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Original scientific paper

NEEDS ASSESSMENT OF AMBIENT CO_2 MONITORING SOLUTION

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A b s t r a c t: Monitoring exhaled CO_2 levels in indoor working spaces is crucial for maintaining employees' quality of performance. Hence, preventing excessive levels of exhaled CO_2 in any working environment is a key factor relevant for increased cognitive capacity, decreased occurrence of headaches, sleepiness, etc. This paper addresses the need for CO_2 monitoring by proposing a novel design of a CO_2 monitoring solution, consisting of a device and an appropriate client-oriented data acquisition and presentation software platform. A Needs Assessment is performed to examine the necessity of such a solution on the market. The outcomes of the performed Needs Assessment show that commercial products using WiFi, 4G, standalone with rechargeable battery power supply, and comparable available technologies are missing on the market. Due to the fact that exhaled CO_2 concentration acts as an indicator for diseases such as COVID-19, tuberculosis, influenza, SARS, etc., from the perspective of the challenges posed by the COVID-19 pandemic, the novel CO_2 monitoring solution can effectively be used for indicative risk prevention of airborne infectious diseases.

Key words: monitoring ambient CO_2; needs assessment; risk prevention; monitoring device

ПРОЦЕНА НА ПОТРЕБИТЕ ОД РЕШЕНИЕ НА СЛЕДЕЊЕ НА АМБИЕНТАЛНИОТ CO_2

А п с т р а к т: Следењето на нивото на амбиенталниот издишан CO_2 во работни простории е од клучно значење за одржување на квалитетот на работниот учинок кај вработените. Оттука, спречувањето на прекумерно ниво на издишан CO_2 во која било работна средина е клучен фактор релевантен за зголемен капацитет на когнитивните способности, намалена појава на главоболки, поспаност итн. Овој труд ја посочува потребата од следење на CO_2 преку ново решение за мониторинг на CO_2, кое се состои од уред и соодветна клиентски ориентирана софтверска платформа за аквизиција и приказ на податоци. За таа цел е спроведена процена на потребите од такво решение на пазарот. Резултатите од процената на потребите покажуваат дека на пазарот недостигаат комерцијални производи кои користат технологии споредливи со WiFi, 4G, а се напојувани преку батерија со репетитивно полнење. Имајќи превид дека концентрацијата на амбиенталниот издишан CO_2 може да служи како прокси индикатор за заболувања како што се КОВИД-19 (COVID-19), туберкулоза, грип, САРС итн., а навраќајќи се на предизвиците што ги донесе пандемијата КОВИД-19, новото решение за следење на CO_2 може ефикасно да се користи за индикативна превенција на ризици од заразни болести кои се пренесуваат преку воздухот.

Клучни зборови: следење на амбиенталниот CO_2; процена на потребите; превенција на ризик; уред за следење

1. INTRODUCTION

Indoor air quality, in particular, levels of exhaled CO_2, is one of the key factors influencing the quality of working performance, not only related to general physical activity, but specifically, related to cognitive and intellectual activities. In that sense, addressing the challenges to maintain the quality of indoor air is in compliance with:

(1) the health and safety requirements of any working environment, including their standardization via e.g. standards from the family of ISO 16000, Indoor air quality [1–3]; ISO 45001:2018, Occupational health and safety management systems [4];

thus, preventing risks from injuries, low cognitive performance and mental concentration caused by increased CO_2 levels therein;

(2) the related national and/or international environmental protection legislation, including other requirements;

(3) the synergy between energy efficiency and energy management and corresponding national and/or international legal or other requirements and standardization via, e.g., the Energy Efficiency Directive (*EU acquis communautaire*) (EU/2023/1791) [5] and ISO 50001:2018 [6];

(4) the overarching sustainable development paradigm [7], via direct or indirect compliance with the following Sustainable Development Goals (SDGs): SDG3 (good health and wellbeing), SDG7 (affordable and clean energy), SDG8 (decent work and economic growth), SDG12 (responsible consumption and production), SDG13 (climate action), and SDG17 (partnership for the goals).

In line with the aforestated, the focus of this paper sets on the assessment of the needs that led to offering a novel solution for monitoring exhaled ambient CO_2 concentrations (levels) on the market, which consists of a device and a software platform. This solution is applicable for various working environments, where intellectual and cognitive activities are being delivered/performed.

2. METHODOLOGY

The process of delivering a new product on the market, *inter alia*, requires a thorough market analysis including a comprehensive and profound assessment of needs (incl. gaps) for such a product from all relevant perspectives, whereby the proposed product is identified as the bridge between the identified gaps and the solution that firmly addresses those gaps.

As per Watkins, West Meiers, Visser (2012) [8], needs assessment is a tool that facilitates delivering better decisions, thereby encompassing identifying the problems, and weighing the alternative solutions in order to deliver informed decisions about which actions (parts of the solutions) must be performed first. E.g., it may incorporate selecting an appropriate product for the market, defining and prioritizing critical aspects (incl. gaps in results/ solutions [9]) of that product for the market, delivering an informed decision relating to that particular product, defining the steps necessary to deliver that particular decision from the perspective of what is the status of the problem in the presence, and in turn, what is planned to be achieved in the future, etc.

The needs assessment protocol utilized in this paper combines the Japan International Cooperation Agency (JICA) [10] and the Australian Institute of Family Studies (AIFS) [11] recommendations. The protocol based on the methodology is presented on Figure 1, whilst Table 1 matches the steps with the corresponding indicators' sets deriving thereby.

T a b l e 1

Needs assessment methodology [8, 10, 11] combined with the corresponding indicators' sets

Step #	Action	Corresponding indicators' set
1st:	Identifying the problem and needs	IPN
2nd:	Determining the design of the needs assessment	A
3rd:	Collecting the necessary data	CD
4th:	Analyzing the collected data	AD
5th:	Providing feedback and proposing adequate solution	AS

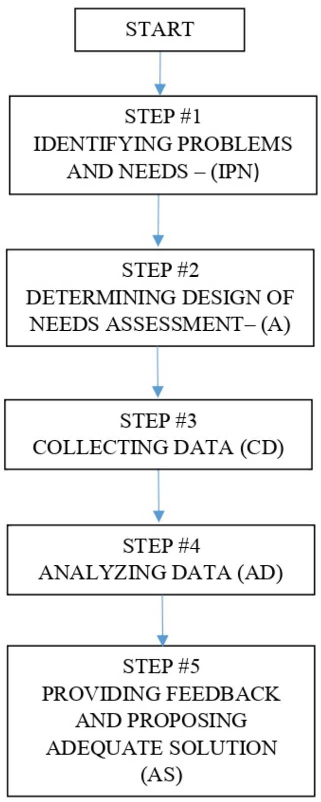

Fig. 1. Needs assessment protocol [8, 10, 11]

3. EXPERIMENTAL CASE STUDY: *Solution for monitoring ambient CO_2 concentrations – DamaLUFT*

Conforming to the 5 steps needs assessment protocol presented in Section 2, this Section focuses on elaborating the performed assessement of needs in relation to monitoring ambient CO_2 concentrations, including the already existing solutions [12, 13], thus to provide a clear distinction among those and the novel approach of the solution proposed therein, which in turn, addresses the identified gaps. The implemented protocol explained in the following subsections is concisely presented on Figure 2.

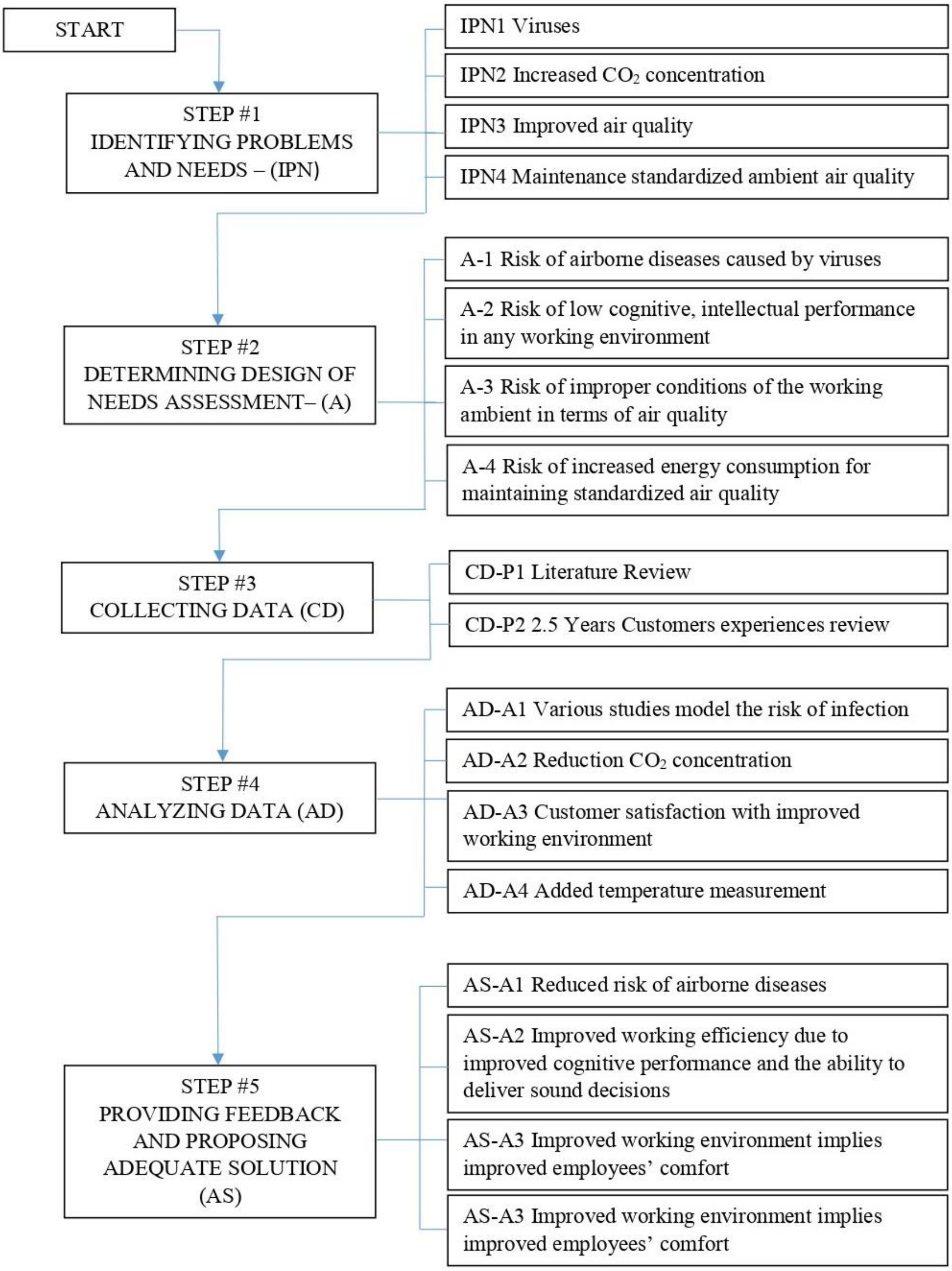

Fig. 2. Needs assessment procedure implemented for the experimental case study. Solution for monitoring ambient CO_2 concentrations – DamaLUFT

3.1. *Step 1: Identifying problems and needs (IPN).*

IPN-1. Due to the fact that viruses (such as COVID-19, influenza, etc.) are spread via respiratory droplets – aerosols in the air exhaled by those present in the room [14] (Figure 3), higher ambient CO_2 concentrations may act as a proxy indicator for increased incidence of such airborne diseases [15].

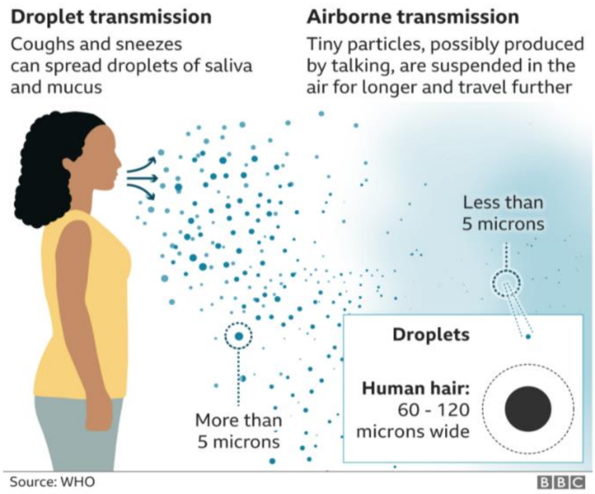

Fig. 3. Difference between droplet and airborne transmision (Source: BBC https://www.bbc.com/news/health-54435240) [17]

IPN-2. Increased/high CO_2 concentrations in working environments imply reduced working efficiency, poorer cognitive performance and decreased ability to deliver sound decisions. Namely, in their study, Wargocki et al. (2020) [16] estimated that reducing CO_2 concentration from 2100 ppm to 900 ppm improves students' scores on psychological tests and school assignments by 12% in terms of the speed at which tasks are performed and by 2% in terms of making errors. Reduction in CO_2 concentrations from 2300 ppm to 900 ppm improves learning achievement test scores by 5%, while reduction of CO_2 from 4100 ppm to 1000 ppm increases students' daily school attendance by 2.5%.

IPN-3. Better air quality throughout the working environment not only infers improved comfort of the employees thus, their improved contentment, satisfaction, sense of wellbeing, but as well, reduced occurrence of headaches, dizziness, confusedness among them.

IPN-4. Optimizing the process of maintaining standardized air quality implies optimizing costs of energy consumed to operate the system for ventilation and/or air-conditioning.

3.2. *Step 2: Determining design of needs assessment (A)*

Having the listed issues in Step 1 in perspective, the needs assessment in this paper is focusing around the overall goal to find a solution that addresses the identified issues, i.e., the following four aspects (A):

A-1. Risk of airborne diseases caused by viruses;

A-2. Risk of low cognitive, intellectual performance in any working/dwelling environment;

A-3. Risk of improper conditions of the working ambient in terms of air quality, implying reduced contentment and satisfaction among employees and increased occurrence of headaches, disorientation, dizziness, etc.;

A-4. Risk of increased energy consumption for maintaining standardized air quality that has a potential to be optimized.

3.3. *Step 3: Collecting data (CD)*

In view of the four aspects (A-1 to A-4) identified in Steps 1 and 2, conducted are two separate processes of collecting data (CD), i.e.:

Literature review, which main goal is to collect notion of the status-quo with reference to experiences (both positive and negative) and recommendations deriving thereafter.

Customers experiences/review of the solution implemented (in real life) to addresses the identified needs in Step 1, in a period of approximately 2.5 years, with a frequency of 3–6 months.

3.4. *Step 4: Analyzing data (AD)*

The data collected in Step 3, thus, the corresponding needs analysis is performed with respect to the four aspects (A-1 to A-4) identified in Step 2, as follows:

AD-A1. Various studies [14, 15, 18] model the risk of infection depending on the volume of the closed spaces/rooms, the type of ventilation, the number of present persons and the infectors among them. The outcomes deriving thereby follow the recommendations and actions in the context of coping with the COVID-19 pandemic taken by governments of Great Britain [19], Ireland

[20], Australia [21], Canada [22], France [23], Belgium [24], etc. Namely, one of the main measures recommended by the governments in the listed countries is installing CO_2 meters in classrooms as a proxy to detect increased risk of airborne diseases caused by viruses.

AD-A2. In their study, Wargotzki et al. (2020) [16] estimate that reducing CO_2 concentration from 2100 ppm to 900 ppm improves students' scores on psychological tests and school assignments by 12% in terms of the speed at which tasks are performed and by 2% in terms of making errors. Reduction in CO_2 concentrations from 2300 ppm to 900 ppm improves learning achievement test scores by 5%, while reduction of CO_2 from 4100 ppm to 1000 ppm increases students' daily school attendance by 2.5%. The aforementioned results represent a solid argumentation for any corporate management to strive for improved air quality in companies' working environment, thus for the benefits derived thereby, including compliance with health and safety standards.

AD-A3. In a period of 2.5 years, the proposed solution DamaLUFT has been offered to a pool of 30 clients, whereby more than 200 devices have been installed. To date, the number of clients and devices is steadily increasing. In order to keep track of Dama LUFT proper operation, thus to maintain customers' satisfaction, clients are communicated quarterly to obtain feedback and overall experience, hence covering monitored parameters variations throughout all four seasons. Thus far, due to its novelty, customers' generally expressed positive attitude and enthusiasm in using the device/solution, in particular, attributable to the following benefits with respect to increased comfort and better working environment:

– regular monitoring of the CO_2 levels at immediate customer's disposal/visibility;
– facilitating maintenance of CO_2 levels below a predefined critical level;
– offering the end-users a tool for self-health-prevention.

Thus far, customers' satisfaction level steadily rises, leading to increased number of installed devices within one network, as well as increased number of clients.

AD-A4. Following the first quartal of DamaLUFT emergence on the market in Sep 2021, several clients inquired whether monitoring temperature levels can be added as a service. The rationale behind this request was: based on employees' presence that can simply be identified via measuring exhaled CO_2, to enable/provide a tool to monitor, control and plan actions for optimizing heating and/or cooling of the working environment. An immediate consequence from adding temperature measurement, is optimizing the related power consumption via scheduling company operations based on planned employees' presence/absence.

3.5. *Step 5: Providing feedback and proposing adequate solution (AS)*

A properly ventilated room implies and, with an appropriate/adequate solution (AS), facilitates/enables achieving low and controlled CO_2 concentrations in closed spaces/working environment, which in turn, as per the identified aspects in Step 2, provide as follows:

AS-A1. Reduced risk of airborne diseases caused by viruses such as: COVID-19, influenza, etc. whereby, viruses are spread via respiratory droplets-aerosols in the air exhaled by those present in the room.

AS-A2. Improved working efficiency due to improved cognitive performance and the ability to deliver sound decisions, which in turn, is negatively affected by the increased/high CO_2 concentrations in working environments.

AS-A3. Improved working environment, implying improved employees' comfort thus, improved contentment, satisfaction and sense of wellbeing for those present in the closed spaces/areas, and prevention/reduced appearance of headaches, dizziness, confusedness due poor air quality.

AS-A4. Added value of measuring temperature in correlation/combination with CO_2 concentrations.

Having the afore mentioned in perspective, DamaLUFT is proposed as a novel solution which provides measurement of CO_2 concentrations in closed room/spaces/areas, thus, measurement of the exhaled air of those present in the room. Such measurements act as indicator of potential risk deriving from airborne diseases transmitted via respiratory aerosols.

4. RESULTS AND DISCUSSION

The DamaLUFT solution consists of a software platform and a measuring device via which, ambient CO_2 concentrations (closed spaces e.g. classrooms, offices, meeting rooms, waiting rooms, shops, sports gym, etc.) are measured indicatively and are reported to the clients and administrator. The platform provides a crucial contribution to improved indoor air quality, enabling room occupants and building managers to deliver appropriate decisions relating to ventilation not only in separate offices/rooms, but as well of the overall building/facility.

The performed Needs assessment, elaborated in the previous Sections, points out that the proposed DamaLUFT solution addresses the identified gaps in Step 2. The highlights of those outcomes are presented in Table 2.

Namely, via concurrent measurement of exhaled ambient CO_2 concentration levels and temperature, and by means of providing visual signalization of the critical levels of ambient CO_2 and graphical display of the measured values, whereas defined are two level ranges – preventive level defined at 800 ppm and critical level defined at 1200 ppm noting that 2% of the total air in the analyzed space is exhaled by the people present in that room – DamaLUFT acts as a preventive tool to reduce risk from infections caused by airborne diseases.

In line with the findings from Wargotzki et al. (2020) [16], DamaLUFT acts as a tool that has a direct impact on the cognitive and the intellectual performance of the employees present in the analyzed ambient, complemented by increased satisfaction and sense of comfortable working environment for the affected employees avoiding headaches, dizziness, sleepiness, etc.

T a b l e 2

Solution for monitoring of the ambient CO_2 concenstrations – DamaLUFT: Overview of the identified needs and the proposed actions enabled/facilitated after implementing the proposed bridge resulting from the Needs assessment

	Identified needs corresponding aspects (A-#)	DamaLUFT solution (Bridge to solve the problem)	Addressed gaps via and proposed actions after utilizing the solution
A-1	Aerosols droplets less than 5 microns spread airborne diseases (e.g., COVID-19, influenza, etc.) over the air.	CO_2 measurements presented in a simple graphical diagram. Visual signaling for reaching critical CO_2 level.	Ventilation of the spaces: Manually: opening windows. (semi)Automatized: switching on the HVAC system automatically or manually.
A-2	Decreased cognitive performance of the persons (students/employees) present in the analyzed ambient. Decreased ability to make decisions. Reduced working efficiency.	CO_2 measurement presented in a simple graphical diagram. Visual signaling for reaching critical CO_2 level.	Ventilation of the spaces: Manually: opening windows. (semi)Automatized: switching on the HVAC system automatically or manually. Short brakes 10–15 minutes while ventilation is active.
A-3	Increased level of CO_2 causes unpleasant working environments and comfort: Adequate/optimal temperature in working environment is needed.	CO_2 measurement presented in a simple graphical diagram. Visual signaling for reaching critical CO_2 level. Temperature measurement in simple graphical diagram.	Ventilation of the spaces: Manually: opening windows. (semi)Automatized: switching on the HVAC system automatically or manually. Introducing adequate plants in the space/room/office that improve the air quality and reduce CO_2 concentrations. Setting up the heating/cooling system on adequate/optimal temperature.
A-4	Energy efficiency Optimizing power consumption based on the employees presence and needs for heating or cooling	Daily, weekly, monthly and yearly data for CO_2 and temperature could be presented in graphical and table format.	Based on CO_2 and temperature measurement, creating optimal working regime of HVAC system providing fresh air and adequate heating/cooling.

Having in mind the combination of registering temperature levels in parallel with CO_2 measurements in buildings equipped with HVAC systems, DamaLUFT can be combined with the Building management system (BMS) and thus, have a direct impact in optimizing power consumption and increased energy efficiency, without reducing the quality of the working environment.

5. CONCLUSIONS

This paper focuses on identifying market gaps and needs for a novel client-oriented solution consisting of a combination of a CO_2 monitoring device and a software platform for related data acquisition and presentation. The performed needs assessment, conducted via a 5 steps protocol – i.e., identifying problem and needs; determining design of needs assessment; collecting data; analyzing data; and providing feedback and proposing adequate solution – identified 4 aspects (risks) relevant for the addressed problem: A-1, Risk of airborne diseases caused by viruses; A-2, Risk of low cognitive, intellectual performance in any working/dwelling environment; A-3, Risk of improper conditions of the working ambient in terms of air quality, implying reduced contentment and satisfaction among employees and increased occurrence of headaches, disorientation, dizziness, etc.; and A-4, Risk of increased energy consumption for maintaining standardized air quality that has a potential to be optimized.

The results of the Needs assessment show that, thus far, commercial products using Wi-Fi, 4G, standalone with battery power supply, and similar available technologies are missing on the market. DamaLUFT solution acts as a standalone device that for communication purposes is using either Wi-Fi technology or 4G (where Wi-Fi is not available) with rechargeable battery lasting between 3–4 months with one charge. The second element of DamaLUFT solution is the software platform available on any widely used browser s.a. Microsoft Edge, Google Chrome, Firefox, and Safari, and it is highly client-oriented, i.e., implementing DamaLUFT does not require any technical knowledge. Accessing DamaLUFT platform is through any of mentioned browsers, whereby users can obtain numeric and visual presentation of the ambient CO_2 levels and temperature in various timeframes, e.g. 1 day, 3 days, and 7 days. The platform administrator can monitor the measured parameters globally, in a timeframe of 30 calendar days, and monthly for the past 12 months. Apart of the aforementioned, DamaLUFT platform includes tools for the end-user as well as the solution administrator, and various respective analyses.

Considering the challenges posed by the Covid-19 pandemic, this novel CO_2 monitoring device exhibited an effective use for indicative risk prevention of airborne infectious diseases (e.g., COVID-19, tuberculosis, influenza, SARS, etc.) due to the fact that exhaled CO_2 concentrations act as an indicator for potential presence of such diseases.

An added value that the DamaLUFT 2.5 years market presence clearly displayed, is the potential to be integrated with HVAC and/or integrated BMS to facilitate optimizing power consumption, thus contributing towards the clients' corporate social responsibility (CSR) (as an internal indicator) and their environmental social governance (ESG) (as an external indicator), in compliance with the sustainable development paradigm, in particular contributing to SDG3 (good health and wellbeing), SDG7 (affordable and clean energy), SDG8 (decent work and economic growth), SDG12 (responsible consumption and production), SDG13 (climate action) and SDG17 (partnership for the goals).

Having in perspective that humidity control, as well contributes to air quality management and energy management in line with internationaly recommended standards could be taken in consideration for future research.

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