Towards a System to Monitor the Virus's Aerosol-Type Spreading

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Abstract. Recent scientific studies indicate that attention should be paid to the indoor spread of the Covid-19 virus. It is recommended to reduce the number of visitors to the premises and to provide frequent ventilation of the premises. The problem is that it is not known what the risk of infection is in a particular room at a specific time, when and what actions should be taken to reduce the risk. We offer a system that helps monitor the conditions in the premises with the help of sensors, calculate the risk of infection and provide information to reduce the infection risk. We give an insight into the created prototype with data collection from public spaces and data visualization according to user needs.

Keywords: Indoor air quality · Respiratory infection risk · Covid-19 risk · Sensor data · Visualization · Monitoring System.

1 Introduction

Covid-19 has affected people's lives as well as functioning of organizations and countries. Activities to guarantee a secure living and working environment are undertaken. WHO admits that the main way of Covid-19 transmission is through large respiratory droplets. At the same time there are many studies [20], [3], [13], [26] devoted to the Covid-19 transmission through aerosols. The microdroplets, that are smaller than 5 μm, fly beyond 2 meters [20] and keep in the air for hours [3], thus calling into question the recommendations of the health authorities. Therefore, the currently recommended protection is not sufficient against the viruses spreading with microdroplets [13]. Researchers recommend different activities to improve the protection, for example, by adequate ventilation [13] or avoiding overcrowding in rooms [21].

Among different technologies used to reduce the impact of Covid-19, Internet of Things (IoT) can be mentioned [4], [23]. IoT in healthcare can be used in

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different ways, including for development of efficient epidemic control systems in smart cities or smart buildings [4]. IoT solutions can ensure safe indoor environment by automating ventilation and air-conditioning or by tracking occupant counts [23]. Building management systems with data analysis features are not often used [12], thus a specialized indoor air quality system can be developed. The aspects that can be monitored to reduce Covid-19 transmission in buildings are ventilation and indoor air quality [6]. Besides, relative humidity, temperature, and CO_2 level are named as indicators that can affect infection risk [1].

The paper's authors participated in the project "New Technologies for Targeted Tracing, Testing and Treatment of Covid-19 Patients" (3T) supported by the National Research Program of Latvia. One of the main goals was to trace and proactively prevent in-room spreading of SARS-CoV2 and other respiratory viruses using smart rooms. We propose a solution that uses embedded systems equipped with sensors for the automatic acquisition of indoor parameters. A numerical model describing droplet and aerosol transport physics is developed to assess the risk of virus's spread indoors based on sensor data and multimodal factor analysis. Information about measurements and calculations is visualized and communicated to various users in real-time or for data analysis later. There are many visualization techniques regarding Covid-19 [5]; nevertheless, there are no convenient solutions for indoor monitoring. This paper focuses on sensor data and potential infection risk visualization to reveal weak places in a building and event organizing procedures.

The rest of the paper is organized as follows. Section 2 gives an overview of the model predicting infection risk. Section 3 provides an insight into the architecture of the system implemented during the project and the choice of information visualization means, and Section 4 presents an overview of the prototype. Finally, Section 5 summarises the achieved results.

2 Infection Risk Modelling

A numerical model for prediction of Covid-19 infection risk was developed within 3T project. The model evaluates the risk of a Covid-19 infection in a particular room based on temperature, humidity, ventilation intensity, the number of people and instances of speech, coughs and sneezing. The virus transport model is integral and mostly uses the mean physical parameter values in the room. Droplets expelled by a potentially infectious person lose mass through evaporation and are partially deposited on the floor. Small particles form an aerosol that can persist for a long time without sedimentation. Virions within the aerosol are transported out of the room via ventilation, partially absorbed by surfaces and lose viability with the time. The droplets and aerosol are inhaled by a person for whom the infection risk is calculated and increasing the infection risk with a time spent in the room. The model is described in detail in [24], the effect of temperature, humidity and ventilation intensity on the infection risk are also demonstrated there. Coughing and especially sneezing greatly increase the probability of infection in the room, therefore, distinguishing these events is crucial.

It is also demonstrated that the model works together with a specially developed dedicated low-cost sensor system [22] which provides all necessary input data for the model.

If the full measurement data set necessary for the model operation is not available, one can measure some of quantities and replace others with typical best guess values. The model can also be used to search for correlations between some conditions in the room and the infection risk. It is obvious that the infection risk is decreased when the concentration of virus containing aerosol in the room is reduced by limiting the number of persons and increasing the ventilation intensity. Increased number of persons and reduced ventilation intensity both raise the CO_2 concentration, which can be measured by commercially available sensors. In this chapter we show how far the infection risk can be correlated with the CO_2 concentration.

The modelled room size is 3x5x3 m, the temperature is 25° C, the RH - 50 %, both constant. In the first scenario, an infected person enters the room without any virus contamination, stays there for 15 min sneezing once per minute, and leaves the room. After 15 minutes pause, two healthy persons enter the room and remain there for 15 or 30 min. Cases with different permanent ventilation intensities (30-240 m3/h) and with/without intensive ventilation of 900 m3/h (corresponds to open window) during the pause are considered. In the second scenario, the only difference is that one infectious and one healthy person enter the room for the second time.

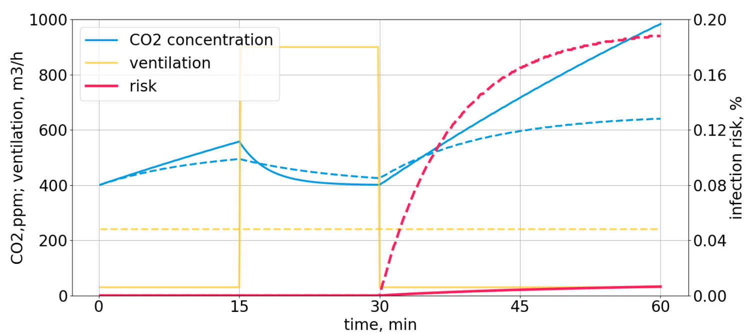

Fig. 1. CO_2 concentration and infection risk vs. time for scenario 1 with permanent ventilation intensity 240 m3/h (dashed lines) and 30 m3/h and 900 m3/h in pause (solid lines)

The CO_2 concentration and the infection risk are shown Fig. 1 for some of the cases as a function of time. In the case with intensive ventilation during the pause (solid lines) the infection risk is considerably smaller. The mean CO_2 concentration during the stay of healthy person in the room and their infection risk at the end of the stay are shown in Fig. 2 for all simulated cases. It can be seen that generally the risk is higher when the CO_2 concentration is higher.

However, the absolute values can differ by orders. The slight decrease of risk at some higher CO_2 concentrations is explained by reduced turbulent mixing and faster sedimentation of small droplets at lower ventilation intensity. The conclusion is that the reduction of CO_2 in room can be used as one measure for the reduction of infection risk, but no recommendations for some CO_2 limit can be given, as it depends also on other parameters.

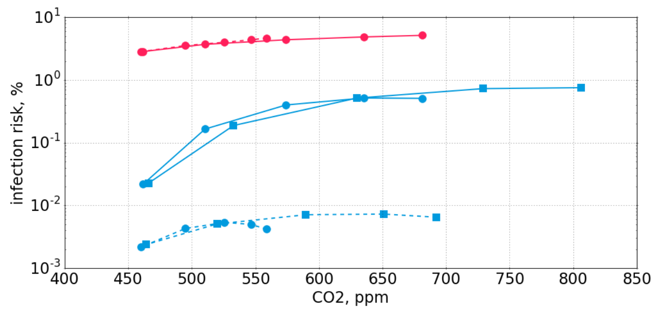

Fig. 2. Infection risk vs. CO_2 concentration for 1st (blue) and 2nd (red) scenarios for 15 min (circles) and 30 min (rectangles) duration of stay; cases with increased ventilation during pause shown with dashed lines

3 System design

3.1 Architecture

We developed a solution that included key components to control indoor infection risk in the future during the project. We pay great attention to the presentation of information because a nonspecialist needs to understand the current situation in the premises as quickly and accurately as possible and analyze the indoor environment in the past. The diagram (see Fig. 3) shows only those parts of the system that are essential for risk calculation and provide relevant information for risk management. Other services are not displayed, as their task is to deliver very primitive information about the current situation. If necessary, the specific mobile application required by the room's visitors can be created (during the project, such applications were made).

Data measurements from the Sensors are received and transferred to the NoSQL database MongoDB. MQTT brokers and MQTT clients connect various devices and services for providing a user with information in real-time, such as Web or mobile applications. All real-time data is stored in the MongoDB database for later data analysis (in fact, other services can work with the data in near real-time). We transfer data to a relational database MySQL. Storing data in a relational database makes it easier to process data, study the data

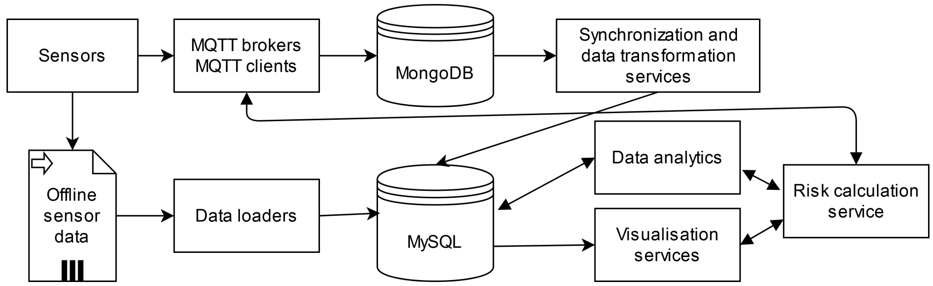

Fig. 3. Conceptual architecture

visualization problem, and improve the risk calculation model by using historical data and events from the premises.

Some partners have different sensors and their accumulated data. They are not yet connected to the network for operational data transfer. Offline sensor data are received with a delay and are imported into the database with Data loaders. Various visualization experiments are conducted on the data (Visualization services). Besides, data analysis is performed, and new information is added to the database (Data analytics). Risks calculation service calculates the risk of Covid-19 infection in a specific room.

Gradually, we are developing a data model for the necessary data analysis and visualization. Our database stores information about buildings, their premises (rooms) with their characteristics, placed sensors, and their data. Rooms in one building can be connected, and this connection is stored in the form of a plan. It is vital for the project to get information about the number of people in the room, sound events (talking, shouting, coughing, sneezing, etc.), ventilation events (working ventilation system, open windows or doors). The climate in the room is also influenced by the outdoors environment, for which data could also be collected. It is possible to show to building managers the condition of the premises and its changes over time. To survey as much space as possible and obtain data, the sensors change their locations, and the system must ensure proper change management.

3.2 Information Visualisation

For delivery of visual data representation to the end-users in IoT domain usually mobile application or web portal is used, but some authors propose also dashboards [9]. Stephen Few's refined dashboard definition [7] states that "A dashboard is a predominantly visual information display that people use to rapidly monitor current conditions that require a timely response to fulfill a specific role". The dashboard's content should correspond to various requirements of different persons, groups or functions [8] as well as take into account specific needs of its usage domain.

In the IoT domain, an overview is provided [16] that describe chart types and their application rules for specific data sets, as well as tool support for visualization goals. According to analysis purposes, for example, finding a correlation or comparing the data, the best suited chart type should be used [16]. The usage of a particular chart type is determined also by the characteristics of analyzed data [16], for example, how many variables are represented in the data-set.

To understand the existing trends regarding visualization in IoT based indoor air quality (IAQ) monitoring projects, a review of scientific papers was done. We analyzed research papers about IAQ monitoring that were included in another work [18], but we evaluated them from the visualization point of view. We included only such papers, where it was admitted, that the described project provides not only the mobile application but also a web portal. We also analyzed some new research papers including one devoted to the IAQ and Covid-19 [14].

Here we present only concise summary of our findings. The most frequently used are the line charts, but at the same time many sub-types were discovered, whose variations depend on 1) different level of time detail, 2) usage of visual aids, for example, lines representing given maximum level values [25], and 3) how many environmental variables and data sets are depicted on the chart. For example, line chart can represent one variable and two or more data sets for comparison of measurements of different CO_2 sensors in different rooms [17].

There were also other chart types discovered in analyzed papers, but they were used only in few projects. For example, data tables or lists of alerts were used in [11], [14]. Map view [10] or widgets [27], [14] were used for presenting the real time data. It should be mentioned, that there were also visualizations dedicated for analysis support. Charts from this group demand specific knowledge from the user. For example, cumulative frequency graph [17],[15], map of the room [19], box-plots [15], and histograms [2] can be mentioned as a representatives of this visualization type. The user must know the used computation method (e.g., interpolation in [19]) and the charts specification to understand the visualized result.

For our project, we chose to implement a dashboard-type layout of web portal for the user interface. The reports were created according to the purpose of the analysis, the specifics of the data and the user's characteristics, providing an opportunity for timely response according to the visualizations. More sophisticated analytic were also supported for analysis of historical data to reveal regularities. The analyzed experience of other projects in data visualization in the field of IoT was taken into account during the development process of our solution.

4 Prototype

We have placed Aranet4 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 (School). The School's sensors have not yet been connected to our project infrastructure, and we imported offline data about measurements harvested during classes with children.

To verify our approach to providing data according to user needs, we developed a software prototype which supports various visualization and analysis opportunities. The selection of chart types and data represented in them was based on the analysis of techniques used in other projects on IAQ. The reports were built with the aim to present the essential information that may impact Covid-19 distribution and emphasize problem situations in various rooms in a building. To implement the visualization of sensor data in a software prototype we used Grafana for visualization of time series data and Highcharts library to visualize metrics other than time series data. Several report examples follow.

4.1 Initial View

The home page view that is provided in the software prototype (demonstrated in the Fig. 4) is aimed at diplaying the operational information about rooms with sensors in buildings. The view shows a plan of several rooms in a building, for instance, rooms at one floor. Sensors are represented as circles positioned in a plan according to their locations in rooms. Circle colors correspond to current values of selected indicators measured by sensors. The ranges of indicator values and their corresponding colors are configured for each indicator. These settings are universal for the whole application and are used in all reports described in the following examples. On the right, the legend explaining the current range settings is shown. Circle colors are automatically refreshed every 10 seconds to display the newest measurements.

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 situation and quickly discover problems in particular rooms.

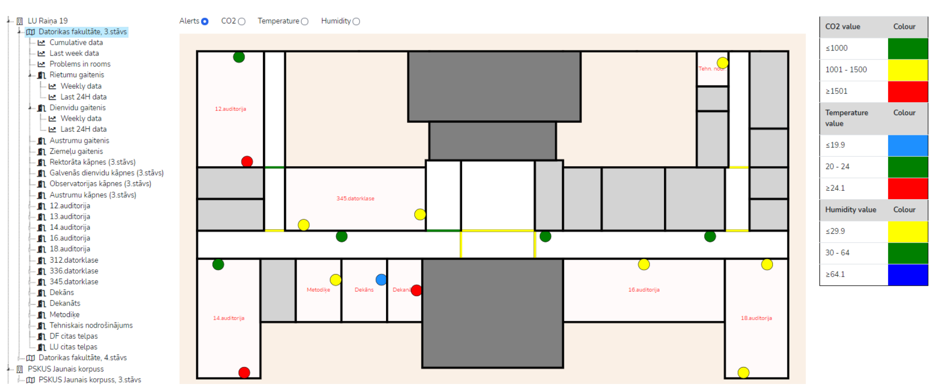

Fig. 4. Fragment of the plan of the Faculty of Computing showing rooms with indicator measurements higher or lower than normal.

On the left in the view, the tree of buildings, their plans and rooms, and various reports is shown. It is possible to compare rooms' data from one plan.

4.2 Building Plan Reports

Several types of reports with different visualization techniques are available for each building plan. Such reports allow to compare multiple indicators for several rooms at the same time, detect correlations between their values and analyze differences.

To visualize fluctuations of indicator values measured by sensors installed in several rooms, we utilize line charts shown in the Fig. 5 implemented in Grafana platform. The default time period used for the report is the last week and initially it shows data about all sensors installed in the plan rooms, however, it is possible to change the time period of the report and show/hide lines that correspond to particular sensors. The chart also allows to zoom-in some part of the original time period. The chart demonstrates thresholds defined for indicator values. For example, the low CO_2 concentration is shown in green, however, the high concentration has a red background. In addition to that, working days are displayed with blue background in these charts. Due to space limitations, the chart showing humidity fluctuations is not included in the figure.

The report shown in the Fig. 6 demonstrates the cumulative distribution function (CDF) of CO_2 concentration, temperature and humidity in rooms of a particular building plan during the selected period of time (defaults to the last week). The line charts were implemented with Highcharts library. Thresholds were set according to the same ranges defined for other reports in the application. CDF chart allows to analyze how many times value of a particular indicator exceeded the thresholds during the period. It is also possible to hide/show particular rooms or select types of rooms to be displayed in charts.

Fig. 5. Weekly information about classrooms in the plan of Riga Teika Secondary School shows fluctations of CO_2 concentration and temperature where peaks are observed during the classes on working days and low values correspond to beaks between classes and a weekend.

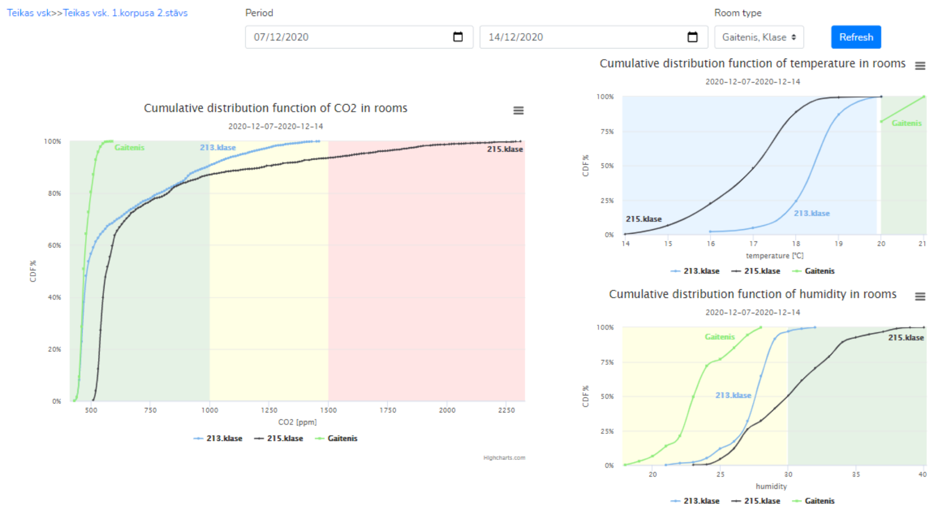

Fig. 6. CDF for selected rooms in the plan of Riga Teika Secondary School allows to compare distribution of indicator values for different room types, for example, hall (shown in green) and classrooms (shown in black and blue).

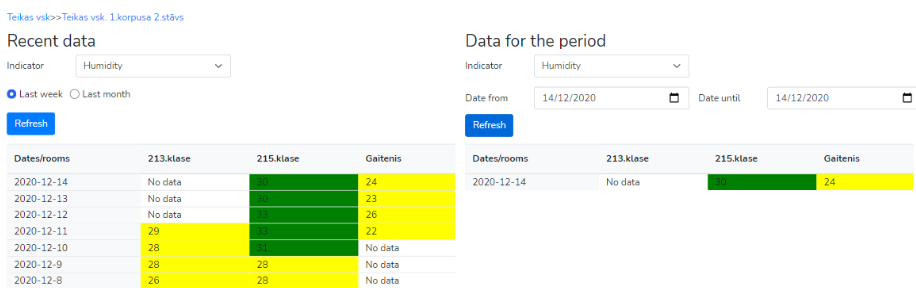

Fig. 7. Healthy and low humidity levels in the hall and classrooms of Riga Teika Secondary School.

To provide analysis of problem situations in rooms within a certain period of time, we created a report shown in the Fig. 7. The report is divided into two parts: one showing recent data for the last week or the last month and another allowing to choose any time period. Two parts of the report allow to compare recent indicator values with values in the past. The table in each part of the report includes average indicator values for each room and date. Cell colors are set according to indicator values.

4.3 Room Reports

We have implemented the line charts that show CO_2 concentration, temperature and humidity measured by sensors in a particular room during the last 24 hours.

Such charts resemble plan charts demonstrated in the Fig. 5, however, they display just one room data. If multiple sensors are installed in the room, the charts show separate lines for each sensor. The points in each line are average values calculated on a 5-minute interval. The charts have been implemented utilizing Grafana platform and allow to zoom-in some part of the original time period. It is also possible to select any date period and display data for it to analyze situation in the past or for a longer period.

To visualize the average values of indicators along with their minimal and maximal values, we implemented the charts shown in the Fig. 8 using Highcharts library. The report allows to analyze minimum, maximum and average CO_2 concentration, temperature and humidity in the selected room during the chosen period of time (defaults to the last week).

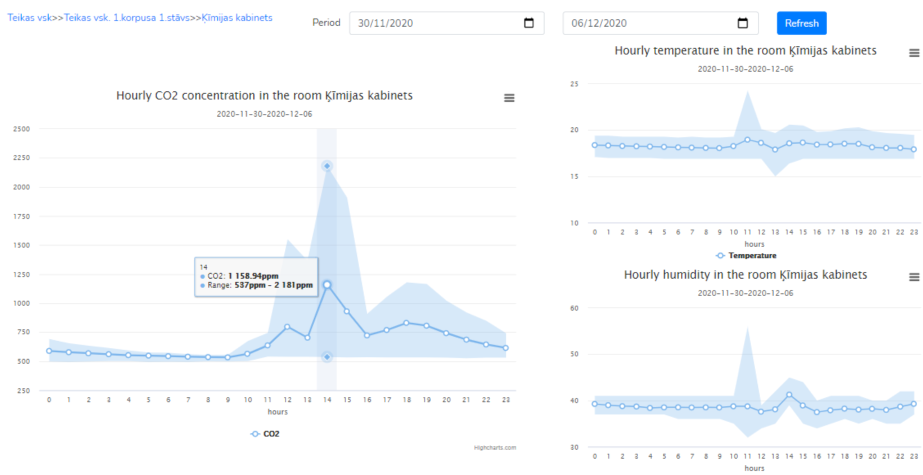

Fig. 8. Hourly minimal, maximal and average indicator values in the chemistry classroom in Riga Teika Secondary School show peaks of all indicators during study hours.

5 Conclusions

During the project, the infrastructure for collecting data from sensors located in public spaces (hospital, university, school) has been created. We have provided an insight into a visualization tool prototype based on research on how to develop the best visualization means aligned with the user's specific demands.

Real-time risk calculation using physical model simulation data is a resource-intensive task that will require a severe computing infrastructure for many thousands of premises. Since the simulation of historical data can be performed, information about typical situations in a room can be obtained. In the case of a school, recommendations were made based on historical data; changes in risk were plotted along with changes in other measurements.

We consulted with various stakeholders with a wide variety of analysis goals and working responsibilities. During the project, it was found that good visualization of data and obtained information is of great importance for the quick reaction according to people's duties if the situation demands and for operational and strategic decision-making as well.

Various organizations, especially educational institutions, are currently actively purchasing sensors for indoor climate control. It is vital to develop the necessary software for effective risk management. The following steps are the systematic evaluation of our prototype by interviewing the end-users from different categories to improve the tool and the proposed visualization means iteratively according to the feedback from the users.

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