Visualization of Indoor Sensor Data to Reduce the Risk of Covid-19 Infection

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Abstract

Indoor air quality (IAQ) is one aspect that can diminish the transmission of Covid-19 inside buildings because of the virus's aerosol-type spreading. The impact of different air quality parameters on the infection risk needs to be investigated, and appropriate visualization can improve understanding of the discovered findings. If a high-risk situation is revealed, it is necessary to respond accordingly, e.g., inform visitors or improve ventilation. This research work presents a review of visualization possibilities in research papers in the IAQ domain. Based on this review and interviews of different stakeholders, we propose a framework that allows the definition of needs, assets, and appropriate tools for visualization for virus risk monitoring. A prototype of a visualization tool is developed as a part of a larger project that uses sensors installed in hospital, school, and university to gather air quality parameters for Covid-19 risk calculation.

Keywords

Visualization, sensor data, indoor air quality, monitoring system, respiratory infection risk, Covid-19 risk

1. Introduction

Covid-19 has changed the lives of everyone. Not only individual people are influenced in their everyday lives. Organizations and countries must work on new regulations and procedures to provide a secure environment for work and living. According to WHO [1], the primary mode of Covid-19 transmission is direct contact of people through large respiratory droplets. WHO admits [1] that the alternative way of Covid-19 transmission through aerosols is still unclear and less important than the droplet mode. The third possible way is indirect transmission through fomites [1].

However, more and more studies [2], [3], [4], [5] are investigating the possible aerosol type transmission of Covid-19. Aerosol type transmission is one of two possible ways of airborne transmission of viruses [3]. During a sneeze or a cough, droplets are typically greater than 5 μm, but, for example, by talking and even exhaling the evaporated microdroplets are so small ($< 5\ \mu m$), that they can remain in the air for hours [3] and beyond 2 meters [2] so impacting people beyond the distance recommended by public health authorities.

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Researchers argue [4] that the currently recommended measures are not sufficient to protect from microdroplets with viruses. Among the measures recommended by researchers [4], [6] to make the protection more effective are providing adequate ventilation with outdoor air and avoiding overcrowding, especially in public buildings.

IoT based building management systems (BMS) are now having more extended functionality. However, all-inclusive BMS with data analysis features are rather an exception [7]. It should be noted that many buildings do not have BMS. Therefore, the idea of developing a specialized indoor air quality monitoring system is obvious.

Ventilation and indoor air quality are named among the aspects that can diminish the transmission of Covid-19 inside buildings [8]. In addition, more specific air quality parameters such as relative humidity, temperature, and CO_2 level are investigated, and it is stated that they can affect infection risk [9].

The authors of this paper participated in a government-initiated project to trace and proactively prevent in-room spreading of SARS-CoV2 and other respiratory viruses. Researchers propose a solution that uses embedded systems equipped with sensors for the automatic acquisition of indoor parameters. A physical model is developed to assess the virus's risk spread indoors based on sensor data and multi-modal factor analysis. Information about measurements and calculations is visualized and communicated to various users in real-time or for data analysis later [10]. This paper focuses only on sensor data visualization, potential infection risk, and revealing weak places in a building and event organizing procedures. During the project, it was found that good visualization of data and obtained information is of great importance in both operational and strategic decision-making.

The rest of the paper is organized as follows. Section 2 gives an overview of sensor data visualization. Review and analysis of scientific research papers in the IAQ domain regarding visualization options are presented in Section 3. Section 4 describes the framework we have developed for data analysis and visualization goals, and Section 5 provides prototype implementation details for the visualization tool. In Section 6, the conclusions and future work are given.

2. Sensor data visualization

In the IoT domain the importance of visualization of sensor data is recognized. Different chart types and their usage rules for different data sets and the tool support for needed visualization are described [11]. They must be understood before starting the development of a web site for an IoT project.

Different chart's types are mentioned as a means available for IoT data visualization [11]: scatter-plots, histograms and bar-charts, bubble-charts, box-plots, and lines-plots. Some other types of diagrams are also used, as revealed from further studies in the indoor air quality domain. Each chart type can be used best for specific purposes, such as assessing a relationship or correlation, evaluating a distribution, comparing data, and studying a composition [11]. The chart type choice also depends on the data to be analyzed, particularly the number of variables, e.g., a single variable, two variables or more than two variables; also, the type is essential, e.g. if the data are discrete or continuous [11].

Some other aspects could also be evaluated that can support selecting appropriate charts. For example, for the same purpose, sometimes more than one chart can be used. In such a case, charts can be prioritized according to the peculiarities of human perception of different charts, user experience and education, the necessity to react immediately according to the gained information, and other features.

One of the possibilities to implement a data visualization solution can be also information dashboards, that are primarily used to represent business data. The dashboard content must be aligned with the specific demands of a person, group or function [12]. Still, as a concept of organizing, providing visual insight, and communicating the data to the end-user, the dashboard can be applied to sensor data. For sensor data visualization, the usage of a web portal or a mobile application is more common; however, some works also describe an implementation of a dashboard [13].

3. Indoor air quality paper review and analysis

To understand the domain-specific visualization features, a deeper analysis of visualization aspects in projects devoted to indoor air quality (IAQ) monitoring based on IoT technologies was performed. We analyzed the research papers included in the review [35], but only such papers were selected that use a web portal to display the IAQ measurements: [36], [15], [16], [32], [37], [38], [17], [18], [19], [21], [22], [30], [25], [26], [27], [34], [28], [29]. This decision is based on the fact that the web interface can be more effectively used for long-term data analysis, but not only to show the current situation as in the case of mobile applications. Some new research papers [14], [20], [24], [31], [39], [33] were added to the list, including one focusing on the IAQ and Covid-19 [23]. Further, the analysis of these research works regarding two aspects is presented: charts and other visualization tools used; analytical tasks performed and goals to be achieved with data visualization.

Line charts are the most frequently used visualization type to present the indoor air quality environmental variables measured by sensors. This can be concluded from the more profound evaluation of the selected papers. The results are shown in Table 1. 8 different line chart types were identified, whose variations depend on 1) the number of environmental variables and data sets depicted on the chart (see references in Table 1 chart types 1,3,6,8); 2) different levels of time detail [19], [16]; 3) some visual aids used on charts. For example, for a better understanding, some variations in line graphs are introduced by the number of y-axes [16], [32], [34], [33], and lines that represent predefined or computed level values [28] or thresholds [27].

Table 1 also shows different intents for visualization, that can be formulated mainly as ”comparison”, and more precisely ”comparison of data sets”, ”comparison with level values”, ”comparison of different environmental variables”, ”comparison with computed values”. However, in the case of one environmental variable and one corresponding data set, the intent is ”changes over time”, which means ”comparing values of the same variable in different time moments”.

The arrangement of many similar charts can also support the comparison. For example, the same chart type is applied for all measured environmental variables presented on the same dashboard page, so providing a possibility for indirect comparison [15], [27].

Table 1
Line chart variations used in IAQ domain

Chart type	Presented environmental variables / data sets	The intent for visualization	Sources	Examples
1. Line chart	one variable, one data set	Changes over time	[14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29]	Changes of CO_2 value
2. Line chart with predefined levels or computed levels	one variable, one data set	Comparison with level values	[27], [28]	"On" or "Off" level to perform activities
3. Line chart	one variable, two data sets (or more)	Comparison of data sets	[30], [26], [31]	Different CO_2 sensors in different rooms
4. Line charts with different level of time detail	one variable, one data set	Analysis on different detail levels	[16], [19]	Hourly, daily and monthly charts
5. Line chart with two (or even 3) different Y axes	Two (or 3) variables (one data set for each)	To compare more than one variables	[16], [32], [33], [34]	Temperature and humidity
6. Line chart, more lines for one environmental variable	One variable, one data set	Compare computed values	[23], [31]	Trends for AVG and Max values, real and predicted values are compared
7. Line chart - 1 Y axes represent 2 scales	Two variables, two data sets	Comparison of data sets	[22]	Temperature (C) and humidity (%)
8. Line chart with more lines for one environmental variable, many lines for different days	One variable, many data sets (one for each day	Comparison of hourly values in different days, can be compared with hourly average	[14], [31], [33]	Hourly values of CO_2 concentration in different days

Other chart types are used mostly in a few projects. However, some observations can be done (see Table 2). The rest of the used chart types can be grouped as follows. List/tabular form charts are displaying source data in table format [21], [19], [23] or alert history [26],

Table 2
Other chart types used in IAQ domain

Chart / visualization type	The intent for visualization	Sources	Example
1. Tabular form	Provide precise information	[19], [21], [23]	Numeric values
2. Alert list	History of events	[17], [20], [26]	When, where, what value exceeds the specified threshold
3. Widgets	Showing current value and ranges	[23], [25], [40]	Colors are used to show the value ranges
4. Bar charts	To compare	[16]	AQI indoor and outdoor on different dates
5. Map view	To show values in different locations	[38], [22], [26]	Moving sensors, geographical location of sensors
6. Cumulative frequency graph	Analysis support	[24], [31], [34]	For CO_2, temperature and others
7. Map of the room	Analysis support	[39]	Interpolated CO_2, temperature and RH
8. Box-plot	Analysis support	[24]	CO_2, temperature
9. Histograms	Analysis support	[14]	Frequency distributions of 15 min averages for temperature, RH and CO_2

[17], [20]. Real-time information is displayed by widgets in [40], [25], [23], or displayed by map view in [38]. Bar charts are used as an alternative for line charts for comparison in [16]. Still, chart/visualization types 6-9 (see Table 2) form a group for ”Analysis support”; they are more complicated than other graphs. The user should know what and how it is computed (e.g., interpolated in [39]) and showed on the chart according to the chart’s definition.

4. Data analysis and visualization framework

We based our Data Analysis and Visualization Framework on well known Zachman Framework ontology [41], [42] that classify different objects according to six dimensions such as *What? How? Where? Who? When? Why?* Our proposed Framework allows to describe detailed characteristics of data analysis and visualization for the Indoor Air Quality monitoring domain, keeping in mind that an additional application aspect of that solution can also be mitigating the impact of Covid-19.

We used the Zachman’s six dimensions and added domain specific meaning to these dimensions. We also added two new dimensions *Chart/visualization type* and *Data set characteristic*s to our framework to describe feasibility of visualization by different visualization means e.g. graphs, maps, charts etc. and to evaluate the appropriateness of these tools to the data set that

Table 3
Context of analysis and visualization

Question	Terms used
What is the object of interest (measured, monitored, and captured)?	Carbon dioxide (CO_2) concentration, temperature, relative humidity, particle concentration, IAQ level, infection risk, number of people, ventilation, surface area, the volume of the space, aerosol, respiratory droplets, an infected person, infected surface, type of activities, e.g. breathing, speech, coughing, singing
Who is the user of the information?	Room visitor, a regular user of the room, organizer of a public event, room manager, building manager, manager of an organization, policymaker, data analyst or researcher
Where is the data gathered or the user located?	User location or measurement place, e.g. auditorium, office room, hospital room, doctor's room, school, university, shop, hospital, public building, gym, office
When is the information available for analysis?	Online data, offline data, real-time information, historical information

Table 4
Visualization and analysis needs

Question	Terms used
How is the data processed, analyzed and visualized?	Automatic or semi-automatic data gathering, manual or automatic data analysis, manual or automatic warning, characteristics of user device (i.e. PC, laptop, mobile phone, etc.), room equipment for visualization/information.
Why is the user interested in this particular system?	- automatic or manual monitoring, - requirements for public buildings, - reaction on type of activity, creation of requirements for responding to an event type for a specific room, - suggestions for changing the working schedule, planning the use of spaces, - identification and improvement of room ventilating capabilities, event planning depending on ventilation options, fast and efficient ventilation of the room, - centralized and operational monitoring of the building and possible response, data analysis and finding deficiencies in the operation of the building, building improvement planning, - planned and controlled climate improvement in public institutions, - protecting yourself and others from the risk of infection

should be analysed. We interviewed experts of the domain (school, university, and hospital representatives) and analyzed the research papers to gather examples and use cases that correspond to all dimensions of the framework. Table 3 provides the context of the analysis and visualization with illustrating examples for the four questions from the framework. Table 4 shows examples for the visualization and analysis needs. As well as Table 5 provides examples for the two new dimensions.

Table 5
Visualization and analysis tools

New dimensions	Terms used
Chart visualization type	Chart types used for visualization (see Table 1 and Table 2), e.g. line chart or cumulative frequency graph and others
Data set characteristics	Number of environment variables presented with one or more data sets for each (see Table 1 and Table 2)

5. Software prototype based on data visualization and analysis framework

To verify our approach to providing data according to user needs, we developed a software prototype that supports various visualization and analysis opportunities described below. We placed *Aranet4*[1] sensors at the Faculty of Computing of the University of Latvia, Paul Stradins Clinical University Hospital in Covid-19 patients and doctors rooms, and Riga Teika Secondary School. Grafana platform and Highcharts charting library were selected to implement sensor data visualization in a software prototype.

The developed software prototype is based on the proposed Data analysis and visualization framework. The following example demonstrates one of the possible scenarios of potential use cases. We can assume the following values for 6 dimensions of the framework: (What; CO_2, humidity and temperature) , (Who; Building manager), (Where; Floor), (When; Current time), (How; Manual data analysis), (Why; Identification and improvement of ventilation capabilities) and the following values for the new dimensions (Chart/visualization type; building plan or line graph), (Data set characteristics; many environment variables and many data sets). According to these values, personalized view of the system prototype is provided. In this case two different reports, for example, building plan view and detailed analysis view are delivered to the user.

The building plan view provided in the software prototype (see Fig. 1) is aimed at displaying the operational information about rooms with sensors in buildings. The view shows a plan of several rooms in a building, for instance, on one floor. Sensors are represented as circles positioned in a plan according to their locations in rooms. Circle colours correspond to the current values of selected indicators measured by sensors. The ranges of indicator values and their corresponding colours are configured for each indicator. These settings are universal for the whole application and are used in all reports. On the right, the legend explaining the current range settings is shown. Circle colours are automatically refreshed every 10 seconds to display the newest measurements. Sensor circles are clickable and lead to detailed reports showing data for a room where the sensor is installed.

Depending on the analysis objective, a user can choose to display data about a particular indicator, such as CO_2, or alerts that show an indicator with the worse value for each sensor. An indicator along with its value is displayed when a user points on a certain sensor. By looking at the plan view showing alerts, it is possible to observe the overall perspective on the current

[1]https://aranet4.com

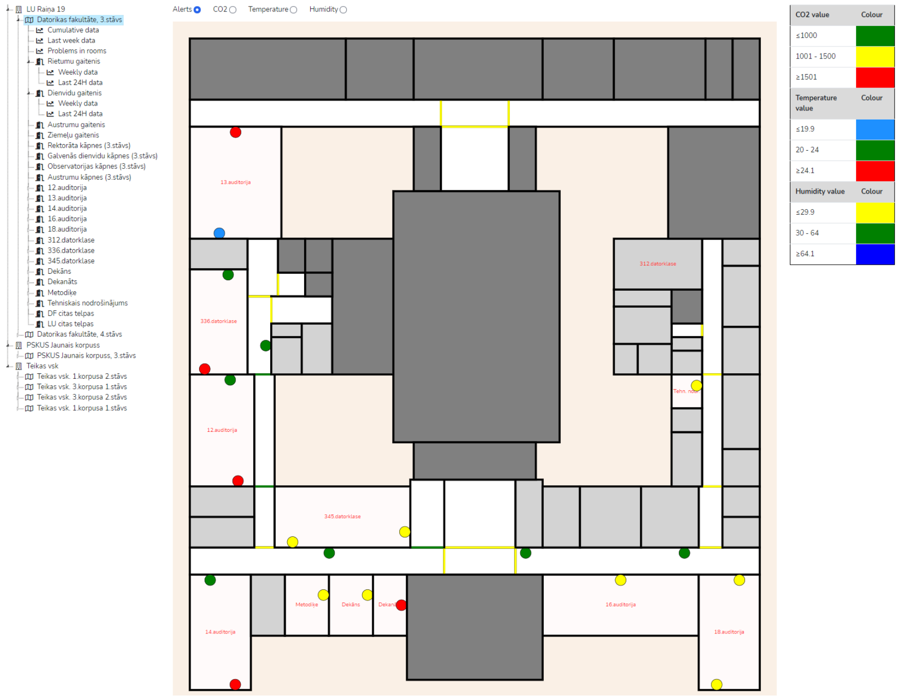


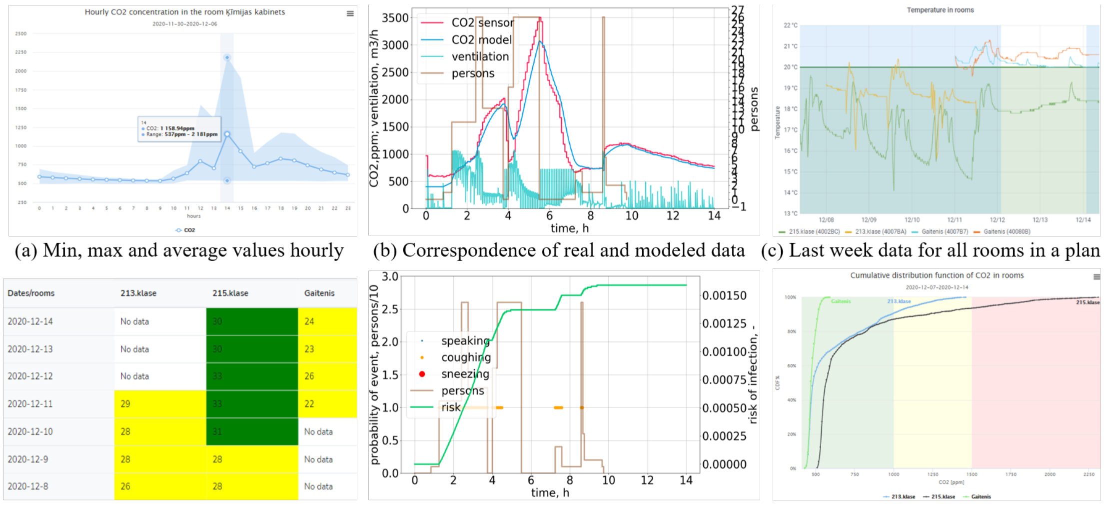
Figure 1: Building plan view

situation and quickly discover problems in particular rooms.

We have implemented several types of reports with different visualization techniques. Examples of such reports are given in Fig. 2. Reports allow analyzing CO_2 concentration, temperature, and humidity measured by sensors at a particular room level, observing and comparing data about several rooms in a plan, viewing data for different periods, zooming in and out data, and viewing the risk of Covid-19 infection. This collection of different report types build the foundation for the personalized views for the user of the prototype according to the current values for all dimensions of the analysis and visualization framework.

By analyzing information about a specific room, one can see unacceptable situations. Let us look at a real example of a room in a school. In Figure 2, chart (b), we see that the CO_2 level is about 3500, which is unacceptable, and chart (c) shows an increased risk of infection. The risk calculation was made on the assumption that the teacher was infected, spoke in class and sometimes coughed (see more details in [10]).

Figure 3 shows data from the same school but another room with a much better usage pattern. The first conclusions from the chart are following 1) the organization of classes in time intervals B, D and F had a favourable usage pattern; 2) ventilation performed during interval H for air exchange gave a small effect, but too much cooled the room; 3) the class in intervals I and J was in a cool room and its duration or the number of people visiting was too great; 4) in the interval L, it was turned on stronger ventilation or the door was partially open; 5) in the interval, Q we see the intensity of the room ventilation system. By collecting more accurate information about the premises and their use, it is possible to create an automatic recording of events, their



(a) Min, max and average values hourly (b) Correspondence of real and modeled data (c) Last week data for all rooms in a plan

(d) Problems in rooms (e) Risk of COVID-19 infection (f) Cumulative data for selected rooms

Figure 2: Chart examples implemented in the prototype

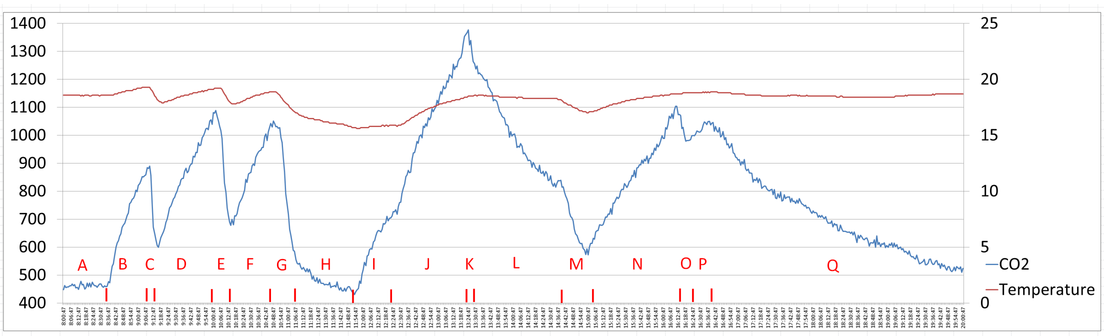


Figure 3: Measurement analysis in a class

visualization, and the creation of recommendations, for instance, by applying AI technologies.

6. Conclusions

We have presented part of the project that focuses on proactive prevention of in-room spreading of SARS-CoV2 and other respiratory viruses. Many involved stakeholders have a wide variety of analysis goals and working responsibilities. Visualization can help users understand the most critical information and react quickly according to people's responsibilities if the situation demands.

We conducted a comprehensive review of research papers to find the existing experience for visualization of results in the indoor air quality domain. Our proposal for a visualization framework bases on the findings from this review and interviews with stakeholders.

We developed a visualization tool prototype to provide the best visualization means aligned with the user's specific demands. The distinguishing features of the tool, built according to the framework, are observing of the whole building through building plans, navigation to detailed more specific charts for rooms, providing data in real-time or for a long-term period, supporting information visualization for immediate reactions or deeper analysis with sophisticated methods and professional knowledge.

The following steps are the systematic evaluation of our prototype by interviewing end-users from different categories in three organizations, where sensor data is collected (university, hospital, and school) to iteratively improve the tool and the proposed visualization framework according to the feedback from the users. During the practical use of the tool, it should be clarified what and how can be determined with AI techniques and how better to display the obtained information or recommendations to the user.

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