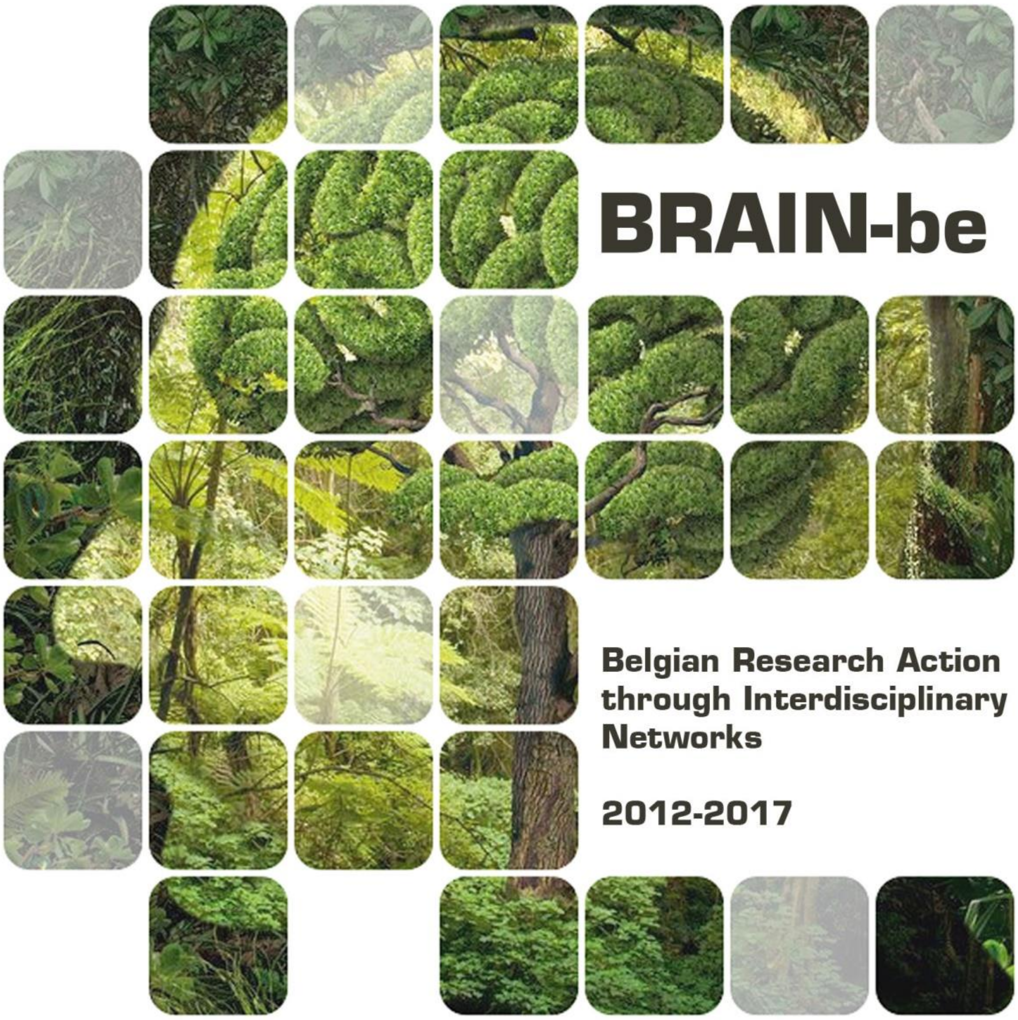

VALORISATION PROJECT

AICHECQ+

Improving the accessibility & reusability of the AIRCHECQ deliverables to new disciplines

BRAIN-be

Belgian Research Action through Interdisciplinary Networks

2012-2017

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AICHECQ+

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FINAL REPORT

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1. SUMMARY

The deliverables from the former BELSPO project AIRCHECQ were reused, modified, and made accessible to new disciplines so that they do not only assess the risk for damage to heritage objects but also to human health. The valorisation project AIRCHECQ+ made it possible to explore new research paths. It also catalysed new projects such as the granted TETRA-project ELGAS. The impact of AIRCHECQ+ is obvious in the measuring campaign where the same indoor air in a painting's restoration studio at a Higher Education Institute has been evaluated for paintings on canvas and on panel (i.e., AIRCHECQ deliverables) and on the health of lecturers and students (i.e., AIRCHECQ+ deliverables). Air quality for lecturers is governed by threshold values mentioned in legislation for occupational health; air quality for students is determined by threshold values mentioned in legislation for public building and other non-occupational situations. In addition, the direct visualization of air quality for human health to a large audience has been extensively evaluated. AIRCHECQ+ has demonstrated that the AIRCHECQ concept could be successfully transferred to other domains where preventive measures play an important role. Finally, the research resulted in 1 publication. The results of this report have been disseminated through a study day that was organized as an extra inspirational day of the International conference IAQ2020 and the research roadmap has been disseminated through the participants of the conference and within the partner institutes.

2. INITIAL OBJECTIVES AND VALORISATION FOCUS

The goals, the milestones and deliverables as described in the work packages were considered as the initial objectives of the project. They are summarized in the list below. Due to covid-19, some of these objectives had to be adapted to fulfil them in the current situation. There was also a substantial delay in the measuring campaign in the restoration studio because of a lack of activity in the studio in the period March – June.

1. **Adaption AIRCHECQ deliverables to visualize impact of the environment on human health:** By collecting threshold values from legislations from several countries it was possible to convert concentration of pollutants into risks for human health and use it in combination with the AIRCHECQ method;
2. **Case study used as an example at the stakeholder meeting:** A measuring campaign has been performed in a restoration studio for paintings. Due to covid-19 there was a lack of activity in the period March-June and during the holidays July-August. For that reason, the measuring campaign covered a much larger period than originally planned. This resulted in a substantial delay in the data processing and the accompanying publication;
3. **Two-day stakeholder meeting:** An extra inspirational day has been organized as part of the international IAQ2020 conference (October 12-16, 2020) organized by the University of Antwerp and the Antwerp Maritime Academy;
4. **Roadmap with future research paths:** The presentations and the Questions & Answers session of the IAQ2020 conference and the extra inspirational day were thoroughly analyzed and summarized in a mindmap that visualized the relation between the sub-topics and the corresponding research questions;
5. **Publications:** The first publication that has been submitted deals with a topic that was also explored during the AIRCHECQ-project: different AQI-standards applied on the same time series resulted in different assessments. The second publication about the longer measuring campaign is in progress. The content of that publication is described in detail in this report.

3. OVERVIEW EXTERNAL COLLABORATION(S)

The AIRCHECQ-project was originally coordinated by the University of Antwerp. During the AIRCHECQ+ project, the AIRCHECQ-methods have been reused, modified, and made accessible to new disciplines by the Antwerp Maritime Academy (AMA). The goal of AMA was to evaluate the risk for human health using the same AIRCHECQ monitoring equipment and using similar evaluation methods. As a result, it is now possible to perform risk assessments for heritage objects/materials and for human health of the same room from the same dataset obtained by the same monitoring system.

In addition, both institutes have organized the international conference 14th International Conference on Indoor Air Quality in Heritage and Historic Environments (IAQ2020). The conference was originally planned as a physical conference of 2 days by an extra inspirational day in the period of March 30 – April 1, 2020. The inspirational day was planned as presentations be several Belgian experts to an international audience about topics that are outside their field of expertise. The afternoon was intended as campfire sessions. Unfortunately, covid-19 made that impossible. Instead, we organized a virtual conference in the period October 12-16, 2020 with afternoon sessions for a complete week. During the inspirational day, researchers of AMA have presented their AIRCHECQ+ work. More information can be found on the conference website:
https://www.uantwerpen.be/nl/overuantwerpen/faculteiten/ontwerpwetenschappen/nieuws-en-activiteiten/archief/indoor-air-quality-2020/

The AIRCHECQ+ concepts made it possible to submit several projects. The most important project is the TETRA-project ELGAS “Effecten van Luchtkwaliteit op de Gezondheid in Accommodaties van Schepen (ELGAS): monitoring van omgevingsparameters, risicoanalyse en aanbevelingen” funded by VLAIO. The project is coordinated by AMA with Karel de Grote Hogeschool and VITO as partners. The ELGAS-project is supplemented by a BOF-academiseringsproject “Proof of concept for a decision support system to reduce the occupational risks of seafarers due to air quality” between AMA and 2 former partners of the AIRCHECQ-project at the University of Antwerp: mathematics-informatics and conservation studies. The AIRCHECQ-project was also an important source of inspiration for the Interreg 2 seas project SOCORRO (www.socorro.eu) that is coordinated by AMA. In that project water-related parameters are continuously monitored to assess the risk of accelerated corrosion of steel constructions submerged in water.

The IAQ-2020 conference also lead to a participation in a project that is currently prepared by MoMu (ModeMuseum Provincie Antwerpen). The goal of the project is to build a measuring network in depots using open-hardware. Since AMA is building a living lab in its school buildings with a similar philosophy, both parties can learn from each other.

4. GENERATED PRODUCTS AND IMPLEMENTED APPROACHES

Covid-19 has radically changed the course of the project. The measurement campaign was delayed because there was no activity at the measurement location for months. The study day organized as part of AIRCHECQ+ also went differently than originally planned. As a result, the publication regarding the measurement campaign has also been delayed. Nevertheless, it can be said that the AIRCHECQ+ project can be successfully closed. Below follows a summary of the results realized for the different objectives. The description below will be used for the second publication that is in preparation.

4.1. Adaption AIRCHECQ deliverables

a) Use of existing Air Quality Indices (AQI)

Organizations collect an ever-increasing amount of data concerning environmental parameters. Persons who are not an expert in data science of environmental science may be confronted with an information overload, making the data meaningless. A way to circumvent this problem is visualizing the trends in the pollution concentrations measured over time. However, non-experts do not have a mental model to derive air quality information from displayed concentration profiles. Therefore, a large fraction of the stakeholders remains unable to read/interpret such data effectively. To improve communication with stakeholders, we superposed health risk information from 9 different Air Quality Indices (AQIs) on different kinds of graphs. The Air Quality Index, or AQI, is a system used to warn the public when outdoor air pollution is dangerous. The visualization methods are applied on data collected by the Belgian Environment Agency from two monitoring stations located in contrasting regions, Ghent and Vielsalm. Despite some limitations of the AQIs, the applied visualizations methods successfully translate the data obtained into actionable information. Interestingly enough, the different AQIs did not result in consistent conclusions. That problem was also encountered during the AIRCHECQ-project when standards for heritage objects were compared with each other.

b) Adaptation of the AIRCHECQ-method

The AIRCHEQ-method was an important source of inspiration to develop a method that converts the measurement of environmental parameters into a level of risk for human health. The method appeared to be more universal that originally expected: it converts expert intuition into a knowledge-based risk model.

The set of environmental parameters that affect human health is substantially different than the set of indicators that affect the degradation rate of heritage objects. In both cases, the overall risk due to the exposure of environmental conditions is determined by a large number of parameters. Unfortunately, it is not feasible for technical or economic reasons to cover all of them. For example, there are no mid-price sensors available to detect all the individual volatile organic compounds in air. To circumvent this situation, it is assumed that the overall situation can be described with a limited number of key risk indicators. Therefore, a correct selection of the indicators is needed to evaluate the impact of the air we breathe on our health. In the current work, we based this selection on the opinion of institutions such as World Health Organization (WHO), European Environmental Agency (EEA) and the Environmental Protection Agency (EPA) from United States. They all use the same set of key risk indicators: NO, CO, NO_2, O_3, SO_2, $PM_{2.5}$ and PM_{10}. The concentration of these pollutants should be as low as reasonably achievable (ALARA principle). The last version of the monitoring system developed during the AIRCHECQ project covers all the required parameters for human health.

Each of these indicators contain indirect information about the risk. That information is related to the toxicity level of the indicator. For example, some pollutants such as NO_2 are more toxic than others such as CO_2. For that reason, each single key risk indicator is converted into a level of risk with the same meaning. To convert the measured parameters into a level of risk, threshold limit values are needed that distinguish the regions of different levels of risk. The Threshold Limit Values related to human health were found in literature and in legislation. They could be classified in 5 categories: the occupational and non-occupational context for both short-term (ST) and long-term (LT) exposure and a situation of zero concentration that is considered as the best possible air quality. For both contexts, legislation establish different concentration levels at which exposure is considered as unacceptable high. The difference in occupational and non-occupational risk can be explained by the difference between (1) 'voluntary' exposure to pollutants by an individual vs. an 'involuntary' exposure imposed by society, and/or (2) the average subject where only healthy persons are considered in occupational conditions vs. the average subject where also babies, eldery and sensitive persons are considered for non-occupational exposure. In both cases, the risk is perceived as different.

All these thresholds are brought together into a single framework and are summarized in Table I. The node number in Table I reflects the ranking of the categories according to the concentration of the threshold value. This means that the concentration range of any pollutant can be subdivided into 4 risk regions. To each category a level of risk has been attributed. The best and worst situation are associated to a risk of 0 and 1 respectively. Although all thresholds distinguish the situation of acceptable and unacceptable risk, it is clear that the level of risk attributed to nodes 2, 3 and 4 must be lower than that of node 5 (i.e., threshold category with the highest allowable concentration). For nodes 2, 3 and 4 and arbitrary risk value is attributed while considering the ranking of the nodes. The risk acceptability is described with a verbal descriptor and is different for the occupational and non-occupational context.

Table I: Classification of thresholds in several air quality categories.

Node nr.	Threshold category	Attributed level of risk	Acceptability of the risk in an occupational context	Acceptability of the risk in a non- occupational context
1	*0*	*0*	*Acceptable (A)*	*Acceptable (A)*
2	*Non-Occupational threshold Lon-term exposure (LT)*	*0.25*	*Low (L)*	*High (H)*
3	*Non-Occupational threshold Short-term exposure (ST)*	*0.50*	*Moderate (M)*	*Intolerable (I)*
4	*Occupational threshold Lon-term exposure (LT)*	*0.75*	*High (H)*	*Intolerable (I)*
5	*Occupational threshold Short-term exposure (ST)*	*1.00*	*Intolerable (I)*	*Intolerable (I)*

The classes defined in Table I are used to construct the conversion functions that allow the calculation of the level of risk that is attributed to a pollutant concentration. These categories represent the nodes in the conversion function and are connected by straight-line segments. Each node has a specific level of risk as defined in Table I. The corresponding concentration depends on the pollutant and is summarized in Table II. It is remarkable that the collected thresholds within the given categories vary significantly from one organization to the other. For example, the US OSHA thresholds are on average nearly 40% higher than those of Poland. This difference evidence the lack of consensus between organizations and countries. By assuming that all these values are opinions that contain some truth, the average value can be considered as the consensus value of all experts.

Table II: Average threshold values associated to the different threshold categories as defined in Table I.

	NO (ppb)	CO (ppb)	NO2 (ppb)	O3 (ppb)	SO2 (ppb)	PM10 (µg/m³)	PM2.5 (µg/m³)	Level of Risk
Non-Occ. LT	*3000*	*2000**	*21*	*25*	*19*	*20*	*15*	*0.25*
Non-Occ., ST	*17667**	*9000*	*32*	*61*	*48*	*40*	*25*	*0.50*
Occ. LT	*25000*	*20000*	*3000*	*100*	*2000*	*90*	*4000*	*0.75*
Occ. ST	*100000*	*87336*	*9000*	*300*	*5000*	*140**	*8025**	*1.00*

*Value obtained by interpolation or extrapolation.

To visualize the level of risk, a colour scale is attributed to the risk acceptability mentioned in Table I. An example of the colour scale for O_3 in a non-occupational and occupational context is shown in Fig. 1. In the case of the non-occupational context, the same conversion function is applied as for the occupational context but the concentration range that the colour scale covers is different to consider the risk acceptability. In Fig. 1a, the colour gradually changes between zero concentration and the occupational short-term limit value; Fig. 1b uses the same colour scale but changes from zero concentration up to the non-occupational short-term limit which is the highest level of risk in a non-occupational context.

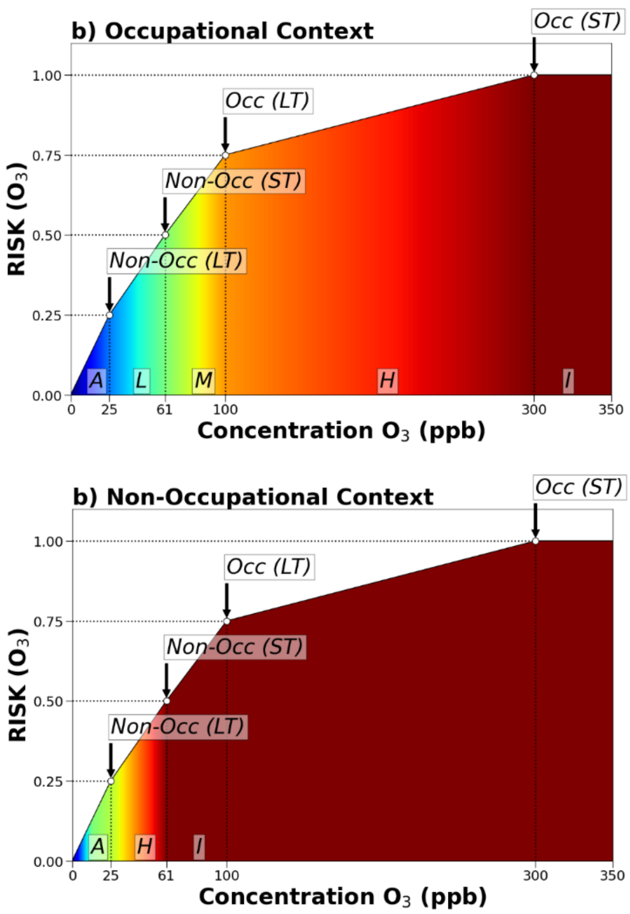

Fig. 1 Graphical representation of the conversion function for O_3 using the reversed colour jet colour scale.
a) Occupational situation and b) Non-occupational situation.

Since humans are simultaneously exposed to several key risk indicators, it is the combination of all these individual risks that must be considered. Each key risk indicator can harm the subject in one way or another. One way to determine the overall risk is to equate it with the highest risk of all the individual key risk indicators considered. However, reality is more complex than that. It is possible that all key risk indicators potentially damage the same part of the human body, that they damage a different part of the human body, or that each indicator affects several parts of the human body at the same time. In addition, one can question when harm occur: (1) when one of the parts start to fail, or (2) when all the affected parts start to fail. Since risk R_i is associated with the probability of occurrence of harm due to key risk indicator i, one can associate each R_i to an independent event. Following the method used in system reliability (see Fig. 2), the human body (i.e., a system) will be harmed when one of the events harms a component of that body. In that sense, the risks must be combined as events linked in series.

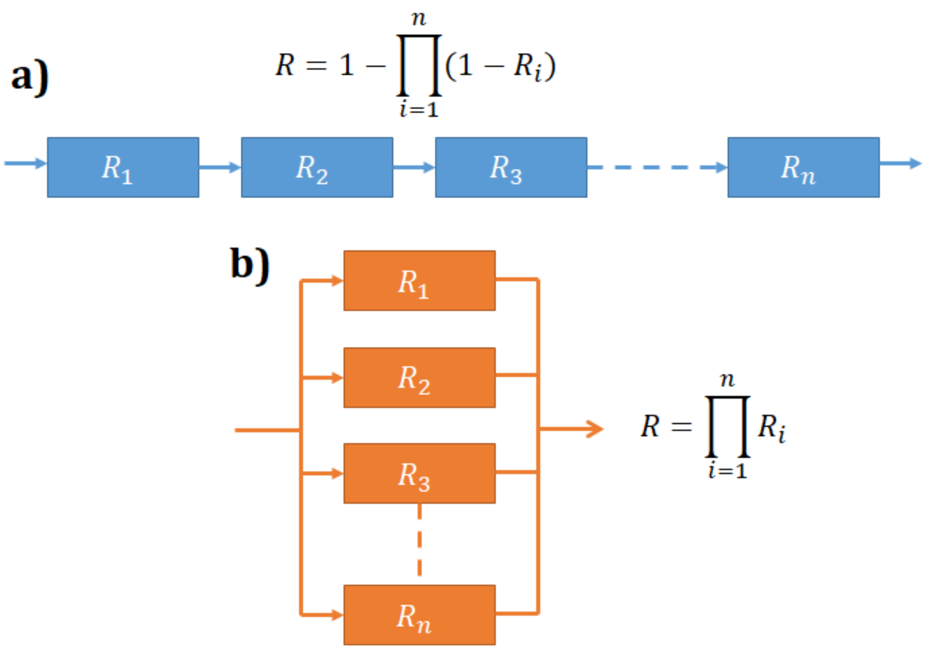

Fig. 2. Two different ways to evaluate the overall level of risk. a) The failure of any single component in the series of components will result in overall failure of the system. b) All components must fail to result in a system failure.

4.2. Case study used as an example at the stakeholder meeting

A measuring campaign was performed in a painting restoration studio at a Higher Education Institute The location of the monitoring system in the room can be seen in Fig.3a, indicated by the arrow. The conservation-restoration studio (see Figs. 3) is located in a historical city-centre. The room contains an entrance door, several windows shielded by curtains, skylights with UV and IR-blocking foils, and an opening to a second room (not seen on the photos). A ventilation system is present but is only active during working hours. To maintain stable preservation conditions, windows are kept closed to avoid draft and to maintain stable climatic conditions inside the room. However, regulations imposed during the covid-19 period required windows to be opened regularly. Also, the curtains are closed to diminish direct sunlight on the objects of art. However, sunlight is still able to enter the room through the skylights. Fig. 3b shows the room from a different point of view where the window with curtains and the lightning can be seen. The lightning system consists of TL fluorescent lamps and is usually turned on when there are people inside the studio. To maintain a stable relative humidity, a mobile humidifier (Defensor PH15) is active in the room. It is important to clarify that the humidifier is next to the monitoring device. Fig. 3c shows the chemicals cabinet and the connection of that cabinet to the ventilation system using a flexible arm. There also bottles for chemical waste underneath the table on the right side of the chemical cabinet (see below the table on the right of the chemical cabinet in Fig. 3c).

Several types of activities are performed in the room such as teaching, restoring paintings, manipulation of solvents, etc. These activities generate fluctuations on the environmental conditions in the room. In some cases, these variations are detrimental to cultural heritage materials (e.g., changes in relative humidity) or harmful to human health (e.g., high CO_2 concentration suggesting that persons breathe each other exhaled air which increases the transmission of diseases). Occasionally, students also use solvents to remove for example yellowed varnish layers or to clean their tools. There is also a rectangular table in the centre of the studio where some works of restoration are performed. On that table, some often used utensils can be seen, for example paints and solvents. Both, lecturers, and students have access to this room. Sometimes, a varnish layer must be applied on a painting using a spray gun in a separate but contiguous room. When a window is opened people inside the room are exposed to external pollution sources (e.g., exhaust gases of traffic). All these activities have an influence on the interpretation of the collected data.

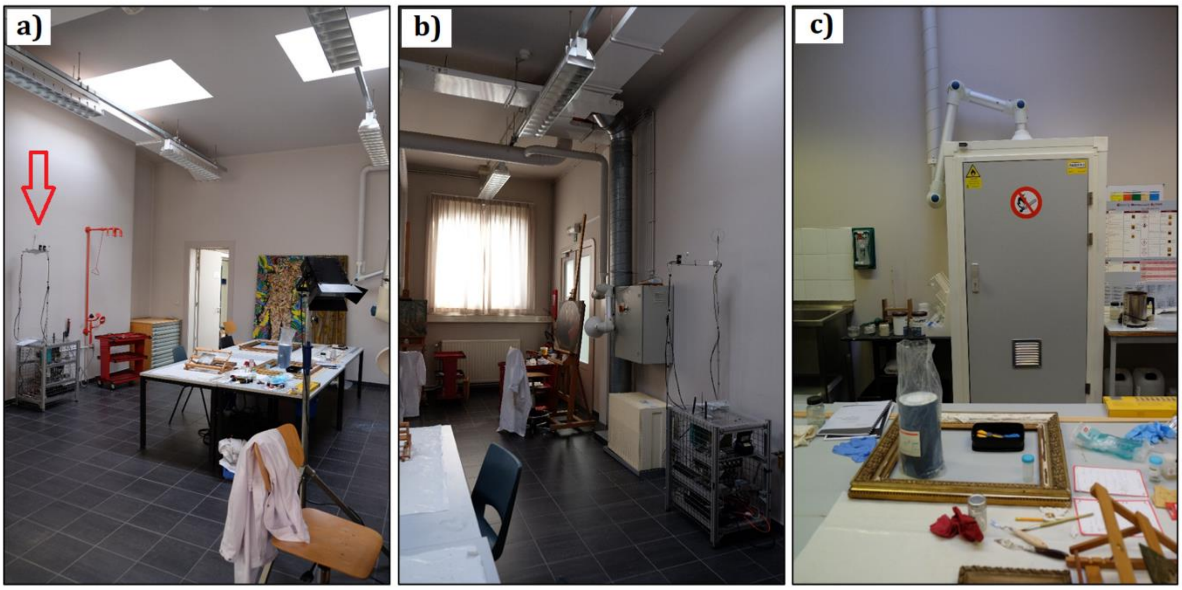

Fig. 3: Some images of the conservation-restoration studio at a Higher Education Institute.

The monitoring device used is an in-house developed multi-sensor tool that measures several environmental parameters. The monitoring tool consisted of a multi-purpose data logger (Data-Taker DT85, Thermo Fischer Scientific, Scoresby Vic, Australia) to which a wide range of off-the-shelf sensors were coupled. The measuring system analyses several environmental parameters from the same location. Temperature, relative humidity, and CO_2 were collected with a GMW90 (Vaisala, Helsinki, Finland). The pressure is measured with a PTB110 (Vaisala, Helsinki, Finland). Particulate matter is recorded with the Shinyei sensors PPD-60 (i.e., it detects all particles larger than 0.5 µm) and PPD-20 (i.e., it detects all particles larger than 1 µm) respectively. Concentrations of CO (CO-B4), NO_2 (NO2-B43F), O_3 (OX-B431), H_2S (H2S-B4), SO_2 (SO2-B4) and NO (NO-B4) were collected using the B4-sensors of Alphasense with a 32 mm diameter package (Alphasense, Essex, UK). The concentration of total volatile organic compounds (TVOC) was estimated with a photoionization detector using a 10.6 eV lamp (sensor 000-0022-AH2 of Alphasense, Essex, UK). The Panasonic AMN24112 motion sensor is directed towards the door seen in Fig. 3a to obtain some information about traffic of people in and out the room and therefore and therefore, to get some indication of the presence of people inside the room. This sensor detects motion within a detection of 10 m. In addition, the monitoring system includes a rod where 3 additional sensors are installed at a height of about 2 m: (1) the intensity of visible and UV light were monitored with the upward positioned sensors SKL310 and SKU421 (Skye Instruments, UK) and the HD403TS omni-directional hotwire sensor (Delta Ohm, Soest, The Netherlands) to monitor air speed. The upward direction of the light sensors makes it easier to evaluate the light from lightning and skylights shining on surfaces of object of art. In the case of the motion sensor, the data logger counts the number of pulses generated by the sensor in a time window of 5 minutes. All sensors were read out in phase with a frequency of 1 minute, while 15 minutes averages were saved by the data logger. The sampling rate is sufficiently high to consider the discrete time series as a continuous signal.

The trends in the collected data are visualized using different types of graphs. These graphs show the parameter values as colours using a colour scale, allowing a more intuitive analysis of the results and the identification of time-dependant patterns present in the time series. The colour scheme 'jet' defined in matplotlib Python library, and its reversed variation were used according to the type of data shown in the graphs. This scale ranges from dark blue through blue, cyan, green, yellow, red, to dark red. The 'jet' is used for data related to level of risk and 'reversed jet' is applied for data related to air quality. For the case of level-of-risk assessment, the blue colour represents low values closer to 0, and the red colour represents high values closer to 1. On the other hand, in the methodology employed for the analysis of the IAQ-index, the blue colour means better air quality represented with values closer to 1, and the red colour means worse air quality with low values closer to 0. For both type of assessments, the blue represents better air conditions and red worse air conditions. The visualization methods are the following:

- **Temporal Raster plot (Carpet Plots):** Carpet plots are generated by plotting the value of a parameter over time in days in the horizontal axis and over time of day in hours in the vertical axis. The colour at these coordinates depends on the value. The advantage of this type of chart is that it visualizes both short term (hourly) and long term (monthly) patterns in a single plot. Carpet plots are created by in-house developed software in Python 3, using the Matplotlib library.
- **Strip Charts:** This type of plots is represented as a horizontal bar where the collected data is organized chronologically, from left to right, and composed by small coloured vertical lines. This type of chart provides a direct interpretation of the time series regarding the impact of air on human health by assigning a colour from a colourmap to the value obtained from the Risk calculation. Such plots are generated by code developed in Python 3, using the Matplotlib library.

In Fig. 4, three temporal raster plots with the intensity of visible light in lux, UV radiation in mW/m^2, and motion of humans in front of the monitoring system are shown. The vertical axis shows the hours of the day (from 0 -24) and the horizontal axis represents the days that the measurements are performed (from November 2019 to February 2021). In Figs. 4 a and b, it is possible to see intermittent vertical red stripes that matches exactly the same moments. These stripes almost always start at 8:00 and ends between 17:00 and 19:00 hours. These stripes are also correlated by human motion and must be due to switching on and off the TL-lightning. The lightning not only generates visible light but also UV-radiation. The lightning gives indirect information about the times and dates persons were present in the room. For example, there is no presence of stripes during lockdown periods or weekends. This is confirmed by Fig. 4c that gives information about people movement inside the studio. In Fig. 4a, another smother pattern can be observed that is related to sunlight. In that pattern, the intensity of visible light is lower during winter months and higher during summer. During summer, the intensity is substantially higher during the early hours. These results are related with seasonal variations and the relative position between the room's windows/sklights and sun trajectory. It is interesting to note that curtains are closed to avoid direct sunlight on the objects of art, but that TL-lightning is emitting considerable amounts of UV-radiation.

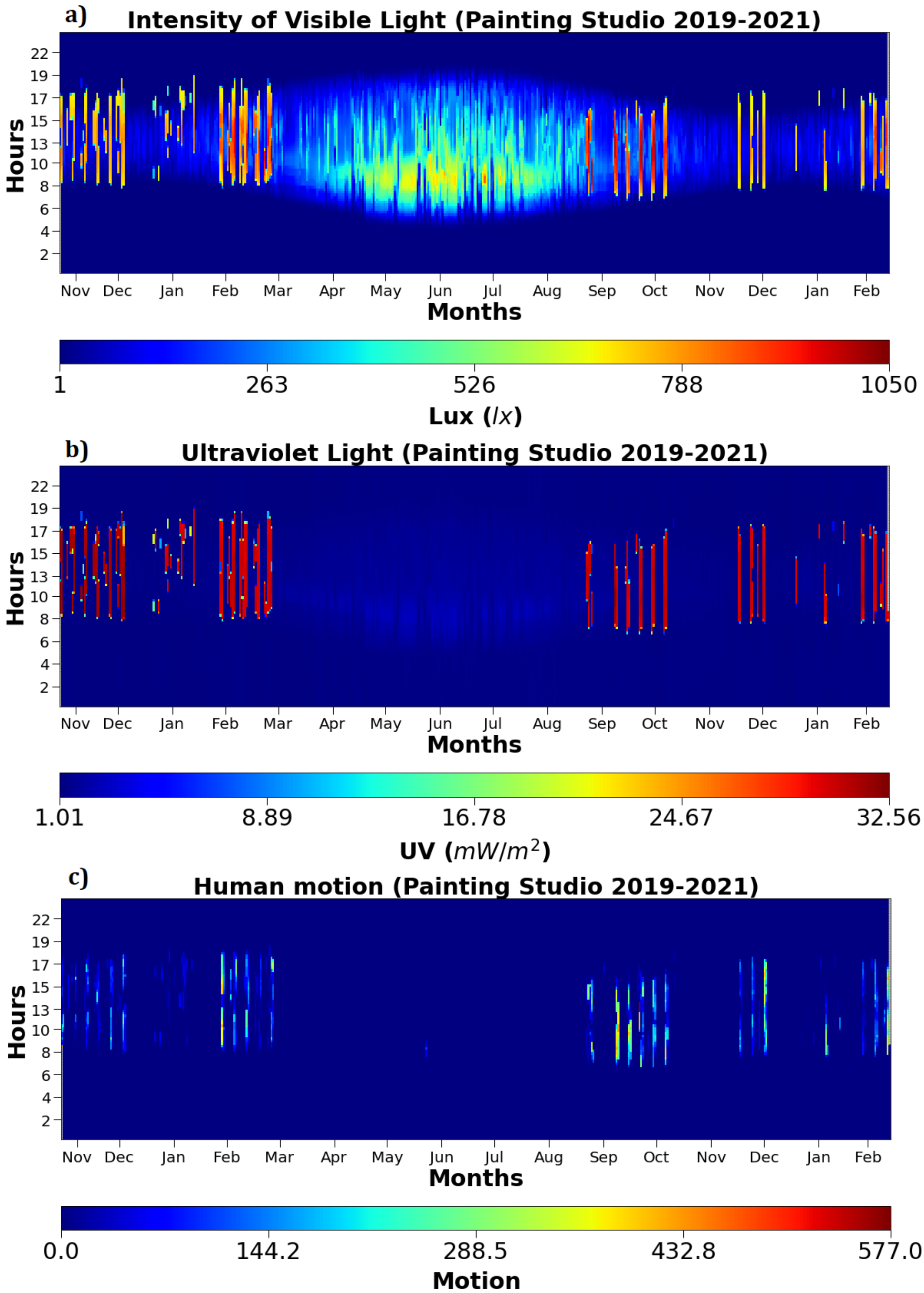

Fig. 4: Temporal raster plot of the Intensity of visible light (up) and UV (low) and human motion (c).

In Fig. 5, three plots represent the concentration of O_3 (ppb), SO_2 (ppb), and NO_2 (ppb) respectively. The main source of these pollutants is located outdoor. For these plots, concentration fluctuations can be seen during working dates and times. These fluctuations are shown as a rectangular pattern that is related to an increase of concentration during the working periods (from 8:00 and 19:00). In the case of the outdoor pollutants, they must enter the building/room by diffusion. However, as we know from Fig. 1c, there were no people during summer times inside the studio to open doors or windows, so it is possible that indoor fluctuations are caused by natural diffusion. This means that the air exchange rate of the room is rather high. In the case of NO_2, a faint opposite behaviour is seen: the concentration decreases instead of increasing during working periods, although the pattern is more subtle. The drop in NO_2 concentration in periods where outdoor pollution is expected to be higher is a well-known phenomenon in city air, and its occurrence is a phenomenon based on the chemical transformation of O2 in O_3 by NO_x compounds. These three pollutants are harmful to humans and paintings.

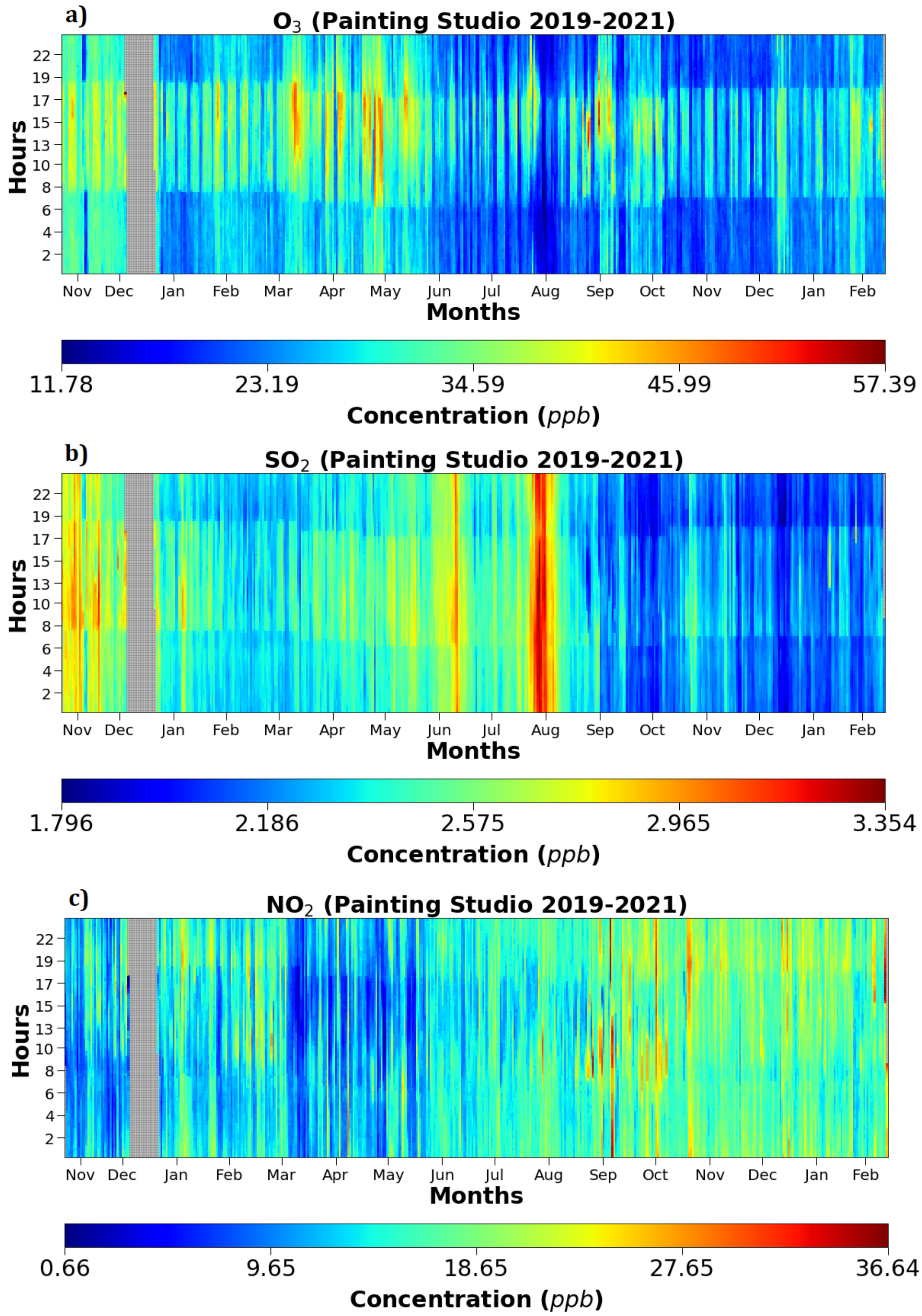

Fig. 5: Temporal raster plot of outdoor pollutants concentration of O_3, SO_2, and NO_2 in ppb. The grey vertical bands in each graph represent moments where data were not obtained during the measurement period.

In Fig. 6, two plots represent the concentrations of CO_2 (ppm) and TVOC (mV) respectively. The main sources of these pollutants are located indoor. In the case of CO_2 concentration (see Fig. 6a), narrow vertical lines are observed and is correlated with human presence. This graph shows a pattern with similarities to the Motion graph in Fig. 2c but with the difference that the lines for CO_2 are longer because it needs to diffuse out of the room. The correlation between both parameters is obvious because they are both related to the presence of people. The intensity of these lines is higher during working times and it slowly fade out at times when there is no presence of people in the room. The TVOC pollutants (Fig. 6b) are due to the use of solvents for conservation-restoration actions and/or cleaning products. In the case of TVOC, the raw signal in voltage is shown and not the concentration values because it was not possible to convert the signal caused by a mixture of products into concentration units. When assuming that the makeup of organic components is constant over time (i.e., it is always the same set of solvents that is used in the studio), a linear conversion can be assumed. Therefore, the trend in the signal contains valuable information about the air quality in the room. The graph shows most of the time a homogenous blue colour indicating that there are little fluctuations of TVOC inside the room. However, some narrow lines of elevated concentration can be observed. These lines appear only during working days and it matches with the moments when restoration activities and activities related to the cleaning of the entire room are performed in the room.

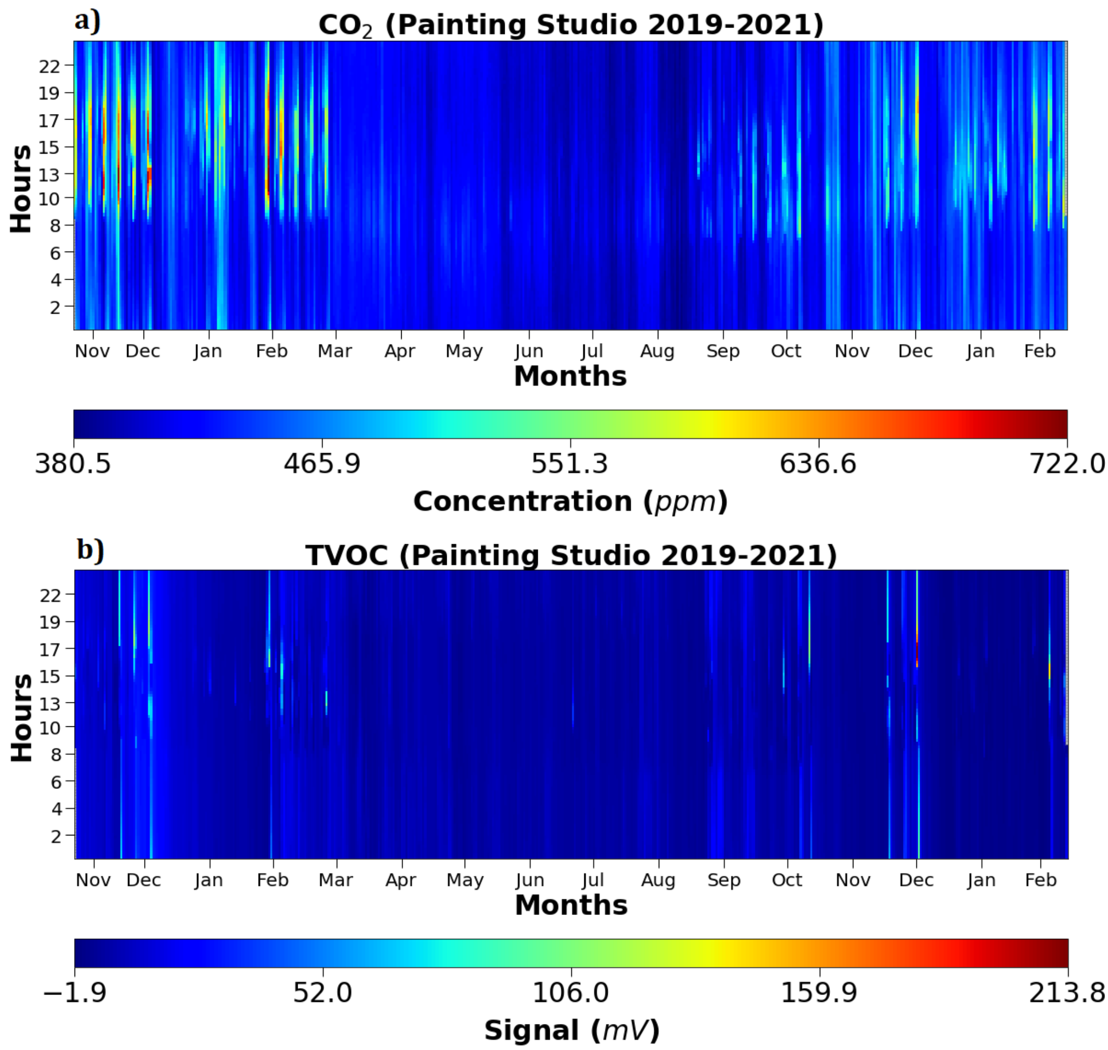

Figure 6. Temporal raster plot of indoor pollutants concentration of CO_2 (ppm) and TVOC (mV).

In Fig. 7, the overall risk for human health is presented in both contexts, occupational (i.e., lecturers, staff) and non-occupational conditions (i.e., students). When looking at the trends, the period of spring and summer appears to be better than autumn and winter, but it is not clear what is causing that improvement (e.g., no heating, lockdown policy, etc.). Fig. 7 shows how the overall risk fluctuates in values around 0.5, with some peaks reaching 0.75. This indicates that it is highly probable that the subject exposed to this environment is exceeding the non-occupational thresholds (R=0.5), and in some brief moments, it is exceeding the occupational long-term threshold (R>0.75). Therefore, it is recommended to manipulate solvents close by the ventilation points.

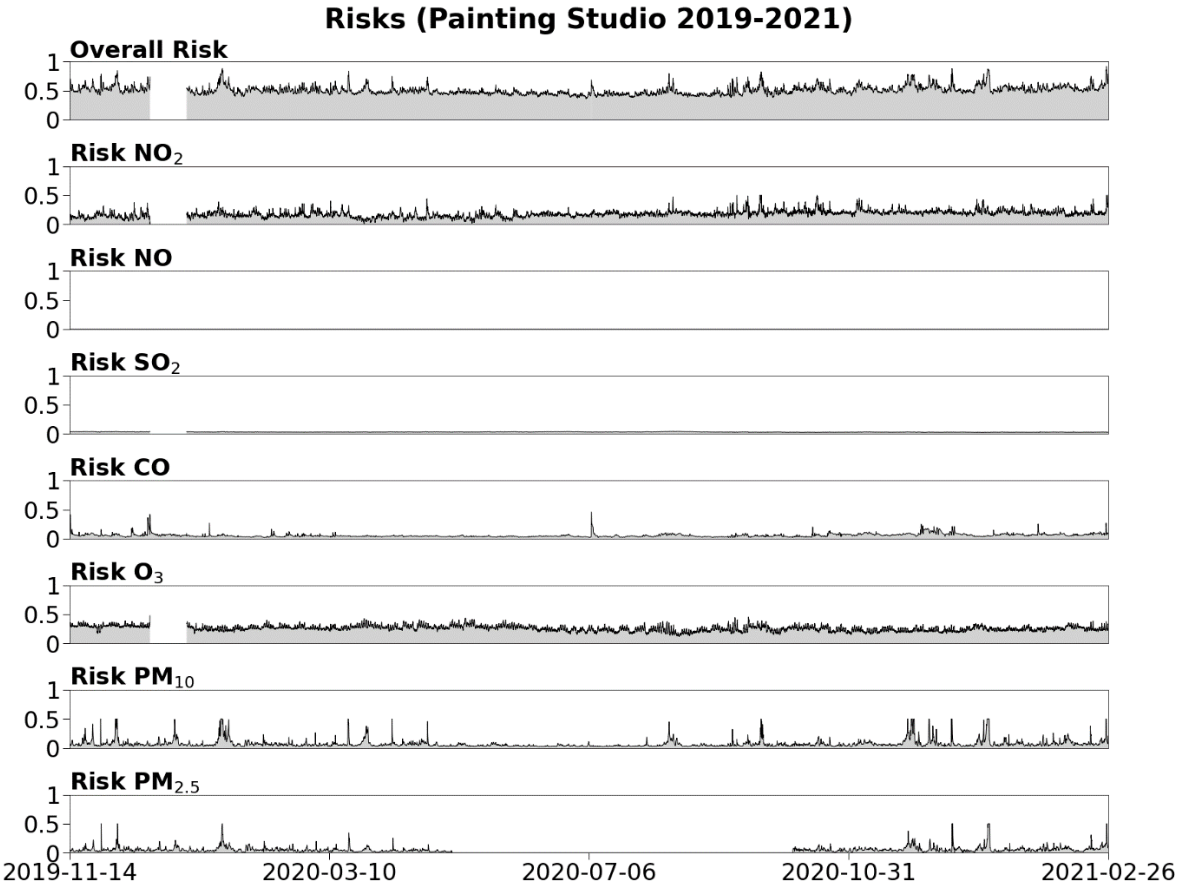

Fig. 7: Overall and individual level risk trends for human health.

The information shown in Fig. 7 can also be seen in Fig. 8a and in Fig. 8b. Fig. 8a, shows the level of risk for occupational conditions. Most of the time, the colours fluctuate from light to darker green. There are short moments where the colour is intense red. Different tones of green are predominant during the full measurements, and these colours correspond to the probability of exceeding a non-occupational short-term threshold. Therefore, for the occupational conditions the level of risk is between low and moderate. Except from those short periods where it is possible to see red colours, corresponding to a high level of risk.

Fig. 8b, shows the level of risk for non-occupational conditions. The colours fluctuate always between different tones of red. For non-occupational condition this means that very frequently the level of risk correspond to a situation between high and intolerable for people exposed to that conditions. By comparing Fig 8a with 8b, it is possible to see that for the same environmental conditions the situation is worse for people exposed in non-occupational context. The most relevant key risk indicator with the highest impact to the overall risk was the O_3. This result has sense, because some authors consider that indoor exposure of O_3 to be typically 45% to 75% of total exposure to pollutants. This outdoor pollutant can enter the building through small openings but can also be generated in badly ventilated rooms where many (old) copying machines and/or laser printers are active. Drastically increased ozone can also be observed. As the highest O_3 concentrations (outdoors) are typically between 12am and 10pm, it is the best to ventilate rooms outside O_3 smog episodes before 12am or after 10 pm. In addition, the last generation of laser printers and copiers are equipped with O_3 filters, which break down ozone and limit the leftover emission to a minimum. It would be convenient to check the technical characteristics of the printers and copiers used in the studio. Filters containing activated carbon, through which air is passed using fans, can also be effective in removing ozone for an extended period.

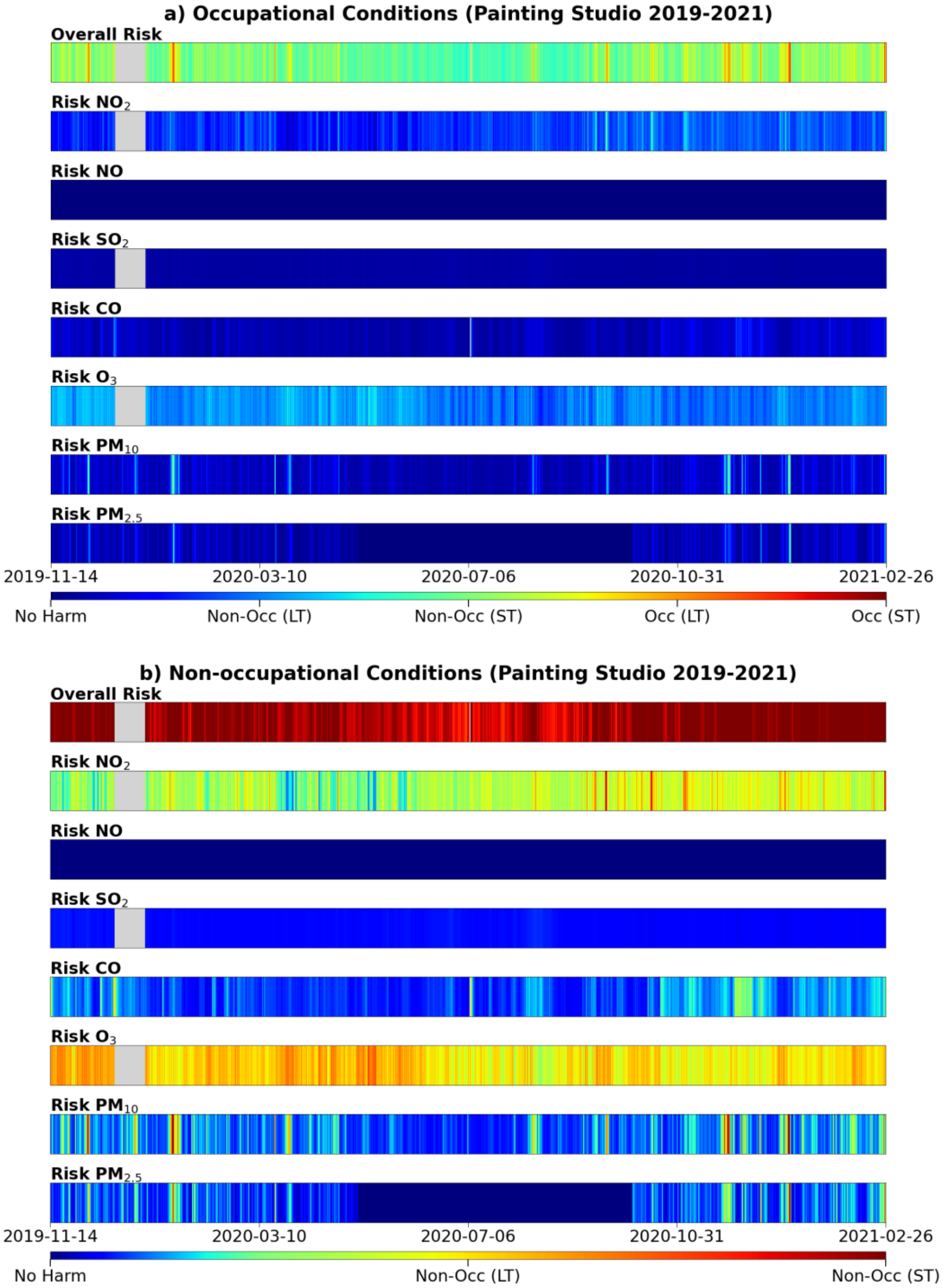

Fig. 8 Occupational and Non-Occupational level of Risk.

The Indoor Air Quality (IAQ) for canvas and panel paintings is shown in Fig 9. For both graphs, it is possible to see the General IAQ-index and the individual IAQ-index for the individual parameters used in the analysis (i.e., relative humidity, temperature, illuminance, ultraviolet light, particulate matter, and ozone). For both materials, the IAQ shows a similar pattern between their general IAQ-index. However, the general IAQ-index shows that the same environmental condition in the room is more aggressive for panel paintings than for canvas paintings. By looking at the individual IAQ-indexes, it is possible to see that for most of the key risk indicators the IAQ-index is fairly similar for both types of heritage objects, except for the ones defined by relative humidity (RH and ΔRH IAQ-indexes). The reason this occurs is because wood is more affected by humidity than canvas. By looking at Fig. 9, it is also possible to see which parameter is more relevant or contribute more to the General IAQ-index. For example, temperature increasing affects more the canvas than panel paintings. For that reason, the moments with maximum of temperature shown for both materials can also be visualized on the General IAQ-index of the canvas only in the General IAQ-index of the canvas.

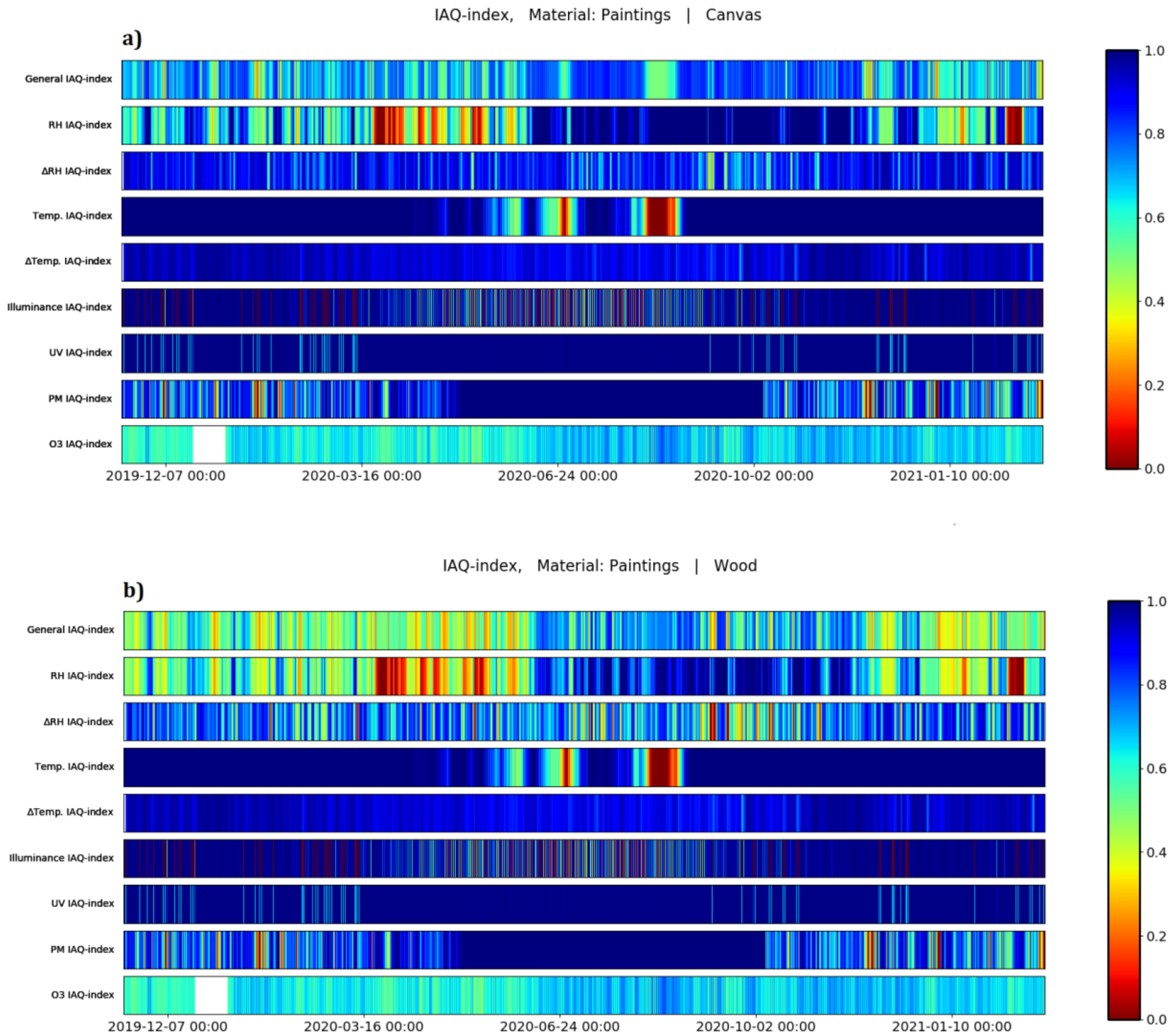

Fig. 9: AIQ-index for objects in painting studio for two different materials. a) canvas, and b) wood.

In this case study, several environmental parameters were monitored during a measurement campaign that was performed in a painting studio. Patterns in the trends such as seasonal, weekly, and daily trends were visualized by using carpets plots. It was possible to associate some of these trends to the presence of people or due to their activity inside the painting studio (e. g. breathing, cleaning, turning on lights, etc.). At the same time, other parameter trends were associated to external sources (e. g. intensity of sunlight, exhaust gases, etc.). It was shown that the environmental parameters always worsen at certain specific moments and that these sudden changes seen as peaks can be attributed to indoor or outdoor sources of harm. This resulted in several recommendations to improve the air quality for both human health (e.g., use of active carbon filters with mechanical ventilation, identification of moments when studio should be aired, identification of possible indoor pollution sources such as old printers and copy machined) and heritage objects (e.g., reduce UV-light from illumination system, reduce seasonal temperature and relative humidity). The analyses performed clearly show that the same environment has a different impact on canvas paintings, panel paintings, students, and staff. This means that air quality is not a universal concept but that it depends on the object/subjects that is considered in the study.

4.3. Two-day stakeholder meeting

The original plan was to invite international speakers to a Belgian public. With the opportunity to organize the IAQ2020 conference we could generate more impact by inviting local experts and offer them an international audience. Moreover, covid-19 also impacted the organisations of the inspirational day and it needed to be organized in a virtual way. The advantage the of the virtual conference is that all contributions of the IAQ2020-conference could be recorded. This means that there was much more background information available to create the mindmap.

4.4. Roadmap with future research paths

The IAQ2020 conference and the Question & Answer sessions have been thoroughly analysed. All the topics that have been discussed are brought together into a backbone structure (the red line that connects several topics Fig. 10). To this structure, the relevant subtopics and research questions have been attached. The mindmap in Fig. 10 is a visual summary of the activities performed by the heritage community active in preventive restoration. It also acts as a source of inspiration for the research about air quality in the accommodations of ships.

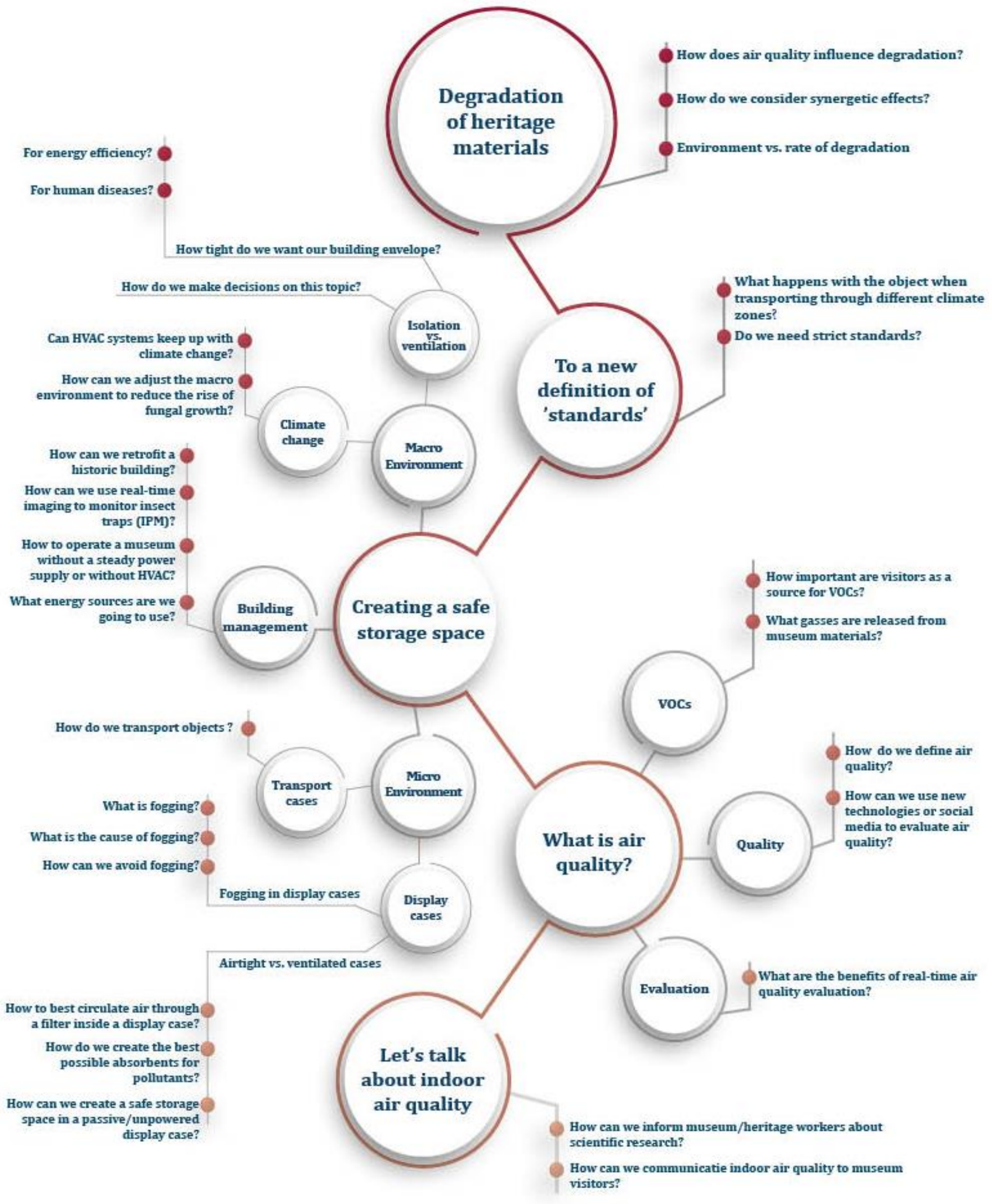

Fig. 10: Mind map with the most important research questions that arise in the heritage community around preventive conservation and air quality.

4.5. Publications

One contribution has been submitted in December 2020 but we still did not reived any feedback yet. The publication about the measuring campaign is delayed because the campaign had to cover a much larger period to get meaningful information. The references of both publications are given below.

Carro G., Schalm O., Jacobs W., Demeyer S., Exploring Actionable Visualizations for Environmental Data: Air Quality Assessment of Two Belgian Locations, Environmental Modelling & Software journal, status: revisions are needed.

Carro G., Schalm O., Jacobs W., Demeyer S., Air quality assessments in a paintings conservation restoration studio: impact of the object or subject on the meaning of air quality, in preparation

5. IMPACT AND ADDED VALUE OF THE VALORISATION ACTION

AICHECQ+ resulted in an innovative method that converts environmental measurements obtained by prototypes containing mid-price sensors or by reference measuring stations (e.g., data published by Irceline) into a level of risk for human health. In that way, the AIRCHECQ results is now accessible by stakeholders outside the original heritage community. These results were presented to the IAQ-2020 audience with an attendance of more than 80 participants.

In addition, a mindmap has been made that brings all the relevant research questions that has raised during the conference together. The mindmap gives a unique overview of that community. It has been sent to all the IAQ2020-participants. Also, for other research communities specialized in indoor air quality and human health, this roadmap is of interest because most of the aspects of the map can easily be translated to their field of expertise. For example, how does a cocktail of pollutants affect human health, with what standards do we evaluate indoor air, how well does safety gear protects a person against pollutants, what is air quality and how do we inform people. The mindmap clearly shows the different domains where future research is needed. It also helped pinpointing topics for research proposals that were granted in the last 2 years.

Finally, the AIRCHECQ method was also used in the ongoing SOCORRO-project. There the method was applied on the Fayoux model to model the risk assessment for H_2S exhaust in sewers.

Both the method for health risk evaluation and the mindmap has assured the sustainability of AIRCHECQ results by translating the AIRCHECQ-concepts to other research communities and to use it as a source of inspiration for dissertations and research projects in related topics.

6. MEASURES TO MAINTAIN THE COLLABORATION(S)

AIRCHECQ+ is based on a collaboration between Conservation Studies at the University of Antwerp and the Antwerp Maritime Academy, 2 domains with seemingly no common ground. However, the use of low-cost sensors is gaining importance in both domains. In addition, AIRCHEQ+ has demonstrated that data processing in both domains show strong similarities. These similarities will be explored in the following years. For example, the Antwerp Maritime Academy will be part of the follow up committee of the MuMo-project, a project that is currently prepared by the Fashion Museum MoMu in Antwerp. In addition, the AIRCHECQ-equipment will be shared by both institutes. It has been used to evaluate the air quality in the accommodation of ships. Now that the measuring campaign in the conservation studio is terminated, it will be used to evaluate other locations