Advanced Workplace Management Platform for Monitoring and Management of Indoor Climate Parameters

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Abstract. The aim of this paper is to develop an advanced system of indoor parameters monitoring and management to increase operational efficiency and improve the life in buildings. The system will monitor the environmental parameters, using a system of sensors for temperature, relative humidity, and the main indoor pollutants measurement. Reports related to the building's CAD plans are defined. Thus, for each room, the corresponding indoor parameters can be viewed in real time. In addition, using the read parameters a heat index is computed by several methods. The solution helps to locate the problems with certainty, due to the relationship with the CAD plans. It could support the facilities managers by alerting maintenance teams when the parameters exceed certain values. The sensor system is cheap, and its scalability allows the management of an unlimited number of objectives.

1. Introduction
The Internet of things (IoT) is composed of interrelated computing devices, mechanical and digital machines provided with unique identifiers and the ability to transfer data over a network without human intervention. In the last period the number of applications that make use of the IoT has increased dramatically and it spans areas from business and manufacturing to home, health care, and knowledge management [1]. Over time, the IoT is expected to have significant home and business applications, to contribute to the quality of life and to grow the world’s economy [2]. Using cloud-based applications, the IoT solution provides the possibility of logging measurements from locations all over the world and of visualizing and analyzing the gathered data from any device connected to the Internet. The main objective of IoT based environment monitoring system is to provide environmental parameters read by sensors at remote location. Environment monitoring is the field where wireless sensor networks have been first used [3].

In IoT we can talk about several types of platforms, hardware platforms where IoT applications run, such as Arduino, UDOO, FriendlyARM, Intel Galileo, Raspberry PI, and other and software platforms that are utilized to provide IoT functionalities, among these platforms, Operating Systems are vital because they incorporate IoT operating capabilities. Cloud Platforms are another important computational part of the IoT. Among them we can mention the following: Thingwork, SensorCloud, RealTime.io, OnePlatform [2].

Another aspect to consider in IoT systems is how to communicate with the sensors, how they transmit data. Among the most used technologies are RFID and sensor networks, they are considered the fastest growing information and communication technologies [4].
In the field of Facility Management (FM), the impact of IoT is growing and IoT is playing an important role in improving FM services. According to the definition given by the International Facility Management Association (IFMA), FM is a profession that includes several disciplines helping to ensure the functionality of the built environment by integrating people, space, processes and technology [5]. To help facility managers in their activity there are various FM software. Usually a FM software is complex, using integration with various digital technologies such as BIM, RFID, GIS. A wide variety of commercial software applications, including ARCHIBUS[6], BIM 360 Ops/BIM 360 Field [7], EcoDomus [8], Onuma [9], QFM Facilities Management Software [10] and IBM TRIRIGA [11], are available on the market to meet the requirements of FM [12]. Both RFID and sensor systems have been considered to have great potential for facilitating FM activities and processes [12].

The integration of Building Information Modelling (BIM) and IoT devices can provide facility managers with automated ways for building operation & maintenance, building performance management, energy management and developing disaster & emergency response strategies [13]. In this context, the aim of this study is to use an FM application and to integrate it with an IoT sensors system that provide data received from sensors that measure indoor parameters. Moreover, it is desired to correlate the data read by the sensors with BIM or with the architectural plans of the building in digital format (Computer-Aided Design, CAD).

The chosen FM software is ARCHIBUS, it is an enterprise application that provides a holistic approach to facility and infrastructure management throughout the entire life cycle of the building. It is made up of several integrated modules, allowing applications to have the same work environment and a common database. The data read by sensors will be related to CAD plans and not to the BIM’s of the building. The reason is that most of the existing buildings, built before the BIM development, have at most 2D plans for the building, some of them also having CAD electronic format.

The integration of ARCHIBUS with the data read from the sensors will be done in the Space Planning & Management module and come to the support the FM team by displaying the corresponding indoor parameters for each room, in real time. The application could alert maintenance teams when the parameters exceed certain values.

2. Method and procedure

2.1. Sensors system description

The sensor system used in this study is composed of a Raspberry Pi board, mounted in a specific box (named Raspberry Pi3 case), which is produced in series and sold separately. The sensor system also includes a BME680 sensor, which, as seen in fig. 1, is mounted in a small, blue box, built especially for it by 3D printing.

![Figure 1. Sensor system: white box with raspberry Pi board and blue box with sensors](image_url)
BME680 sensor, made from Bosch is an integrated environmental sensor. It integrates for the first time high-linearity and high-accuracy gas, pressure, humidity and temperature sensors. The gas sensor within the BME680 can detect a broad range of gases to measure air quality for personal wellbeing. Gases that can be detected by the BME680 include Volatile Organic Compounds (VOC) from paints (such as formaldehyde), lacquers, paint strippers, cleaning supplies, furnishings, office equipment, glues, adhesives and alcohol [14]. According to Datasheet, the operating ranges for BME680's sensors are: [-40, 85°C] for temperature sensor, [0, 100%] for the sensor that measures relative humidity, and [300, 1100 hPa] for the sensor that measures relative humidity. For the temperature sensor, the accuracy value is ±0.5°C if the temperature is around 25°C, and in the rest of the operating range it can reach ±1°C. For humidity sensor, accuracy tolerance is ±3%. Pressure sensor has an absolute accuracy of ±0.6 hPa. For the gas sensor the accuracy value depends on the parameter it measures. Thus, for Ethane it is 5%, for Isoprene / 2-methyl-1,3-Butadiene it is 5%, for Ethanol it is 5%, for Acetone it is 5% and for Carbon Monoxide it is 2%.

The sensor is connected to a Raspberry Pi 3, Model B + board [15]. It is a 1.4 GHz 64-bit quad-core processor, dual-band wireless LAN, Bluetooth 4.2 / BLE, faster Ethernet, and Power-over-Ethernet support.

2.2. Building CAD’s plans integration in ARCHIBUS

The application used is ARCHIBUS, a multilayer, 100% web application. Client layer provides intuitive web interfaces in which users can enter and view data as well as numerous reports. At application layer, ARCHIBUS can work on a Tomcat, WebLogic or other application server. For integration, many web services are developed at the application level. Back-end application development is done in java programming language. Regarding the database level (DB), the application allows the use of several types of databases. In this study, ARCHIBUS software is deployed on a WebLogic server running on Linux OS (Operating System) and the database used is Oracle.

In terms of business, ARCHIBUS is composed of several modules, each module having certain applications. ARCHIBUS module Space Planning & Management consists of four applications. One of them, the application named Space Inventory & Performance, mainly deals with the classification of spaces and the determination of the rentable surfaces, being the starting point for the other applications of space management.

For the calculation of the rentable area, the surfaces can be classified according to the main international standards. For this classification, clear, correct, and complete building CAD plans are needed. ARCHIBUS has a well-made hierarchical structure of the space in building, see fig. 2 (This hierarchy is also performed at the database level). In user interface is developed a screen where space is structured hierarchically in Geo-Region, Country, Region, State, City and Site and another screen where space is structured at a lower level, composed of Site, Building, Floor and Room. Fig. 2 shows the screen in which the space is classified from Site to Room. In addition, using this hierarchical structure, the CAD plans of the building can be viewed and queried.

This work aims, using this hierarchical structure of space to relate the information read by the sensors located in a certain room with the corresponding CAD plans. In addition, using the data read from the sensors, some heat indices will be calculated. Using building plans, reports for indoor parameters read by sensors will be developed in ARCHIBUS.
3. Solution and implementation

In order to improve the management of the input data, read by the sensors, the solution for the ARCHIBUS integration software will be modularly designed and will be composed of three sub-solutions (applications), see fig. 3. In this structure any module could be replaced, for example another physical sensor system could be used and, why not, another application instead of ARCHIBUS (A3-Client Application).

A1 represents the sensor’s solution, it is composed of A1b (Sensors configuration application) that represents the applications of the sensors on their Printed Circuit Board (PCB) and A1a (Sensor application). It is very useful that certain parameters of the sensor application can be modified from the outside, without accessing the software on the Raspberry Pi. For this purpose, there is A1a which may or may not be under the ARCHIBUS framework. Next is A2 (Sensors management application), it is a specific application for this sensor monitoring project. As can be seen from the image, it is integrated with both A1 and A3 applications. For this, A2 contains two APIs. This application was developed to ensure the independence of the A3 application from the sensor’s solution. Through the configurations of the A2 application (A2 depending on the sensor’s solution), it is possible that the A3 application remains unchanged regardless of the sensor system used.

The A3 application (Client application) is the final application, which contains the front-end part, meaning the interaction with the user. Here the data are used effectively, and the various reports are made. This could be ARCHIBUS or another application; for this study the A3 application will be ARCHIBUS.
Figure 3. Applications and connections between them

Technical details about the realization of the applications A1 and A2 will not be presented in this paper. Regarding the customization of the A3 application, only reports made will be presented, as well as formulas that were the basis for their creation. The chosen hardware solution will also be presented.

3.1. Reports developed in Client application

For the monitoring of indoor climate parameters, in A3, Client application (ARCHIBUS in the present study) two reports were developed. The purpose of the first report is the real-time monitoring of the data received from the sensor system presented in subchapter 2.1. This is done at room level. Thus, using ARCHIBUS the hierarchical structure of the space (see subchapter 2.2), for a certain chosen room will be displayed the information represented in fig. 4. The screen is structured in five zones (panels), the one on the left side of the screen represents the tree structure of the space, another panel contains heat index (HI), next is the panel for temperature, humidity and air quality instantaneous values and at the end two panels with temperature and indoor air quality variation in time.

Figure 4. First report developed in Client application

Since not all the indoor thermal climate parameters used in computation formulas for the well-known thermal comfort PMV (Predicted Mean Vote) and PPD (Predicted Percent of Dissatisfied) indices were
available and rough approximations were not wanted, heat indexes (HI) that consider only indoor air temperature and humidity have been searched in the literature. HI is an accurate measure of how hot it really feels when the effects of humidity are added to high temperature. According to [16] this index was empirically obtained by experimentally subjecting a sample of people to varying temperatures and humidity values and polling them as to the discomfort they felt. Numerous formulas for HI can be found in the literature. In the report presented in this paper three well-known formulas are used to calculate heat index. One of the formulas is a 16-term multiple-regression model, developed by the National Weather Service (NWS) [17], starting from the model originally obtained by Steadman [18], see equation 1.

\[
\text{Index}_{\text{heat}} = 16.923 + 1.85212 \times 10^{-3}T + 5.37941R - 1.00254 \times 10^{-4}TR + 9.41695 \times 10^{-5}T^2 + 7.28898 \times 10^{-3}R^2 + 3.45372 \times 10^{-4}T^2R - 8.14971 \times 10^{-4}TR^2 + 1.02102 \times 10^{-5}T^2R^2 - 3.86464 \times 10^{-5}T^3 + 2.91583 \times 10^{-5}R^3 + 1.42721 \times 10^{-4}T^3R + 1.97483 \times 10^{-7}TR^3 - 2.18429 \times 10^{-6}T^2R^2 + 8.43296 \times 10^{-5}T^2R^3 - 4.81975 \times 10^{-5}T^3R^3
\]  
\text{where: T - temperature [°F];} \\
\text{R - relative humidity [%].}
\]

The second used formula is Rothfusz model [19], see equation 2.

\[
\text{Index}_{\text{heat}} = -42.379 + (2.04901523 \times T) + (10.14333127 \times rh) - (0.22475541 \times T \times rh) - (6.83783 \times 10^{-3} \times T^2) - (5.48171 \times 10^{-2} \times rh^2) + (1.22874 \times 10^{-2} \times T^2 \times rh) + (8.5282 \times 10^{-4} \times T \times rh^2) - (1.99 \times 10^{-6} \times T^3 \times rh^2)
\]  
\text{where: T - temperature [°F];} \\
rh - relative humidity [%].
\]

The Temperature-Humidity Index (THI), developed by Kibler [20] is the third used formula, see equation 3.

\[
\text{THI} = 1.8 \times T_a - (1 - RH)(T_a - 14.3) + 32
\]  
\text{where: T_a - average ambient temperature [°C];} \\
RH - average relative humidity as a fraction of the unit.
\]

The significance of temperature humidity index can be found in [21]. According to authors, for THI>80, 100% of subjects (human / animal and plant) feel not comfortable. THI values in interval 75-80 corresponds to 50% of subjects that are not comfortable, for 65-75 interval, 100% of subjects are quite comfortable, for 60-65 interval 50% of subjects are partially comfortable and for THI<60 almost 100% has uncomfortable.

Rothfusz formula is used by other well-known weather channel, National Oceanic and Atmospheric Administration (NOAA) [22]. The National Weather Service of NOAA provides, in a tabular form, the significance of this heat index [23]. For pairs Relative Humidity (%) - Temperature (°F) are given the already computed values for HI and each value has a color corresponding to: Caution, extreme Caution, Danger and Extreme Danger.

All three formulas are implemented in the software presented in this paper and one formula or another can be easily chosen. At the time of writing this document in application is used equation 1 and the value obtained with it can be seen in the gauge indicator in fig. 4.

The purpose of the second developed report is to display, for a room, the values read by the sensors for that room in real time, both as an instantaneous value and as a chart that is updated with the last value read.

Using the hierarchical structure of space in ARCHIBUS (see subchapter 2.2), the user can choose a room in which he wants to see the values read by the sensors located in that room.

After the choice has been made, a new screen opens. The user sees this report as being composed of two main parts, on the left side is an area where the floor plan can be seen and on the right side is the
information about a certain room within that floor. In the example used in fig. 5, one can see the ARCHIBUS stand that was selected from the plan of an exhibition pavilion. On the right side of the screen one can see, presented as current values as well as charts, the following parameters: temperature, relative humidity, carbon dioxide equivalent and total volatile organic. The charts are updated each time the application read the parameters values. The browser refresh rate is set at 20 seconds.

The highest importance was given to the temperature and thus a new functionality was developed, the selected room is colored according to different temperature thresholds. In tab. 1 are presented the temperature limits for different EN15251 [24] category limits. In accordance with these, the following types of highlighting have been established: red <19°C, orange 19-20 °C, yellow 20-21 °C, green 21-25.5 °C, yellow 25.5–26 °C, orange 26–27 °C and red >27°C. The highlighting limits are only informative, it does not impose any decision or restriction so for the purpose of this work, the operative temperature, to which the EN15251 standard refers, has been approximated to the indoor air temperature measured by the studied sensors.

Table 1. Temperature thresholds for room highlighting, according to EN15251 category limits

| EN15251 | Buildings with HVAC systems- Landscaped office (open plan office) |
|---------|---------------------------------------------------------------|
| CATEGORY I | CATEGORY II | CATEGORY III |
| Lower limit | 19°C | 20°C | 21°C |
| Upper limit | 25.5°C | 26°C | 27°C |

This second report is in the testing phase and for this reason the sensor reading values are not of the presented sensor system but taken from the ThingSpeak platform [25]. The main parameter, the temperature, with which the rooms are highlighted on the floor plans, exists in both cases, so there will be no problems when the parameters received by application A2 will be changed.

Figure 5. The second report developed in Client application
3.2. Hardware solution

In fig. 6, it is presented a complete hardware solution, including Sensor’s solution. Currently, the system is made in the Local Area Network (LAN) but the solution also allows Wi-Fi connection. As shown in the figure, the environmental sensor BME682 integrates four sensors: gas, pressure, humidity and temperature sensors. The hardware sensor’s system is composed of the BME sensor and Raspberry Pi device, including physical interfaces (it supports both wire and wireless connection). The physical system is also scalable, so it can be allowed to connect any number of sensor systems.

![Figure 6. The hardware architecture of the sensor monitoring solution](image_url)

The application server can also be connected wire and wireless in LAN. Although the figure of the hardware solution is represented schematically and the ARCHIBUS application (as "execution environment") to highlight that in addition to the existing application, was added the new sensor monitoring application, both now representing a whole, called ARCHIBUS application.

As can be seen from fig. 6, in the network layer, care must be taken when communicating and establishing data transmission protocols and other details, in order to successfully connect all devices in the network.

4. Conclusions

In this paper an advanced system of indoor parameters monitoring, and management is proposed. The need to correlate CAD or BIM plans with data read from indoor climate parameters sensors in the context...
of workplace platforms specific to FM applications is presented. The FM software called ARCHIBUS is chosen. For it, a modular solution that allow the integration of various sensor systems is designed. The solution consists of three applications, one of them is represented by physical sensors, located together with the specific software on the PCB of a Raspberry Pi board in this case, the second is a sensor monitoring application, it is a kind of buffer application between sensors and the ARCHIBUS application. With the help of this second application the independence of the client application (in this case ARCHIBUS) compared to the sensor solution is ensured. At the same time, it is designed flexibly, being able to easily adapt to various sensor solutions. The third application in this study is ARCHIBUS. The solution is designed in such a way that it can be ARHIBUS software with another one.

The data received from the sensors could be sent directly to the cloud, see [26], and decisions could be made directly based on the information received from them [27] but in this paper is performed the integration of the information received from the sensors in an enterprise application. In this way the CAD capabilities of the application are used, ARCHIBUS also has the ability to integrate BIM models but in the studied buildings only CAD plans of the buildings were available.

Two sensor’s monitoring reports are developed in the application. In the first report the visualization of the data read by the sensors is performed, and a heat index is computed by several methods. Three calculation formulas are implemented in the software, and there is the facility to choose which of them to use.

In the second report is made the visualization of the data read by the sensors in the CAD plans, in addition the respective room is colored differently depending on various temperature thresholds. In both reports the hierarchical structure of the space existing in ARCHIBUS is used; by selecting the desired camera, the results of the measurements made by the sensors in that room will be displayed.

Using these reports, facility managers are helped in their work, they can have an overview of each floor of a building, colored according to certain temperature levels. This allows an overview in real time of the problem areas. They can see if it is an isolated room or a large area.

Other modules in ARCHIBUS can also be improved with the help of data received from sensors. The application can easily be customized so that alerts could be sent to maintenance teams when the parameters read by sensors exceed certain values or even maintenance tickets could be generated under certain conditions. In areas where the heat index repeatedly exceeds certain values, teams that perform high-performance measurements of comfort parameters could be sent. This identifies areas with potential thermal comfort problems.

The solution is designed so that it can be integrated in larger scale buildings or complex buildings like hospitals, production buildings because in ARCHIBUS an entire portfolio of buildings can be managed. In future studies will be considered possibilities to use the solution to control the existing HVAC systems of these buildings. The optimal solution between the local control of the various actuators, for example, directly from the Raspberry Pi software and the possibility of manual or automatic control from the client application will have to be found. The advantage of centralized control, from the client application, is that various decision algorithms can be implemented based on information received from several sensor systems, located in different rooms of a building.

Remote troubleshooting for sensors can be done. Using the connection from the LAN or Wi-Fi network, you can access, through an application such as remote desktop, directly the software on Raspberry Pi and make announced corrections or reset of parameters. Or you can use directly the interface of the A1a application that allows the direct modification from the outside of certain parameters of the software on the Raspberry Pi board. The causes of problems can be multiple, starting with the physical failure of the sensors, updates of libraries used in the code that can generate problems, network configuration changes and most undesirable, error in writing the code. It should be noted that one of the reasons why testing solutions for as long as possible is useful is the fact that if there is an error to correct in the source code on the Raspberry Pi board, not only must the server be restarted but the correction does not spread automatically on all sensor systems, it will have to be made individually for each one.

The system is scalable in terms of both hardware and software, which means that the number of sensor systems monitored is not a problem. Although the sensors do not allow very accurate measurements, the solution is inexpensive and suitable for simultaneous monitoring of many spaces.
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