are dry EEG headsets. This system has some good features: good quality of bandwidth, optimal API without additional SW, comfortable and ambulatory. The ANT Neuro inspiring technology (6), presented in Table 2, is a wired system with clinical quality. It has up

Table 3. Collection of BCI systems for BMS

No.	System name	Connection type	Count of channels	Dedicated SW	Bandwidth [kHz]
1	Emotiv EPOC [54]	Bluetooth	5–32	Yes/No	0.2–45
2	Neurosky MindWave [55]	Bluetooth	4	No	3–100
3	Muse 2 [56]	Bluetooth	4	Yes	?
4	OpenBCI [57]	Bluetooth	4–16	No	?
5	Wearable Sensing DSI [58]	Bluetooth	4–21	No	0.003–150
6	ANT-Neuro eego [59]	Wired	24–256	Yes/No	?
7	Neuroelectrics Enobio [60]	Wi-Fi/USB	32	Yes/No	0–125
8	MBT Smarting [61]	Bluetooth	17	Yes	0–250
9	Advanced Brain Monitoring B-Alert X-Series [62]	Wi-Fi	9–24	Yes	0.1–100
10	CGX Quick [63]	Bluetooth	8–128	Yes	0–131

? – Value is not present in the datasheet

to 256 channels of EEG. The system is compatible with many platforms. A similar platform is manufactured by Neuroelectrics (7). This product is also dedicated for medicine. It has 32 EEG channels. The Company describes this system as dedicated for: Research, Clinical, Telemedicine, and Modelling Services. MBT Smarting Mobi (8) is presented to bring convenience and simplicity to research experiments, also with mobile. This system has a special Software Development Kit (SDK) and dedicated SW for Android. It has good bandwidth with submilisecond time precision. Advanced Brain Monitoring's wireless B-Alert from series X (9) is dedicated for neuroscience application (including also the BMS). The system is elementary to start-up. It has a special SDK with multiple options for data synchronization. The headset has an on-board accelerometer to detect position and movement. CGX in the series Quick (10) is a significant advancement EEG headset. A good feature of that is that they work with dry electrodes. This system can be integrated with a special SW. In the highest version the device has 128 EEG channels.

The number of measurement channels describes how many points on the brain we will receive information from. The greater quantity, the greater measurement accuracy is, but most often the price goes together, it results from the use of better and more efficient measurement systems. The data from more measurement channels increase the accuracy. A large data set allows for the creation of more complex control blocks. Quality of measurements depends on many more factors and parameters of the equipment. One of them is the value of the bandwidth that we can measure. Many of the equipment suppliers provide it very reliably, but unfortunately some of them lack such data (3, 4 and 6). The measurement bandwidth affects what measurement signals from the brain we will be able to measure. From the point of view of integration with the building system, an important parameter listed in the table is the need for additional software that will be necessary to read data directly from the device. In some cases, the software is used as an intermediary between the device and the application that we can create for the building system (1, 6 and 7). The best solution is when there is no need for additional SW solutions to receive data from the device. Depending on what type of target device we want to communicate with, we must verify the integration methods, e.g., SDK or API are available and possible to use.

4. BCI as interface in the building

In Table 4, the used user-device communication interfaces in building systems are summarized. This shows what interface is currently used and where the authors notice the possibility of using or increasing the use of BCI in the context of the BMS.

Table 4. Table of human interfaces usage in individual building sub-systems

System name	Human interfaces	BCI current usage	Possible to implement BCI
HVAC	Manual, Sensor, Voice, Physical	No	High
Lighting control	Manual, Sensor, Voice, Gesture, Physical, Brain	Yes	High
Device control	Manual, Sensor, Voice, Gesture, Brain	Yes	High
FPA	Manual, Sensor	No	Low
Security system	Manual, Sensor, Authentication	No	Low
CCTV	–	No	Low
Energy system	Sensor, Physical	No	Medium
Water system	Sensor, Physical	No	Medium

The analysis shows that the user communicates using different types of interfaces. In device control systems and lighting control the use of the BCI interface is highly recommended. The use of this interfaces is not visible in other building systems. Nevertheless, we see in many of them the possibility of using it as an additional way to manage building systems. According to the analysis, a great need is to use this interface in HVAC systems where it could introduce a great innovation in the field of ventilation, air conditioning and heating parameters control. In the following list, a few sample research papers describing the use of the brain-human-computer interface in devices control were collected (device control and lighting control):

- Ghodake and Shelke used the interface as only way to communicate with home devices without using any interface other than brainwaves. The classification of the level of concentration ranging from 0 to 100 was used as input to the control system and to define the on or off state. A NeuroSky helmet was used as the source of information collect by device [64].
- Lee used the EEG signal to control the mouse of the computer in which the application simulating the building was running, and in which each device had its alphanumeric identifier. The system classified the signs read from the human brain. The algorithm used in the publication requires significant training before making the first control attempt. The authors used the Emotic EPOCH helmet [65].
- Holzner, like Lee, used a similar teaching method and classification of places in the building, which were marked with the appropriate letters. He also used virtual reality as an add-on in control. The system used was based on P300 signals [66].
- The use of virtual reality as a support for BCI was also presented by Edlinger and Alrajhi in their publications. The measurement method is like that used by Holzner. Waves used in steering are also P300 [67, 68].
- Alshbatat used PIC-P40 in conjunction with EMOTIV EPOC to control home appliances based on P300 waves [69].
- Virdi described a similar control system using Arduino and a different command recognition algorithm [70].
- Boucha used a combination of two interfaces in his work: speech and the user's brainwaves to control [71].
- Putze used SSVEP classification to control home equipment with additional support from Augmented Reality. The accuracy of presented classification is above 85% which on scale of using that system to control is marked above good. Putze controlled Lights, Blinds, and TV [72].
- Kosmyna shared the concept using BCI for smart environments in the home. Research presents how BCI can control 5 devices in the home system. Accuracy was 81%. Authors prepared a test scenario which was using to verify the probability of control [73].
- Cortez presents accuracy in control home devices with P300 waveforms. The maximum accuracy was about 90%. Authors used multilayer perceptions and SVM in the control process [74].
- Abdul and others described using SSVEP system to help human in the control without hands. They used additional devices such as smart glasses to improve the quality of the control. They got accuracy above 80%. Smart glasses were used to decode QR from devices [75].

5. Concept of using BCI building interface in the smart city

The long-term idea that authors noticed during the analysis is the possibility of integrating the BCI helmet with every building user enter or interact with. An example would be a simple scenario. A person leaves home to work equipped with a system with a BCI interface that will intelligently protect them and prepare them for a mode in which energy consumption will be as effective as possible. A person reaching his workplace can also manage the parameters of his room, box, or other sector in which he works through some form of authentication. It can regulate the temperature and lighting to make it work as optimally as possible.

The concept of multi sharing using BCI is close to creating the smart city. The whole open-source concept of BCI still requires a lot of work and standardization, maybe a special data exchange protocol, which could be available for all building systems as one of the reading protocols. Many trends of leading companies, e.g., telecommunications, de-fine this method of communication as crucial [2].

In many publications we find the results of research into the use of BCI in building control, individual devices. Kather described the use of the P300 method to control various applications including cameras with 65% confidence/repeatability [76]. Edlinger used SSVEP for asynchronous control of home equipment such as TV, telephone, light, door [77]. The control is carried out by means of icons on the control panel which translate into the appropriate devices of the building. Kim used a similar method to control a virtual building through an on/off action [78]. With an approximate application SSVEP was applied by Park, Putze and others [72, 79–81]. The parameters of his room, box, or other sector in which he works through some form of authentication. It can regulate the temperature and lighting to make. Dobosz described using BCI for mobile devices, the mobile devices and the buildings can support each other via BCI [82].

6. Challenges and problems

The analysis described in this paper aims to check the state of the art and present the concept of using BCI as one of the building control interfaces. Current scientific works contribute to the development of this interface, however, a lot of work is still needed to make it universal and accessible, such as voice control. Several challenges are facing this interface as mentioned by Ramadan [3] and Lee [43], from the point of view of building control, we can specify: (1) standards, (2) lack of accuracy, (3) electro physical errors, (4) system performance, (5) HW, (6) privacy and security.

The first of the challenges and at the same time the problems are the lack of standardization that would allow the application and building systems to adapt to the interface standard. Currently, BCI equipment suppliers create their solutions based on their knowledge and experience without synchronization between different suppliers. In this case, there are various ways of communicating and obtaining data from the interface, and the same method of data collection is different. Even when we look at the same type of 7th EEG sensors, we have many differences. In the future, when we have the standardization of this method of communication included in the standards, it will improve and, in our opinion, it will accelerate the popularization of this interface in building systems.

The second challenge that we are currently facing is the measurement accuracy and repeatability of decisions taken by BCI systems. In all BCI solutions, the accuracy depends on the time and amount of data transferred. In some building applications where operational reliability is critical, e.g., security, the current BCI parameters may not be sufficient. To achieve greater accuracy and repeatability in BCI systems, it would be necessary to wear equipment and take continuous measurements over a longer period. Building control can better adapt such an interface that, for example, medical applications, where human life may depend on the reliability of the interface.

The third problem that BCI systems face is the complexity of the human nervous system. The human brain is an extraordinarily complex system, measuring systems strive to be able to read the electrical signals of the brain as well as possible. The direction that can reduce the measurement problem is mounting the measurement systems under the skull. A big problem is also the non-linearity of the EEG signal, which makes it highly susceptible to noise that is difficult to filter out. The classification methods currently available and used are more efficient on linear signals than on non-linear ones. An additional problem is the multitude of external signals affecting the reading from the sensors.

The performance rate has three components: the target repeatability ratio, the number of classes (system complexity), and measurement time. The ideal values for a BCI system are high repeatability, low complexity, and fast measuring time. In building systems, complexity may turn out to be crucial because the number of reads and classified commands may be large, depending on the control algorithm used. The measurement time could be as short as possible because it depends on how quickly we can be able to e.g., turn the device on or off, or adjust the parameters of the building.

The fifth problem is the state of the current hardware that we measure electrical impulses from the neurons in the brain. The most popular and best methods for the building are a non-invasive measurement system. This method is burdened with many measurement errors. The invasive system is more resistant to disturbances, but nowadays, it requires a surgical procedure, which is a serious interference with the human organism.

The last challenge is to properly secure your data, just like you protect your account access data and many others. We need to secure our sensitive data, which is neural information. Currently, we use this interface mainly for research purposes, but in the future, when it becomes more popular, you should take care of their security. Maybe in the future it will also be used as a method of payment. The data retrieved from the brain is private.

In the development of BCI systems, we must ensure that its development is more controlled and systematized, as is the case, for example, in the field of telecommunications. There are international organizations such as 3GPP. During previous research authors verified latencies in building based on telecommunication which show that we are able to use that medium of transmission [83]. Current verification in the laboratory shows that the accuracy from tests usually is above 80%, sometimes above 90%.

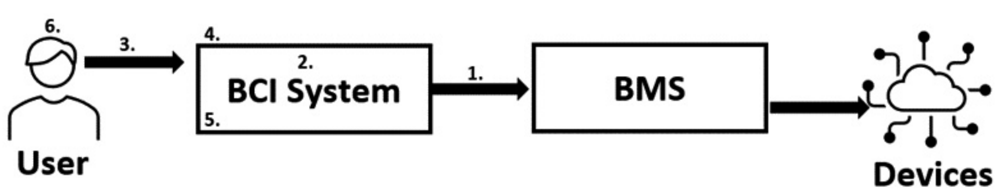

Fig. 3. Challenges location in the process of control BMS via BCI: 1 – standard communication between BCI and BMS; 2 – accuracy of BCI system; 3 – errors during measuring signal from the brain; 4 – performance problem of BCI system; 5 – HW quality of BCI; 6 – Privacy and security data from brain

Figure 3 presents the challenges for BCI. Currently, many authors use their own communication system. Some of the listed articles present solutions with an accuracy of above 90% which is classified as almost good. BCI systems use some filters to help ignore errors. Completing these challenges will ensure an accuracy of above 95% on a high number of test users. The BMS does not need incredibly low latency, but the quality of signals should be good due to important systems included in the BMS. That topic was considered in section 3.1 where the EEG devices were described. Security is crucial in the current world, and we should have special rules how data from the brain can be transferred in the network.

7. Conclusion

Summarizing the review of BCI technology in terms of its use in building and household appliances control was presented. Authors anticipate that this interface is a particularly useful technology that will certainly develop in the next several years. It is also worth emphasizing that this interface can be used by every person, including people with disabilities, which means that a new trend in the development of interfaces, which is BCI, may contribute to even greater popularity of building management systems. Such communication will allow us to exchange information with devices by thinking about it without any additional action. Ultimately, this interface can be used in all building systems such as building automation management, security, and access, as well as in measurements. Many aspects, described in Chapter 6, remain to be done in terms of the development and dissemination of this technology, however we can already say that BCI introduces a new evolution of the BMS. In this publication, the authors show their contribution to building control using this system and introduce the state of the art. In subsequent publications, we would like to present the results of research on the use of BCI in building control with a strong emphasis on energy efficiency. The solution is based on cloud computing. All systems will benefit significantly from BCI. Currently, the world is trying to reduce the energy consumption of buildings because it is one of the main emitters of CO_2. The use of an additional new interface, hopefully, will contribute to the quality of control. In our opinion, proper building management can help with this. During further research, we want to verify whether these systems can help us with this.

In the next publication, the use of BCI as the main interface to control HVAC systems in the BMS will be verified. HVAC based on BCI allows us to control the air quality by people who has a problem with setup parameters of that system. Additional value of using BCI in HVAC can be a better algorithm of control, e.g., Artificial Intelligence connected with BCI.

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