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How to improve the perceived health, comfort, and well-being of primary school teachers? A quantitative self-reported survey during the COVID-19 pandemic in Scotland

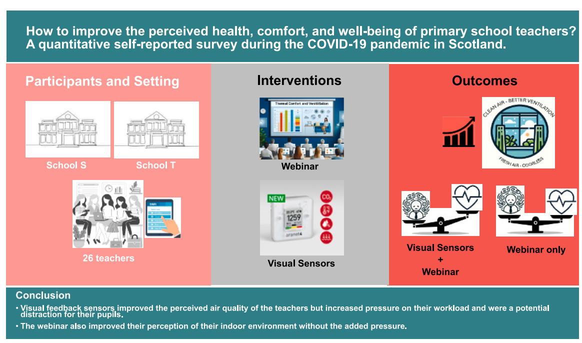
Natalie Bain-Reguis [a,*], Andrew Smith [a], Caroline Hollins-Martin [b], John Currie [a]

[a] School of Engineering and the Building Environment (SCEBE), Edinburgh Napier University, 10 Colinton Road, Merchiston Campus, Edinburgh EH10 5DT, UK
[b] School of Health and Social Care (SHSC), Edinburgh Napier University, Sighthill Campus, Edinburgh EH11 4BN, UK

HIGHLIGHTS

- Visual sensors improved perceived air quality.
- Webinar raised IAQ awareness without increasing teacher pressure or distractions.
- Teachers felt more burn-out and stress post-intervention with visual feedback.
- Educating teachers on IAQ is key to improving classroom environments effectively.
- CO_2 monitors were useful but led to excessive air movement and cooler classrooms.

GRAPHICAL ABSTRACT



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ABSTRACT

Teachers are among the most stressed professionals, for whom the built environment has an influence. In addition, the COVID-19 pandemic has increased the pressure on schools, where enhanced ventilation is deemed essential to help reduce virus-laden particles in classrooms. Good Indoor Air Quality (IAQ) is required to maintain an adequate level of comfort, health, and well-being. Therefore, solutions to improve IAQ quickly and cheaply are essential. As such, the Scottish Government has funded Local Authorities to purchase CO_2 sensors for school classrooms. This study explores two interventions designed to improve the quality of indoor air. The first one by raising the awareness of the teachers on ventilation strategies via a webinar. The second one by deploying devices that visually inform the occupants of the indoor conditions: Temperature, Relative Humidity, and CO_2 levels in the classrooms. The novelty of this study is that it evaluated the influence of engaging teachers in the management of their working indoor environments. This paper presents the results of the perceived health, comfort, and well-being of teachers from two primary schools built before 1919 located in Edinburgh, Scotland. Visual feedback sensors improved the perceived air quality of teachers in their classrooms but increased pressure on their workload and were a potential distraction for their pupils. In contrast, raising the awareness of the teachers via the webinar improved their perception of their indoor environment without added pressure.

* Corresponding author.
E-mail addresses: n.reguis@napier.ac.uk (N. Bain-Reguis), a.smith7@napier.ac.uk (A. Smith), c.hollinsmartin@napier.ac.uk (C. Hollins-Martin), j.currie@napier.ac.uk (J. Currie).

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Therefore, awareness programs should be devised to educate school staff on Indoor Air Quality in addition to the development of sensors with visual feedback.

1. Introduction

The teaching profession is commonly reported to be one of the most stressful, with burnout being a frequent phenomenon (Kokkinos, 2007; Arvidsson et al., 2016). A significant proportion of teaching staff report high levels of work-related stress in the UK (Ravalier and Walsh, 2018; Health and Safety Executive, 2019) and in Scotland (EIS, 2021).

The built environment has been shown to influence the health and well-being of workers (WHO Europe, 2013; World Green Building Council, 2014; Bluyssen et al., 2016). The main complaints are related to the quality of the indoor air and indoor temperature (Edem et al., 2017). School staff has provided similar feedback, with factors such as the physical design of classrooms, lighting, temperature, noise levels, and ventilation. This has impacted the teachers' stress levels, their job satisfaction, and their overall well-being (Higgins et al., 2005; Chatzidiakou et al., 2012).

Researchers have shown that the comfort, health and wellbeing of teachers and their students are interlinked (Greenberg et al., 2016; Sparks, 2017; Harding et al., 2019; Roberts and Helyn, 2019; Glazzard and Rose, 2020). Therefore, maintaining appropriate thermal comfort, Indoor Air Quality (IAQ), and ventilation in classrooms is crucial for both students and teachers (Coley et al., 2007; Mazurek et al., 2008; Haverinen-Shaughnessy et al., 2011; Tak et al., 2011; Bakó-Biró et al., 2012; Chatzidiakou et al., 2012; Annesi-Maesano et al., 2013; Haverinen-Shaughnessy and Shaughnessy, 2015; Allen et al., 2016; Toyinbo et al., 2016; Fisk et al., 2019).

In addition to the usual concerns of preserving optimal indoor environmental conditions, the COVID-19 pandemic and its SARS-COV2 airborne virus (WHO, 2021; CDC, 2022) have put additional pressure on schools (Hyde, 2020; Kim and Asbury, 2020). Researchers and government advisory teams have highlighted the need to enhance ventilation by providing detailed guidance to facility managers/users (Morawska et al., 2020; REHVA, 2020; SAGE EMG, 2020a, 2020b; Hegarty, 2021; Noakes, 2021; Scottish Government, 2021). People exhale carbon dioxide as part of their metabolism. Therefore, ventilation in occupied rooms can be assessed by monitoring Carbon Dioxide (CO_2) concentrations (Rudnick and Milton, 2003; Chatzidiakou et al., 2015; SAGE EMG, 2020b), as advised by ASHRAE Standard 62.1, the COVID-19 Education Recovery Group CERG (2022) guidance and CIBSE COVID-19: Ventilation guidance (CIBSE, 2021; ASHRAE, 2022; Scottish Government, 2022).

When occupants have the opportunity to control their environment, they are more satisfied and change their behaviour (Boerstra et al., 2013; Yun, 2018; Kwon et al., 2019). In a naturally ventilated classroom, teachers can control the CO_2 concentration levels by opening more windows and doors. However, studies have shown no reduction in CO_2 levels when the occupants have no access to feedback information (Geelen et al., 2008). Whereas, apparatus with feedback have been found to improve ventilation in classrooms in different countries. The feedback can be informing the occupants by showing a measurement and/or a colour (Wargocki and Silva, 2015; Bastien et al., 2024), alerting the occupants by sending visual alerts (Kong et al., 2023) or acoustical warnings (Zivelonghi and Kumar, 2024). However, as the primary aim of a classroom is to facilitate learning and help students grow and develop, sensors with intrusive feedback systems like multiple visual alerts or acoustical warnings can be too disruptive (Vassella et al., 2021).

Studies have highlighted the importance of understanding IAQ and how to enhance it (Vassella et al., 2021; Green et al., 2023; Bastien et al., 2024). This can be done by training teachers and their students (Batterman et al., 2017; Korsavi et al., 2020) using workshops and seminars to improve their knowledge regarding the importance of IAQ (Ekren et al., 2017).

In 2021, during the second wave of the COVID-19 pandemic, the Scottish Government allocated £10 million to Local Authorities to purchase and deploy CO_2 monitors in educational spaces. The aim was to assess and improve classroom ventilation (Scottish Government, 2021). No specific requirements were set regarding the type of sensors to be used, allowing for both visual and non-visual options.

Solutions to quickly and cheaply improve IAQ are essential to support governments, institutions, facility managers, and occupants. For other applications, the use of visual feedback monitors can encourage behaviour changes and lead to energy savings in domestic settings (Zangheri et al., 2019; Agarwal et al., 2023).

To date, no study has examined the impact of sensors with visual feedback (without additional alerting systems), combined with teacher awareness-raising sessions, on improving classroom ventilation during a pandemic. This study investigated interventions aimed at improving indoor air quality (IAQ). The first intervention involved raising teachers' awareness of IAQ and ventilation strategies through a webinar. The second intervention entailed the deployment of devices that visually display Indoor Temperature, Relative Humidity, and CO_2 levels within classrooms. The objective of the study was to assess the impact of these interventions on the perceived comfort, health, and well-being of teachers. The novelty of this study is that it assessed the impact of engaging teachers in managing their indoor work environments.

2. Material and methods

2.1. Selection of schools and participants

This study follows a preliminary study undertaken during the winter of 2020–2021 which demonstrated that traditional stone-built, naturally ventilated schools constructed before 1919 (sometimes called Victorian or Georgian) have the highest CO_2 concentration levels and the lowest ventilation rates in classrooms (Bain-Reguis et al., 2022). This concurred with previous literature (Bannister, 2009; Burman et al., 2018). Additionally, primary school classrooms are where pupils and teachers stay in the same room all day. Good air quality in those classrooms is consequently essential. Therefore, the actual study involved two pre-1919 primary schools School S and School T, located in the City of Edinburgh (Scotland) representing 28 % of their building stock. These buildings account for 20 % of the national non-domestic public building stock and are classified as 'hard to treat' due to their structural and historical characteristics (Reguis et al., 2023). The teachers from both schools worked in similar built environments, which was a fundamental criterion for eligibility to participate in the study. The classrooms of the two selected schools are similar in terms of their average volumetric density (7.5m^3/person for School S and 7.2m^3/person for School T) and have the same type of windows (timber framed, sash and case) with the same percentage of openability (33 % on average for both schools).

10 classrooms in each school were selected.

Fig. 1 and Fig. 2 show the locations and floorplans of the two selected schools S and T. The classrooms where the monitoring devices were installed are numbered from 1 to 10.

Note: The floorplans are for illustration purposes and are not to scale.

To obtain a representative overview of the entire staff, all teachers from both schools were invited to participate in the study. Part-time staff members were also asked to participate. 26 teachers were involved: 16 from school S and 10 from school T.

2.2. Study design and procedure

This study was performed simultaneously in schools S and T from November 2021 to March 2022. The study design and timeline are illustrated in Fig. 3.

At the start of the study (October 2021), all 20 classrooms across both schools were equipped with sensors measuring Temperature, Humidity, and CO_2 (Tinytags). Sensors' specifications are detailed in Section 2.3.2. The purpose of this deployment was to have a baseline of data before the start of the interventions.

In early November 2021, all 26 teachers from both schools received an email from the principal investigator explaining the study's purpose, the participants' privacy, the timeframe for filling in the questionnaire, and the link to the pre-webinar digital questionnaire on the NOVI survey platform. Novi Survey is the University's web-based application to facilitate the gathering of data from different audiences, both on and off campus.

In mid-November 2021, the interventions took place once the first questionnaire was closed. All teachers received a link to the webinar by email. In the same week, the sensors visually displaying Indoor Temperature, Relative Humidity, and CO_2 (Aranet4Home) were deployed in the 10 classrooms of school T. This deployment happened three weeks after deploying the sensors without visual display.

In early March 2022, all teachers from both schools received an email with a link to the second digital questionnaire on the NOVI survey platform, to complete the post-intervention survey. The second questionnaire followed the same format as the first, with the same timeframe allocated for completion.

2.2.1. Intervention 1: the webinar

The aim was to create a useful resource for teachers to improve their understanding of IAQ. The content was specifically designed to provide

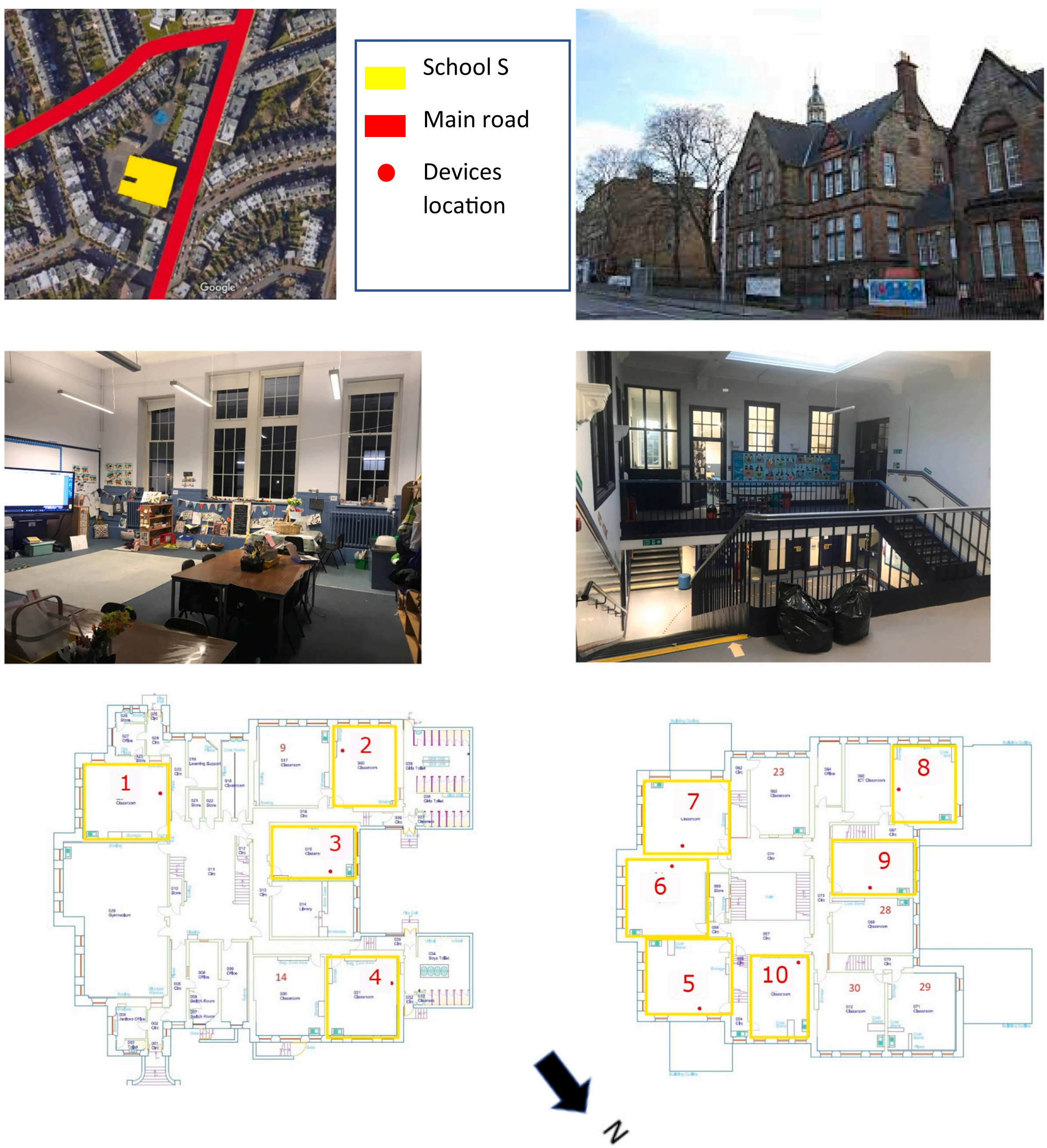

Fig. 1. Location, photos, and floorplans of School S, illustrating the layout and placement of monitoring devices for indoor air quality assessment.

them with the necessary scientific knowledge to maintain good IAQ in their classrooms. This 16-minute "The Air We Share" webinar can be viewed on YouTube (Bain-Reguis, 2021). The following list provides its key content:

- Understanding the Science: What is indoor air?
- What are the health benefits of adequate indoor air quality?
- What are the regulations in relation to indoor air quality?
- How can Indoor Air Quality be measured?
- What are the steps to remedy indoor air quality?
- And how to use visual sensors?

2.2.2. *Intervention 2: environmental monitoring with visual feedback*

Additional sensors with visual display were deployed in the classrooms of School T to enable the occupants to visualise the following parameters of the indoor environment - namely Indoor Temperature, Humidity and CO_2 (Aranet4Home). Furthermore, the devices employ a tricolour LED indicator system to provide rapid visual feedback on CO_2 levels. Sensors' specifications are detailed in Section 2.3.2.

2.3. *Data collection*

2.3.1. *Online survey*

Self-reported data via online questionnaires were used to assess the impact of the interventions on the health, comfort, and well-being of the teachers involved. The teachers were asked to answer two rounds of questionnaires, one pre-intervention (November 2021) and one post-intervention (March 2022). The pre-intervention questionnaire was

Fig. 2. Location, photos, and floorplans of School T, illustrating the layout and placement of monitoring devices for indoor air quality assessment.

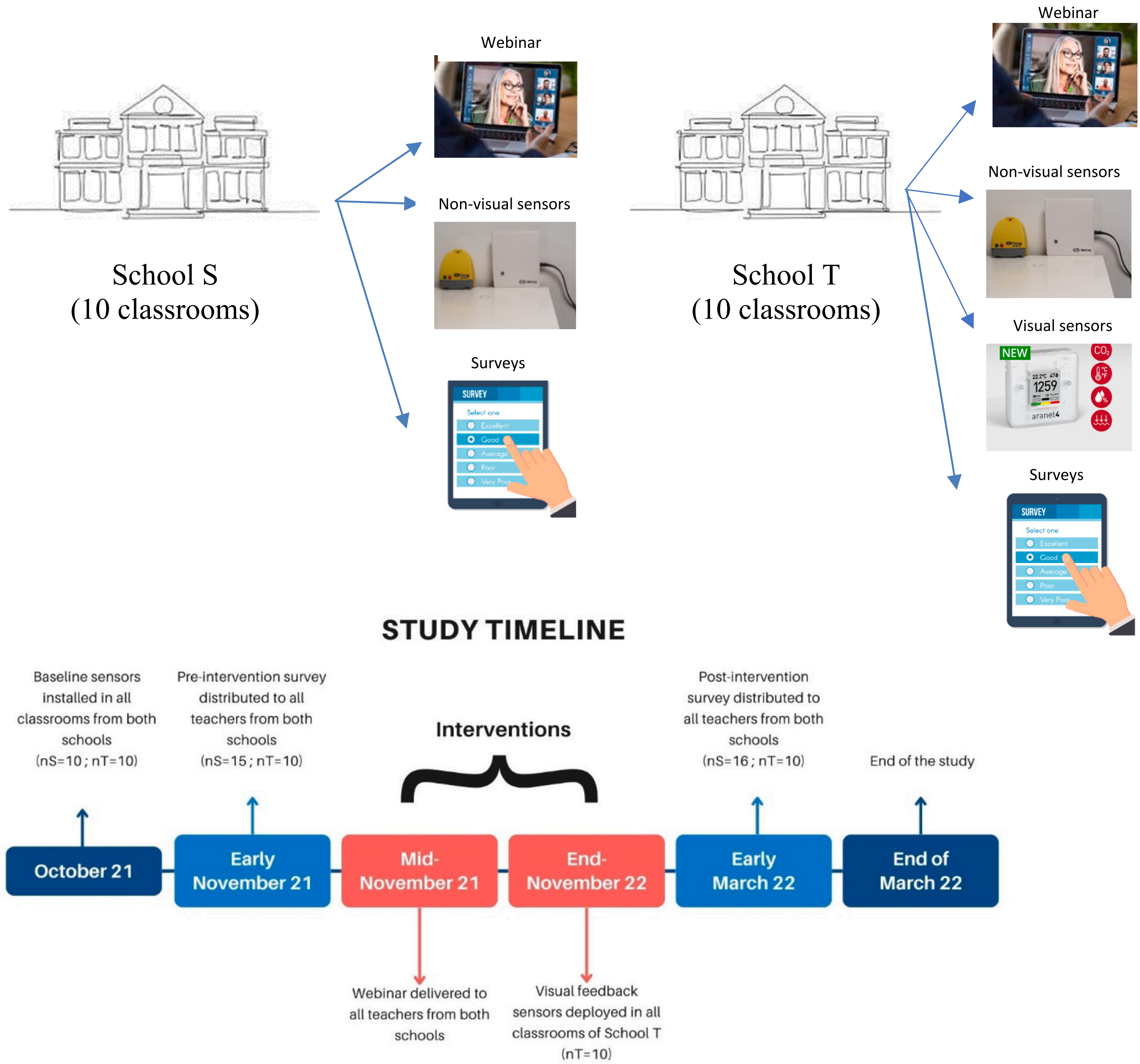

Fig. 3. Overview of the study design and timeline, detailing the activities conducted at School S and School T, including baseline measurements, surveys, and interventions (webinar and sensors with visual feedback).

divided into three parts: health symptoms, indoor environment perception, and psychological scale, as detailed in Table 1 to Table 3.

Table 1
Self-reported health symptoms of teachers, assessed via a 4-point Likert scale (1 = Often, 4 = Never), to evaluate the impact of environmental interventions on teachers' physical well-being in both study schools.

Health symptoms	4-Point scale answered by the teachers
Dry/watering eyes	Often (1)
Blocked/runny nose	Regularly (2)
Dry/irritating throat	Sometimes (3)
Chest tightness	Never (4)
Dry/irritating skin	
Headaches	
Dizziness	
Lethargy/tiredness	
Pain in neck/shoulder or back	

The post-intervention questionnaire was identical to the pre-intervention questionnaire with the addition of a fourth part, where the participants were asked to provide feedback on the sensors, as detailed in Table 4.

The teachers were asked to answer a total of nine questions about health symptoms they experienced when "*working in the same room for more than 4 hours*", using a four-point Likert Scale (1 = Often and 4 = Never) (see Table 1).

Concerning the condition of their working environment, the teachers were asked to answer questions about the overall working conditions and some specific ones on temperature, air movement, air quality, and ventilation (see Table 2). Participants responded to the overall work environment items on a 1–4 Likert Scale (1 = Strongly disagree) to 4 (Strongly agree). For specific parameters, each item was rated on a Likert Scale. For example, for temperature, the answer could range from 1 = Often too cold to 5 = Often too warm.

A proven psychological scale was used to assess the psychological

Table 2
Teachers' self-reported environmental conditions feedback and scales used.

	Conditions	Scale answered by the teachers
Overall work environment	Comfort	Strongly disagree (1)
	Privacy	Disagree (2)
	Design	Agree (3)
	Facilities	Strongly agree (4)
Specific parameters	Temperature	Often too cold (1) to often too warm (5)
	Air movement	Still (1) to draughty (7)
	Air quality	Dry (1) to humid (7)
	Air quality	Fresh (1) to stuffy (7)
	Air quality	Odourless (1) to smelly (7)
	Air quality	Clean (1) to dirty/dusty (7)
	Ventilation	Good (1) to poor (7)
	Overall air quality	Satisfactory (1) to unsatisfactory (7)

state of teachers. The Professional Quality of Life Scale (PROQOL) is a self-reporting tool designed to measure the impact of helping and caring for others in professional settings. It has been designed and developed by Hudnall Stamm (Stamm, 1995). It assesses an individual's professional quality of life through three dimensions: compassion satisfaction, burnout, and secondary traumatic stress. PROQOL has been extensively used in nursing research and more recently in studies involving teachers (Leech et al., 2022). This scale consists of 30 items rated on a 5-point Likert scale, ranging from "never" to "very often." Respondents rated the frequency with which they experienced certain feelings or behaviours associated with their work. This scale provides a quantitative measure of an individual's professional quality of life, enabling them to identify areas of strength and areas that may require attention or support.

The items of the PROQOL are detailed in Table 3.

Compassion Satisfaction (CS) refers to the pleasure individuals derive from effectively performing their work. Those who scored higher in this area tended to have a significant level of professional satisfaction. However, scores below 23 indicate issues with the job or other underlying factors (alpha scale reliability 0.88).

From a research standpoint, burnout (BO) is considered a component of Compassion Fatigue (CF) and is characterised by a sense of hopelessness and challenges in effectively performing work duties. Scoring high on this scale may indicate an increased risk of burnout, while a score below 23 suggests positive feelings regarding job efficacy. A score above 41 may be a cause for concern if it is persistent (alpha scale reliability, 0.75).

The second component of Compassion Fatigue (CF) is secondary traumatic stress (STS). This component involves exposure to extreme or traumatic stressful events in a work-related setting. A score above 41 does not necessarily indicate a problem but rather suggests a need for further examination of how one feels about their work and work environment (alpha scale reliability 0.81).

Finally, in the post-intervention questionnaire (March 2022), teachers were asked to provide feedback on the sensors deployed in their classrooms. To evaluate their level of involvement and interest in the study, they were asked if they knew which sensor they had in their classroom and which visual parameters they used the most (Indoor Temperature, Relative Humidity or CO_2 concentrations). They had to specify how confident they were using it, and how often they used it. To cross-check their perception of their working indoor environment, they were asked whether they thought it helped improve their indoor working environment. Finally, they had to rate out of 10 the sensor deployed in their classroom (Table 4).

Table 4
Teachers' self-reported feedback on the sensors deployed.

Evaluation of the sensors	Scales answered by the teachers
Confident using it?	Not at all (1) to Very (5)
How often using it?	Never (1) to All the time (4)
Improves ventilation	Completely agree (1) to completely disagree (5)
Improves IAQ	
Helps to have a comfortable and healthy working environment	
Reduces internal temperature	
Adds more pressure on workload	
Overall mark of the sensor out of 10	/10

Table 3
Content of the Professional Quality Of Life Scale (PROQOL).

1. I am happy.
2. I am preoccupied with more than one person I help.
3. I get satisfaction from being able to help people.
4. I feel connected to others.
5. I jump or am startled by unexpected sounds.
6. I feel invigorated after working with those I help.
7. I find it difficult to separate my personal life from my life as a helper.
8. I am not as productive at work because I am losing sleep over the experiences of a person I help.
9. I think that I might have been affected by the stress of those I help.
10. I feel trapped by my job as a helper.
11. Because of my helping, I have felt "on edge" about various things.
12. I like my work as a helper.
13. I feel depressed because of the distressing experiences of the people I help.
14. I feel as though I am experiencing the distress of someone I have helped.
15. I have beliefs that sustain me.
16. I am pleased with how I am able to keep up with helping techniques and protocols.
17. I am the person I always wanted to be.
18. My work makes me feel satisfied.
19. I feel worn out because of my work as a helper.
20. I have happy thoughts and feelings about those I help and how I could help them.
21. I feel overwhelmed because my case workload seems endless.
22. I believe I can make a difference through my work.
23. I avoid certain activities or situations because they remind me of distressing experiences of the people I help.
24. I am proud of what I can do to help.
25. As a result of my helping, I have intrusive, distressing thoughts.
26. I feel "stuck" by the system.
27. I have thoughts that I am a "success" as a helper.
28. I can't recall important parts of my work with the distressed people I have helped.
29. I am a very caring person.
30. I am happy that I chose to do this work.

Two open-ended questions were included at the end of the questionnaire: "*What would you improve if you could?*" and "*Comments on the CO_2 sensors you have in your classroom*".

The questionnaire took approximately 25 min to complete. Participants could save their answers and resume taking part later within a 14-day period.

2.3.2. Environmental monitoring

The outdoor data were provided by the Met Office (Edinburgh weather, 2024) from the local weather station at Gogarbank. The outdoor CO_2 was not monitored and was assumed to be 420 ppm, which was also the average measured concentration when unoccupied.

Indoor Temperature, RH and CO_2 concentrations were monitored in each classroom. The data were collected with 20 TinyTag (TGE-0011 and TGU-4500) and 10 Aranet4 Home monitors. All monitors are commercially available in Europe. The CO_2 ones use Non-Dispersive InfraRed (NDIR) technology. Measurement ranges and accuracy for each monitor are reported in Table 5.

Logging intervals were set to every 5 min for all sensors. The CO_2 display threshold values for the Aranet4 Home were set between 800 ppm and 1500 ppm for Amber and Red above 1500 ppm (REHVA, 2020; Scottish Government, 2021), via the Aranet application (Aranet, 2024).

Once in the classrooms, the Tinytag CO_2 monitors were plugged into an available power socket and made safe with the logger installed at head height, between 1 and 2 m. The Temperature/RH sensors and the Aranet4 Home (both battery-operated) were located next to the CO_2 monitors, positioned either on the teachers' desks or adjacent shelves (as shown in Fig. 4).

All monitors were positioned away from direct sunlight, radiators, doors, and windows.

2.4. Ethical aspects

The University Ethics Committee conducted an ethical review of the study on October 5th 2021. Participants were made aware that their data would be securely and anonymously stored for three years before being deleted. Teachers were informed that they had the option to decline answering any questions and could withdraw from the study at any point. Before completing the online survey, teachers were required to sign a consent form.

2.5. Data analysis

The data gathered from the survey were imported from the NOVI survey platform to IBM SPSS Statistics 26 for analysis. Due to the difference in the number of participants in School S and between schools, the changes were analysed using the Mann-Whitney *U* test. When comparing data from School T, the responses from different teachers were analysed using the Wilcoxon matched-paired signed-rank test. These tests are commonly used when responses are collected on an ordinal scale (Siegel and Castellan, 1988).

Table 5
Specifications of monitoring equipment deployed for environmental data collection, including CO_2 levels, temperature, and relative humidity. Each device's measurement range and accuracy are specified to illustrate their suitability for indoor air quality monitoring.

Monitors	Element measured	Measurement ranges	Measurement accuracy
Tinytag TGE-0011	CO_2 (ppm)	0–5000 ppm	± 50 ppm or 3 % of reading
Tinytag TGU-4500	Temperature (°C)	−25 to +85 °C	±0.6 °C
	Relative Humidity (RH)	0 to 95 %	±3.0 % RH at 25 °C
Aranet4 Home	CO_2 (ppm)	0–2000 ppm	±50 ppm or 3 % of reading
	Temperature (°C)	2001–9999 ppm	±10 % of reading
	Relative Humidity (RH)	0 to 50 °C	±0.4 °C
		0 to 85 %	± 3 %

Fig. 4. Visual sensor placed next to teacher's desk.

The open-ended questions of the post-intervention questionnaire were analysed using NVivo 20 via thematic analysis. This method consists of "identifying, analysing, and reporting patterns (themes) within the data. It minimally organises and describes your dataset in (rich) detail" (Braun and Clarke, 2006). Following the 'reviewing themes' phase of thematic analysis described by Braun and Clarke (2006), codes were created and then checked by a critical friend before the themes presented in this paper were decided. The 'critical friend' was a researcher working in a broadly similar field to the authors. After reading a draft of the selected themes, a face-to-face discussion between the first author and the 'critical friend' took place. The 'critical friend' was invited to question the themes selected to stimulate dialogue about alternative possibilities. All teachers who replied to the open-ended questions were assigned a letter to differentiate and anonymise them.

All the data from the environmental parameters were extracted to Microsoft Excel for analysis.

3. Results

3.1. Demography

25 teachers replied to the pre-intervention survey (15 in School S and 10 in School T) and 26 teachers (16 in School S and 10 in School T) responded to the post-intervention survey.

More than half of the respondents lived close to the schools (either in the same postcode or in a neighbouring one): 60 % of teachers in School S and 70 % of teachers in School T.

The average time since graduating as a teacher was >10 years: 14.1

years for the teachers in School S (with a Standard Deviation of SD = 7.1) and 12.9 years in School T (SD = 9.9).

For both schools, more than half of the teachers who took part in the surveys had been working in their schools for at least 5 years (73 % in School S and 60 % in School T).

The teachers worked on average (SD):

- 35.1 h per week in school S (8.8) and 33.1 h per week in school T (13.6),
- 4.1 days per week in School S (1.1) and 4.0 days per week in School T (1.1).

The sample response rate was adequate, considering the number of respondents, their experience as teachers in their actual schools, and the number of hours they worked in the buildings.

3.2. Health symptoms

Table 6 illustrates the potential impact of the visual feedback sensors on health symptoms. Although the teachers from both schools rated their health symptoms as more regular post-intervention, the results showed no significant evidence that the sensors had any impact on the teachers' perceived symptoms, as the *P* values were above 0.02.

3.3. Perceived indoor environment

Table 7 shows that teachers from both schools felt that their indoor working environment had deteriorated in all but one of the criteria.

Nevertheless, there was no significant difference in perceived work environment pre- and post-intervention for teachers from both schools, as the P values were above 0.02 in all cases.

Looking at more specific parameters, such as air movement, air quality, and ventilation, Table 8 highlights some different perceptions pre- and post-intervention. The teachers from both schools felt significant improvements in air freshness, odour, ventilation quality, and overall indoor air quality post-intervention, with *P*-values lower than 0.02. Despite all teachers from both schools having given the same trend, only the teachers from School T with visual feedback felt significant improvement in air cleanliness and deterioration in air movement.

3.4. PROQOL scale

The mean scores and Standard Deviations (SD) for each of the three components of the PROQOL scale pre- and post-intervention are summarised in Table 9. The three components of the PROQOL scale described in Section 2.3 are Compassion Satisfaction (CS), BurnOut (BO) and Secondary Stress Scale (SSS).

There is a difference between the two schools.

The teachers in the school with visual display sensors (School T) have been impacted as shown in the results of the three components CS, BO and SSS, as the p-value is <0.02 when a visual display sensor has been installed.

On the other hand, when the sensors did not have a visual display, the teachers did not report any changes in their CS, BO and SSS ($p > 0.63$).

3.5. Teachers' feedback about sensors

3.5.1. Awareness of sensors deployed in their classroom

In the school with visual display (School T), 60 % of the teachers knew the type of sensor they had in their classroom. This result drops to 44 % in the school without visual display (school S).

3.5.2. Confidence to use the sensor

Since only the teachers from School T had sensors with visual display deployed in their classrooms, the following applies only to them. Their confidence (1 = not confident to 5 = very confident) on how to use the sensor was 3.4 on average (SD = 0.86). 80 % of the teachers used the device sometimes during the week and 20 % used it once or twice a day. However, none of them said that they used it all the time. 70 % of the teachers looked at the indoor temperature, 50 % at the CO_2 level, and 10 % at relative humidity.

Fig. 5 illustrates the answers the teachers having sensors with visual feedback sensors gave to the following question: "*On a scale from 1* (*Completely disagree*) *to 5* (*Completely agree*), *what are your thoughts about the product?*"

3.5.3. Overall teachers' rating of sensors

When asked to give an overall score out of 10 to rate the sensor deployed in their classroom, the teachers gave an average 7.1/10 mark (SD = 1.73) (Min 2 and Max 10).

For the two open-ended questions, 8 out of 10 teachers from School T replied to one or both questions.

Teachers	What would you improve if you could?	Comments on the CO_2 sensors you have in your classroom:
A		Do not use it at all
B		They don't work as well when the weather is not windy
C	I have no thoughts on the product. I don't go near it.	This means nothing to me. It's been of no interest to me.
D	I wish it didn't reduce the room temperature	A huge difference when a sensor with a reading was set up. I could now control CO_2 and temperature more.
E	Have air purifiers rather than open windows	The visual sensor is helpful
F	Link it to my smart watch so it vibrated to tell me the air quality threshold was breached.	
G	Knowing at which point we can close more windows.	
H		The sensors do not affect my day, I have little time to check them other than first thing in the

(*continued on next page*)

Table 6
Health symptoms indicated by teachers with different types of sensors [Mean].

If you are working in the same room for more than 4 h, do you experience any of the following symptoms? (Often = 1, Regularly = 2, Sometimes = 3, Never = 4)	With visual sensors			Without visual sensors		
	Pre-intervention ($n = 10$)	Post-intervention (n = 10)	P (Wilcoxon)	Pre-intervention ($n = 15$)	Post-intervention ($n = 16$)	P (Mann-Whitney)
Dry/watering eyes	3.56	2.91	0.066	3.43	2.75	0.186
Blocked/runny nose	3.33	2.91	0.059	3.43	3.25	0.213
Dry/irritating throat	3.44	2.91	0.096	3.29	3.19	0.947
Chest tightness	3.78	3.73	0.157	3.71	3.88	0.931
Dry/irritating skin	3.89	3.27	0.066	3.36	3.13	0.430
Headaches	3.11	2.91	0.366	2.57	2.63	0.983
Dizziness	3.89	3.73	0.157	3.50	3.63	0.384
Lethargy/tiredness	3.11	2.45	0.366	2.79	2.63	0.573
Pain in neck/shoulder or back	3.22	2.91	0.726	3.00	2.63	0.253

Table 7
Teachers' perceptions of their overall work environment (mean values), rated pre- and post-intervention on a 4-point Likert scale. Perceptions of comfort, privacy, design, and facilities were assessed in classrooms with and without visual feedback sensors to examine intervention effects.

(1 = Strongly disagree, 2 = Disagree, 3 = Agree, 4 = Strongly agree)	With visual sensors			Without visual sensors		
	Pre-intervention (n = 10)	Post-intervention (n = 10)	P (Wilcoxon)	Pre-intervention (n = 15)	Post-intervention (n = 16)	P (Mann-Whitney)
The work environment is comfortable	2.89	2.55	0.157	2.69	2.59	0.467
I have sufficient personal privacy in my work environment	3.11	2.82	0.234	2.38	2.29	0.701
My work environment is well-designed for the job I do	2.89	2.45	0.059	2.43	2.35	0.610
I have adequate facilities in my workplace which support my health and well-being (e.g. lighting, washing, toilet, rest and changing facilities, and somewhere clean to eat and drink during breaks)	2.78	2.27	0.098	2.46	2.59	0.781

Table 8
Perceptions of Indoor Air Quality indicated by teachers with different types of sensors [Mean]. *P*-values show whether the differences between schools with and without visual feedback sensors, pre/post-intervention were significant, as indicated by an asterisk (*).

In winter, how do you rate the following aspects of typical conditions in your room? Please tick one box for each aspect on the 7-point scale. The "ideal" point on each scale is at the start of the question in brackets (ideal point).	With visual sensors			Without visual sensors		
	Pre-intervention (n = 10)	Post-intervention (n = 10)	P (Wilcoxon)	Pre-intervention (n = 15)	Post-intervention (n = 16)	P (Mann-Whitney)
Air movement: Ideal Point (4)	4.10	4.60	0.025 *	4.27	5.00	0.269
Air humidity: Ideal Point (4)	3.80	4.00	0.157	3.80	3.94	0.824
Air Freshness: Ideal Point (1)	3.90	2.60	0.004 *	4.27	2.44	0.008 *
Air odour: Ideal Point (1)	4.10	2.50	0.004 *	5.73	3.44	0.012 *
Air cleanliness: Ideal Point (1)	3.60	2.80	0.011 *	3.73	3.00	0.259
Ventilation quality: Ideal Point (1)	3.20	2.00	0.003 *	3.87	2.38	0.004 *
Overall Indoor Air Satisfaction: Ideal Point (1)	3.40	2.20	0.003 *	3.47	2.19	0.005 *

Table 9
Means and Standard Deviations (SD) of the three components indicated by teachers of the PROQOL scale detailed in Table 3. P-values show whether the differences between schools with and without visual feedback sensors, pre/post-intervention were significant, as indicated by an asterisk (*).

	With visual sensors, mean (SD)			Without visual sensors, mean (SD)		
	Pre-intervention (n = 10)	Post-intervention (n = 10)	p (Wilcoxon)	Pre-intervention (n = 15)	Post-intervention (n = 16)	p (Mann-Whitney)
Compassion Satisfaction	42.1 (4.2)	37.5 (4.9)	0.021*	37.8 (4.7)	37.5 (4.2)	0.874
Burnout	20.6 (3.7)	24.1 (5.5)	0.024*	25.5 (6.1)	25.2 (6.9)	0.843
Secondary Stress Scale	19.4 (4.8)	24.8 (5.6)	0.015*	24.6 (7.6)	25.4 (6)	0.634

(*continued*)

Teachers	What would you improve if you could?	Comments on the CO_2 sensors you have in your classroom:
		morning before the children arrive. In the evenings I am so cold that I shut my windows.

3.6. Environment monitoring

Edinburgh has a temperate maritime climate moderated by its proximity to the sea. The temperatures are rarely extreme, whereas the RH can reach 100 %.

Fig. 6, Fig. 7 and Fig. 8 show the minimum, maximum and mean values of the indoor and outdoor temperatures, relative humidity and CO_2 concentrations before and after interventions.

Both schools maintained relatively stable average temperatures despite significant changes in outdoor temperature, while their temperature ranges widened from Pre to Post interventions.

Both schools experienced a decrease in Relative Humidity average post-interventions with a larger range of values.

The average CO_2 concentrations in both schools show relatively small decreases after the interventions, with School T seeing a slightly greater decrease than School S. Whereas a significant increase in the range of CO_2 levels post-intervention in both schools can be noticed, particularly the upper limit (maximum concentration).

Fig. 9 and Fig. 10 represent the indoor temperature and CO_2 concentration averages across school hours at each time step, comparing conditions before and after interventions and differentiating between schools with and without visual displays.

The indoor temperatures pre-intervention, both with and without visual displays, steadily rise through the morning, peaking around midday or early afternoon, and then slightly dip before rising again toward the end of the school day. Post-intervention, the temperature follows a similar pattern but exhibits distinct differences between the two groups, especially post-noon.

The school without visual display consistently shows higher indoor temperatures throughout the day, peaking around 11:30 am, then fluctuating mildly after noon. This group starts at a temperature near 18.0 °C and peaks at around 20.5 °C. After the intervention, the temperature curve is slightly lower than pre-intervention, peaking at a lower value.

The temperatures in classrooms with visual displays start similarly to those without displays but remain consistently lower throughout the day. Post-intervention, the indoor temperature is consistently lower than before the intervention. The peak temperatures after the

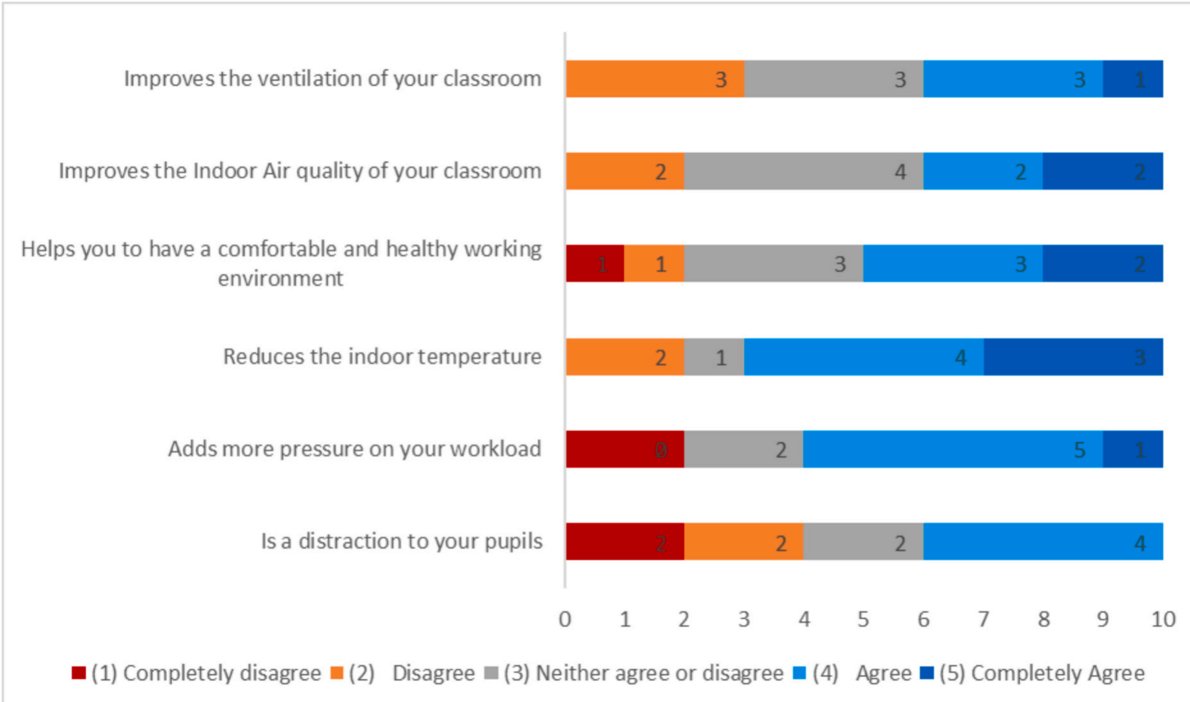

Fig. 5. School T teachers' thoughts about visual sensors ($n = 10$).

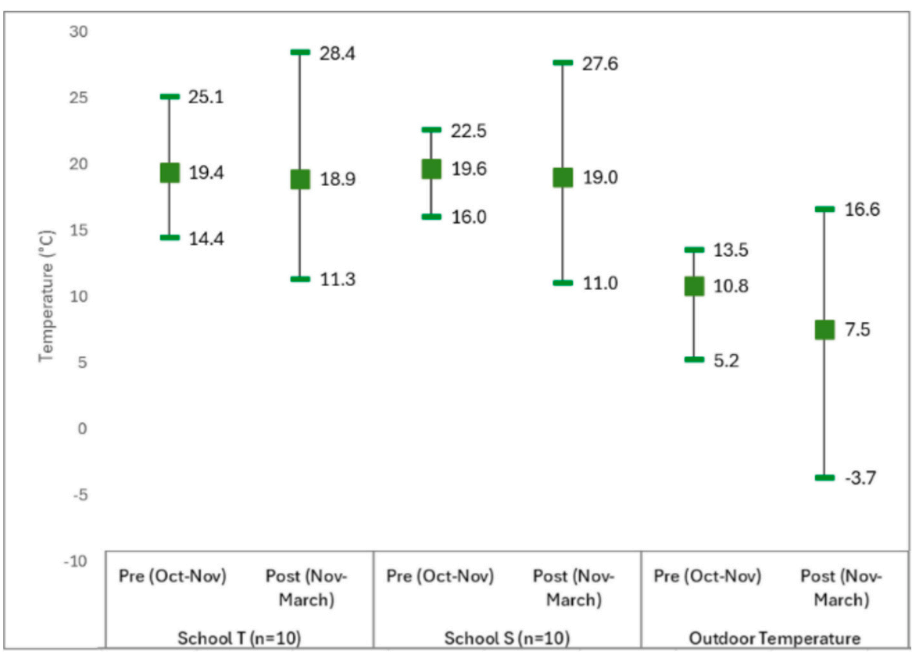

Fig. 6. Minimum, maximum, and mean values of indoor temperature recorded in School S and School T classrooms pre and post-interventions.

intervention are much lower than in the other group.

Before the intervention, the CO_2 concentrations in both schools increase throughout the morning, peaking around midday and then decreasing slightly during lunch break before rising again toward the end of the school day.

After the intervention, the CO_2 levels decreased slightly in both groups, especially noticeable in classrooms with a visual display (dotted blue line), which show a lower overall CO_2 concentration throughout the day compared to before the intervention. Classrooms without visual displays (yellow dashed line) continue to exhibit higher CO_2 levels compared to those with visual displays, but both groups show a slight reduction in overall CO_2 concentrations post-intervention. The mid-day peak is still present, but the post-intervention trends show a smoother, slightly lower pattern.

4. Discussion

4.1. Demographic characteristics

The demographic results indicated that the teachers in both schools

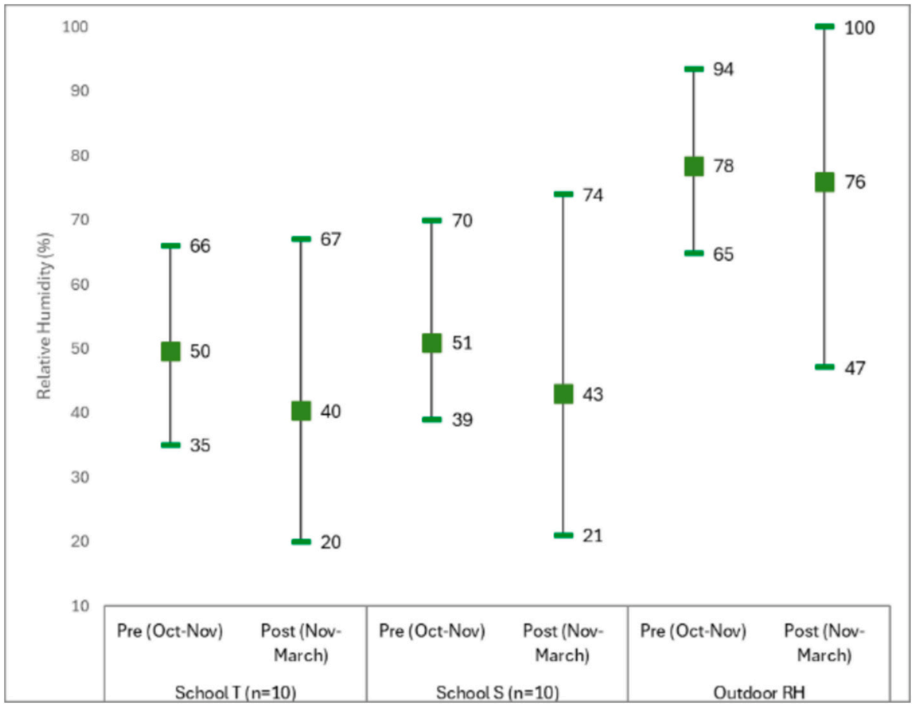

Fig. 7. Minimum, maximum, and mean values of indoor relative humidity recorded in School S and School T classrooms pre and post-intervention.

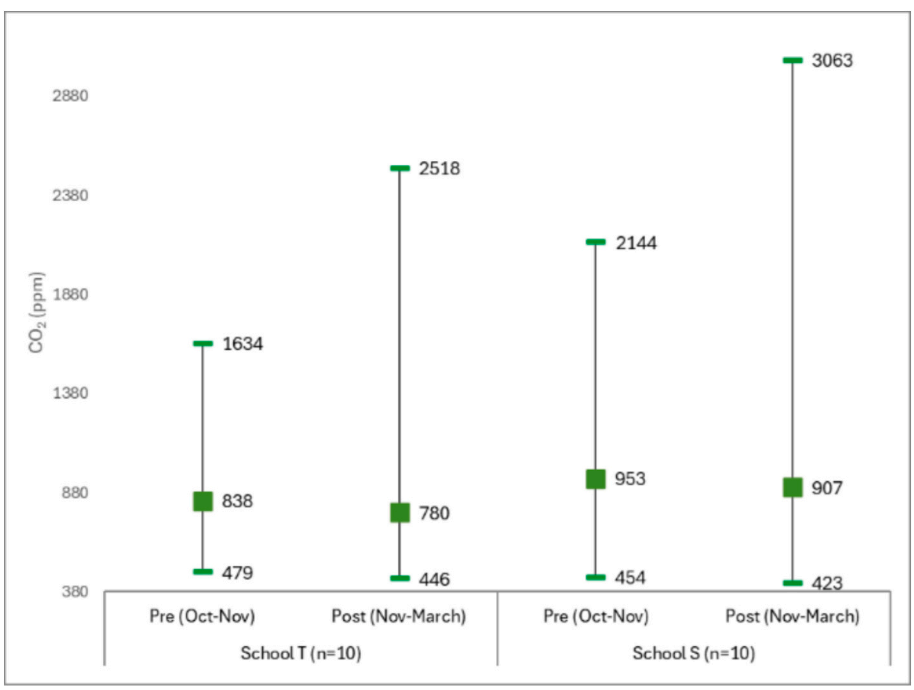

Fig. 8. Minimum, maximum, and mean values of indoor CO_2 concentrations recorded in School S and School T classrooms pre and post-interventions.

were experienced, with >10 years of post-graduation teaching experience and significant tenure at their current schools. Most teachers lived close to their schools, which may have contributed to their engagement in the study. These factors strengthen the validity of the sample, as experienced teachers who are familiar with their environment are more likely to provide insightful feedback.

4.2. Health symptoms pre- and post-intervention

The intervention aimed to evaluate the potential reduction of teachers' health complaints related to IAQ. However, the results showed no significant improvement in symptoms regardless of whether the sensors had a visual display, as indicated by P values above 0.02. For example, symptoms like dry or irritated eyes, blocked noses, and chest tightness persisted at similar levels. One possible explanation is that the duration of the intervention was not long enough to see tangible health

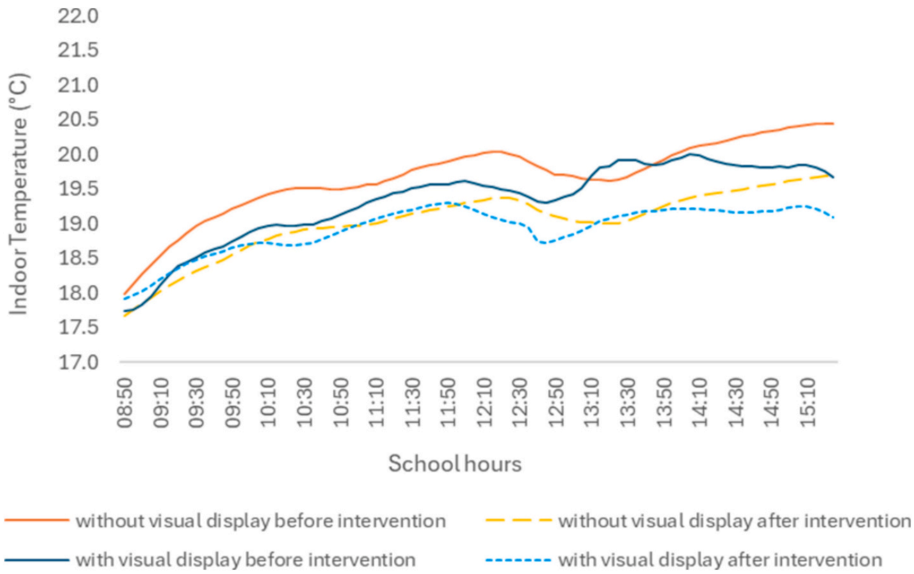

Fig. 9. Indoor temperature pre/post-intervention in both schools ($n_T = 10$, $n_S = 10$).

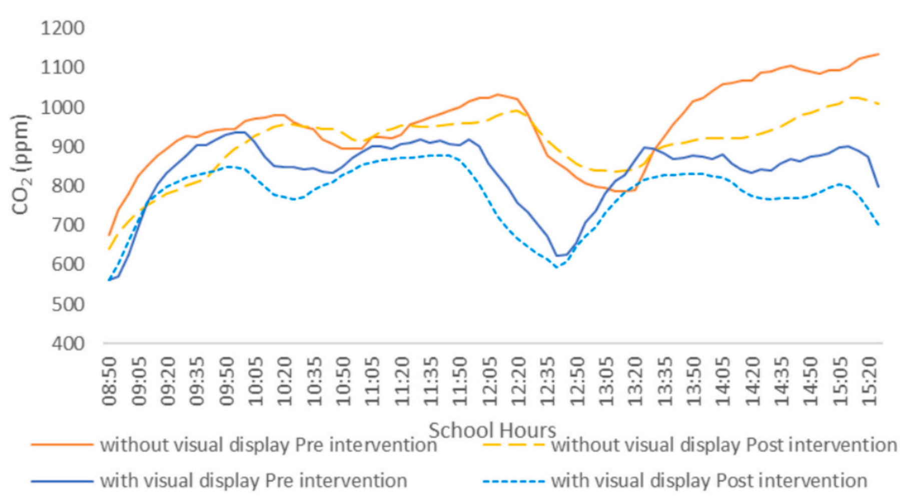

Fig. 10. CO_2 concentration levels pre/post-intervention in both schools ($n_T = 10$, $n_S = 10$).

improvements. Additionally, the relatively small sample size may have limited the ability to detect significant changes.

4.3. Perception of overall indoor environment

Although teachers reported a decline in work environment comfort post-intervention, no statistically significant changes were observed ($P > 0.02$). This suggests that despite having the opportunity to visually check information, unless prompted to take action, there is no impact on the perceived indoor environment (Kong et al., 2023).

4.4. Indoor air quality perception

By contrast, significant improvements were recorded in specific IAQ parameters post-intervention. Teachers from both schools felt that the sensors were positive tools to enhance air freshness, air odour, air cleanliness, ventilation, and overall indoor air satisfaction. This could be attributed to the Hawthorne effect, where awareness of participating in a study and being observed may have influenced their behaviour (Hawthorne effect (Landsberger, 1958; Franke and Kaul, 1978; McCarney et al., 2007)). Additionally, their heightened awareness may have been reinforced through the information provided in the webinar.

Nevertheless, these changes were most notable in School T, where visual feedback sensors were used, suggesting that the visible display of real-time air quality data may have motivated teachers to make adjustments, such as opening windows. The monitored indoor parameters support this hypothesis. In both schools, the interventions had an impact on teachers' behaviour, resulting in a decrease in CO_2 levels. However, classrooms in School T, equipped with visual sensors, experienced a more significant reduction. This is in line with the findings of previous studies (Chatzidiakou et al., 2015). In addition, the same teachers of School T reported that having sensors had a negative impact on the air movement in their classrooms: more open windows implied more air movement to the point of feeling too much draught. These findings are also found in past studies (Wargocki and Silva, 2015; Vassella et al., 2021; Burridge et al., 2023; Green et al., 2023; Toftum and Clausen, 2023; Bastien et al., 2024; Zivelonghi and Kumar, 2024).

Overall, the interventions appear to have had a positive effect in reducing CO_2 concentrations, particularly in classrooms with visual displays. Classrooms without visual displays show a smaller improvement. This suggests that visual displays may contribute to maintaining more stable and improved ventilation during school hours, though potentially at the expense of the indoor temperatures. These findings align with the idea that visual feedback can influence behaviour change and environmental control, even if overall perceptions of comfort remain unchanged.

4.5. Impact on professional quality of life

The Professional Quality of Life (PROQOL) scale revealed significant differences between schools with and without visual feedback.

No impact was observed on Compassion Satisfaction (CS), Burnout (BO) and Secondary Stress Scale (SSS) of teachers from School S, where the sensors provided non-visual feedback. However, in School T, where visual feedback sensors were deployed, teachers reported lower Compassion Satisfaction (CS) and higher Burnout (BO) and Secondary Stress Scale (SSS) scores post-intervention. These findings suggest that visual feedback may increase stress or create a heightened awareness of IAQ issues, contributing to a sense of burden. Additionally, the teachers were aware that the data were gathered weekly. Teachers may have felt that their behaviour was being observed, making them more conscious and potentially susceptible to criticism regarding their level of engagement.

The contrast in the teachers' responses from both schools may indicate that the presence of visual feedback can have unintended psychological consequences.

4.6. School T teachers' feedback on sensors

The distinction in awareness of the types of sensors used in classrooms suggests that teachers with visual sensors were more cognisant of the available equipment, leading to higher levels of engagement in the study.

The main information the teachers were interested in when looking at the visual feedback was the temperature, where only one teacher out of the two had been looking at the CO_2 levels. This is in line with previous studies in which workers were primarily concerned with indoor temperatures (Higgins et al., 2005). This is also confirmed by the open-ended questions of the present study given by teachers who wished that the devices would have helped achieve a warmer temperature (Teachers D and H) or informed them when to close their windows (Teachers E, G, and H). The teachers reported that they felt the sensors implied a reduction in the indoor temperature as more windows were open. This is confirmed by the data gathered and reported on Fig. 4, where the indoor temperatures are lower post-intervention with a minimum of 11 °C. In comparison, the interventions may have marginally lowered the temperature in the classrooms of school S without visual display, though the reduction is minimal. This confirms that cold climates prevent occupants from opening windows and doors to avoid lowering the indoor temperature and if occupants are unaware of the need to ventilate more, they keep their windows closed to avoid being cold (Toftum and Clausen, 2023).

Despite the sensors being rated 7.14 out of 10 overall, the open-ended comments revealed frustrations, such as the belief that sensors did not work well in certain weather conditions. The majority of the teachers felt that the sensors added pressure to their workload, having to manage their indoor environment. They also felt the sensors could be a distraction to their pupils. These confirm the findings of the PROQUOL scale discussed in 4.6. Although 2 teachers (Teachers D and E) felt that the visual feedback was helpful, 4 teachers saw no (Teachers A, B, C) to very little (Teacher H) use of the sensors, with 3 teachers suggesting improvements to the device (Teachers E, F, and G). This suggests that while some teachers appreciated the real-time data, others felt it added minimal value or complexity to their workflow.

4.7. Study limitations

Several limitations may have affected the results:

- The sample size was relatively small, reducing the study's statistical power.
- The intervention period may have been too short to observe long-term changes in health or perceptions. Although the study was initially intended to span the entire school year, teachers faced increased workloads due to end-of-year demands during the pandemic, including lockdowns and restrictions. As a result, they requested not to participate in surveys during the summer months, which may limit the representativeness of the teachers' perceptions.
- Given the nature of the study as a citizen-science project, it was not possible to rigorously control the experimental conditions. This limitation contributed to the variation in the number of teachers participating in the surveys before and after the intervention.

4.8. Recommendations for practice

- Educating teachers on indoor air quality (IAQ) and ventilation, and providing them with tools to manage their indoor environments, has demonstrated positive impacts. Consequently, incorporating modules on IAQ and ventilation strategies into teacher training programs is recommended to ensure sustainable improvement. This approach will enable staff to manage classroom air quality and will also provide an opportunity to educate students on maintaining a healthy indoor environment, potentially fostering a broader cultural shift.
- This cultural shift may help alleviate any psychological burden by normalising the presence of sensors in classrooms, empowering staff to take immediate actions as part of routine practice.

5. Conclusion

This study investigated the impact of two interventions—visual feedback sensors and a teacher awareness-raising webinar—on indoor air quality (IAQ) management in pre-1919 primary school classrooms in Scotland. The visual feedback sensors encouraged improved ventilation behaviours, resulting in significant perceived improvements in air freshness, ventilation quality, and overall IAQ. However, these sensors also increased teachers' workload and stress levels while occasionally distracting students. In contrast, the webinar intervention effectively enhanced teachers' understanding of IAQ and their perception of their indoor environment without imposing additional psychological or practical burdens. Both interventions highlight the potential for targeted strategies to improve IAQ in educational settings.

These findings suggest that while visual feedback sensors can be valuable for improving IAQ, their implementation should be accompanied by adequate training and consideration of their potential impacts on teacher well-being and classroom dynamics. Awareness programs may offer a less intrusive and more sustainable approach to improving IAQ in schools. Further research is warranted to explore the long-term effects of combining visual feedback tools with education-based interventions to optimise IAQ management in schools.

CRediT authorship contribution statement

Natalie Bain-Reguis: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Formal analysis, Conceptualization. **Andrew Smith:** Writing – review & editing, Validation, Supervision. **Caroline Hollins-Martin:** Writing – review & editing, Validation, Supervision, Methodology. **John Currie:** Writing – review & editing, Supervision.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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