School-based citizen-science action measuring IAQ comfort levels

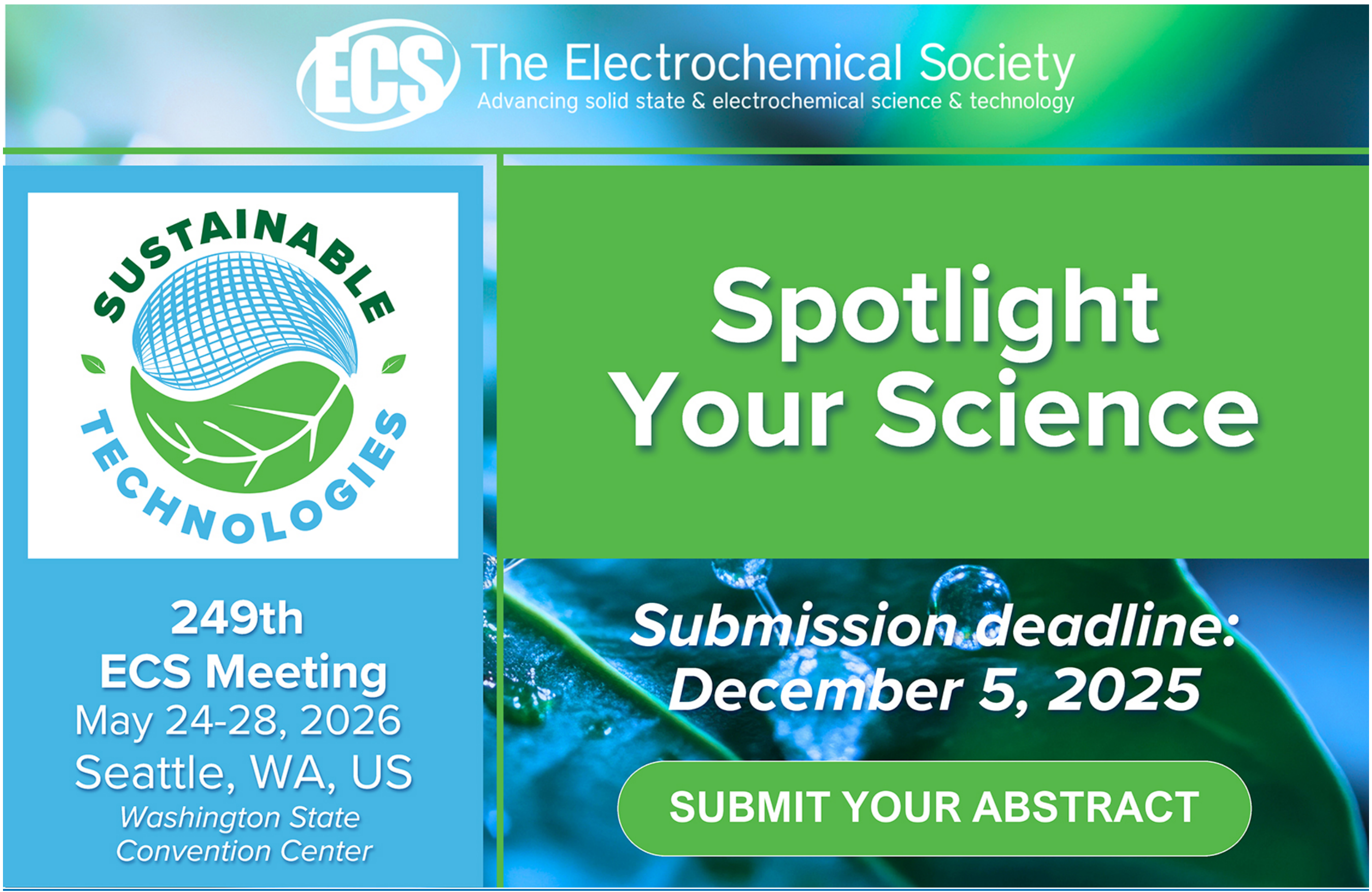
Original
School-based citizen-science action measuring IAQ comfort levels / Chiesa, G.. - In: JOURNAL OF PHYSICS. CONFERENCE SERIES. - ISSN 1742-6588. - ELETTRONICO. - 3140:9(2025). [10.1088/1742-6596/3140/9/092005]

Publisher:
IOP publishing

Published
DOI:10.1088/1742-6596/3140/9/092005

School-based citizen-science action measuring IAQ comfort levels

To cite this article: G. Chiesa 2025 *J. Phys.: Conf. Ser.* **3140** 092005



IOP Publishing
doi:10.1088/1742-6596/3140/9/092005

School-based citizen-science action measuring IAQ comfort levels

G. Chiesa[1]

[1] Politecnico di Torino, Department of Architecture and Design, V.le Pier Andrea
Mattioli 39, 10125 Turin, Italy

giacomo.chiesa@polito.it

Abstract. Indoor Air Quality (IAQ) is an essential comfort domain in public spaces, especially educational ones. This growing interest is underlined in the post-COVID pandemic period, requiring the testing and diffusion of different solutions, from mechanically driven solutions to controlled natural ventilation ones. The latter may also be easily applied to existing buildings, requiring minimal interventions, including installing intelligent monitoring solutions that allow end-user alerting and support self-actuation actions. This paper investigates this issue, proposing a citizen-science methodology based on six steps developed during an H2020 IA project and involving six schools and 42 classes in a long measuring period. This work introduces the methodology and initial results. Results show improvements in the IAQ conditions after the students' activation, with, in some cases, a slight decrease in the level of attention after a specific period. However, in 75% of the classes where a student lecture is given, IAQ improves in the short and the long run.

1. Introduction and objectives

Smart building implementation is a vast research domain, covering many application areas, ranging from energy building management to different comfort domains. Indoor environmental and indoor air quality (IEQ and IAQ, respectively) are essential to guarantee comfortable conditions for building end-users. In the post-pandemic world, IAQ has become crucial in confined spaces, particularly public and educational ones. Confined spaces are known to have high pollutant concentrations, causing diseases and the well-known Sick Building Syndrome [1,2]. Prolonged exposure to high concentrations of pollutants is correlated to loss of attention, lack of memory and focusing ability and may cause irritations, headaches, or chronic problems. On the contrary, high IAQ levels reduce the risk of virus concentration and the spread of airborne diseases [3]. It is essential to elaborate strategies to maintain high IAQ levels, considering different air-movement means, i.e. mechanical, hybrid, and natural ones, and building-correlated conditions and technological backgrounds [4]. This paper focuses on schools, i.e. public spaces notoriously crowded, requiring a very high level of IAQ, analysing self-actuation actions driven by a citizen-science adopting smart sensoring solutions to support controlled natural ventilation (CNV).

1.1. Background

Spending most of our time in confined spaces, the control of air pollutants is essential to guarantee our health in the short and long term, requiring the implementation of ventilative strategies. Airflows in buildings can be activated by natural (NV) or mechanical (MV) ventilation means [5], adopting different control logics. With these premises, it is possible to identify and classify different solutions considering NV or MV and two aspects: sensoring (random or measured) and actuating (manual or automatic). Random natural ventilation, manually driven by end-users, is the simplest approach, although, based on personal perceptions, it does not guarantee specific levels of performance [6,7]. Especially in schools, random NV generally exposes pupils to high levels of CO_2 concentration, especially during the cold season [8]. MV strategies not based on sensors, e.g. adopting constant air flow rates, can also envisage limits, being not correlated to real-time conditions with the risk of over- or under-ventilation or potential increases in energy consumption [4]. Sensor-driven controlled natural ventilation (CNV) can be exploited by informing users and driving self-actuation actions or by controlling mechanical actuators, opening and modulating air intakes and outtakes, e.g. via pistons or chains. Both approaches were effective [9,10,11], although the self-actuation needs additional studies to analyse the long-term performance [12]. Finally, sensor-driven MV solutions may balance vents to support the required airflow exchanges to maintain the defined levels of IAQ – see [4]. Nevertheless, most buildings, especially in the South of Europe, do not have a mechanical ventilation system, relying on the proper air exchange via manually activated natural ventilation solutions that are generally randomly driven. This is still valid for national cases such as the Italian context, where schools rarely have mechanical ventilation and where the possibility to install these systems in existing buildings is minimal due to the lack of spaces and the specific spatial organisations [8]. Studies have demonstrated that the proper use of windows may support the correct level of IAQ in classrooms, supporting controlled natural ventilation with different potential KPIs [11,13]. The latter is also received in national governmental and ministerial decrees, e.g. [14], supporting schools' pandemic and post-pandemic IAQ requirements. Other countries have adopted more restrictive IAQ requirements for schools, such as France, which adopted the ICONE confinement index method, and Switzerland, via the SIA 180. The applications of those performance studies require sensors supporting mechanical activations and/or self-actuation actions via alerts. This paper investigated this latter point.

1.2. Paper's objectives

This paper aims to report the preliminary results of a significant citizen science project that was part of an EU-co-founded H2020 Innovation Action project involving six schools in the Piedmont Region, North West of Italy. In line with Italian buildings, those schools do not have the MV or the space and budget to install this system, basing IAQ levels only on random NV. The proposed study investigates the possibility of installing cloud-sensing solutions with school alerting options to support a consciously controlled NV solution based on self-actuation actions driven by user-informing methods. The work included specific analyses to verify the sensor market, costs, replicability, maintenance issues, user acceptability, and barriers, including regulations and permissions. Furthermore, citizen science aims to diffuse growing attention to the IAQ and IEQ topics while supporting students and teachers in properly activating windows via self-actuation actions reinforced by alerting solutions. Additional scope is disseminating smart building correlated aspects of the mentioned H2020 project to a large public, including free-running based comfort self-actuation actions, smart building monitoring, proactive actuation issues, and IEQ aspects.

Nevertheless, this paper describes the citizen science approach, the developed methodological pipeline, and some initial results of the self-actuation in different buildings.

The high number of involved students makes this experiment innovative, allowing for the analysis of the impact of student activation and the importance of increasing the smartness level of educational buildings to know and improve local IAQ and IEQ levels.

2. The proposed methodology

To describe the elaborated methodology, two main aspects are detailed here: the organisation of the citizen science action (see Section 2.1) and the definition of the technical aspects, such as the identification of the monitoring infrastructure and the key performance indicators (KPIs) to be computed/measured from the collected data (see Section 2.2).

2.1. The proposed citizen-science pipeline

The schools participating in the initiative have been identified, and a methodological pipeline has been defined to support the citizen science action based on six operative steps.

1. Step 1: sensors' installation: This step starts with a survey conducted with relevant school stakeholders (e.g. teachers or the master), identifying the rooms to be measured, collecting teachers' expectations, and identifying a place where the gateway should be located.
2. Step 2: mute measurements to define a benchmarking database: In this second step, during at least 2-3 weeks, sensors are left measuring current IAQ and IEQ conditions without activating any alerting or suggestion facilities. The scope is to analyse the current conditions and be able to discuss with students and teachers the starting point to define together thresholds for CO_2 alerting activation and increase their interests by showing them their classroom performances.
3. Step 3: lecturing: A short lecture is given to each class, introducing students to building and energy topics, comfort-building domains, and IAQ challenges. The lecture also introduced citizen science and the activity they were asked to participate in. The previously measured data are also detailed to help them understand potential risks and the importance of the action, as well as increase their engagement. A survey about smart buildings is also distributed.
4. Step 4: citizen science and self-actuation actions: An alerting facility is activated for all involved classrooms/spaces, allowing students to support self-actuation, i.e. opening windows and potentially doors to increase natural ventilation air exchanges, under request avoiding hyperventilation in winter with consequent rising in heating energy costs, i.e. if the heating system allows a room-by-room control, or a reduction in the thermal comfort conditions, i.e. when local radiators are not based on a local thermostat. This step stays for at least 1 month.
5. Step 5: restitution: A short communication is given back to students, class by class, to report the effect of their self-actuation behaviours on the IAQ performances, identifying potential improvements and open challenges, and discussing their experience and issues they may have envisaged. This step is essential to support the 6th step, maintaining high participation in citizen science over time. Additional checkpoints may be planned, discussing with the reference teachers if the self-actuation performances decrease over time.
6. Step 6 (facultative): continuation of the activities: This last step prosecutes the citizen science self-actuation action in the additional months of the school year, following students in improving their IAQ levels over the different seasons, including the neutral periods and the start of the summer one. In Italy, school lectures continue till the beginning of June, followed by the exams. Nevertheless, in the northern part of the country, where schools are localised, internal temperatures can quickly rise over 26°C since the end of May.

2.2. Data acquisition and elaboration

Considering the literature findings, the IAQ tracker adopted for this study is CO_2. This gas is primarily produced by occupants and allows the monitoring of air-quality deterioration during occupation [15,16]. In all the schools, a series of CO_2 probes, also measuring temperature and relative humidity, have been installed in different rooms to support the action. Sensors are cloud-connected and are selected in order to minimise data losses and facilitate data elaborations. The sample measuring period is 10 minutes, with post-elaborated hourly averaging for general trends, although primary analyses are based on the 10-minute time-step data to avoid peak loss.

The possibility of self-producing customised sensors, e.g. using do-it-yourself electronics based on Raspberry Pi and Arduino, has been preliminarily investigated. Still, after prototyping, this possibility has been substituted by adopting commercial solutions to respect the school requirements of accepting only certified and documented instruments. The selected sensor infrastructure needs to cloud-monitor the above-mentioned IAQ and IEQ variables, allowing for the potential integration of additional sensors with other probes, e.g. TVOCs (Total Volatile Organic Compounds) or PMx (Particle Matter), and integrates alerting solutions to support students in activating self-actuation. The sensor facility also needs to allow data storage and minimise the risk of data losses, e.g. supporting local storage during potential periods without internet connections. Furthermore, they must be based on batteries, limiting the number of required plugs to one for the gateway. Moreover, the possibility to modify via a cloud platform the alerting thresholds and the ability to host an autonomous internet connection not based on the local Wi-Fi is also required. Considering these requirements, the selected monitoring infrastructure was the Capetti Winecap^{TM} solution – see the probe technical specifications in Table 1. Alerting is based on activating a red blinking LED on the CO_2 probes. This light alerting approach has been defined in discussions with teachers as not being possible to ask students to use mobile apps or internet facilities, or to use sound alerting to avoid lecturing interruptions.

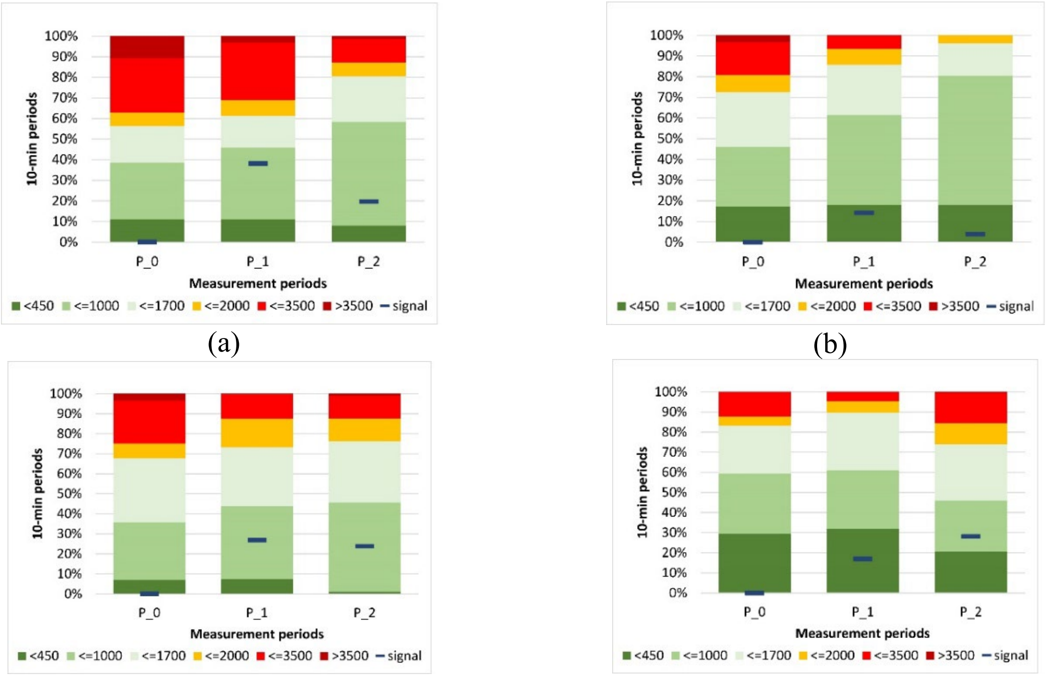
Table 1. CO_2 probe characteristics, Capetti winecap models: WSD00THCOP and WSD00TH2CO_S.

	Indoor Temperature	Relative Humidity	CO_2 concentration
Transducer type	NTC10KΩ	CMOSens® tech.	NDIR principle
Measure range	-10°C ÷ +60°C	0 ÷ 100%	0 ÷ 5000 ppm
Measure precision	±0.2°C whole range	±2.0% (typical) from 0% to 90%	< ±50ppm (+3% of measured value) whole range
Measure resolution	0.01°C	0.05% RH	1 ppm

Looking at the KPIs, the latter mainly focuses on IAQ, with special regard to CO_2 levels. In particular, the measured data are classified following air confinement domains reinterpreted by the ICONE approach [17] and correlated with French and Swiss limits. Six domains are adopted: ≤450ppm (aligned to outdoor conditions); 450<ppm≤1000 (very good – ventilation may be excessive if based on CNV in winter); 1000<ppm≤1700 (good/acceptable); 1700<ppm≤2000 (slightly bad, actions needed); 2000<ppm≤3500 (bad conditions, urgent actions); and >3500 ppm (awful conditions). These domains are used for data elaboration, while for the citizen-science self-actuation suggestions, a single LED threshold is adopted (1700 ppm). Post-elaboration for research and student restitutions includes line charts, cumulative frequencies, data distribution (percentage of time on bar charts) in the different domains for selected periods, and carpet plots. Additionally, the number of periods during which LED alerts were active was analysed to study the classrooms' ability to respond to suggestions. Data are filtered by occupancy profiles, analysing the school's regional and municipal calendars and the single school hourly profiles. TVOC, PM10-PM2.5 and thermal comfort (air temperature and relative humidity) are also analysed but not reported here.

3. Sample results

Six schools participate in citizen science: three middle and three high schools, covering a total of 42 classes/rooms, directly involving more than 500 students and 22 professors, plus an additional 750 students using the involved laboratories and thematic classes, while the dissemination among the involved school populations exceeds 2000 people. This paper mainly focuses on the methodological pipeline. However, some preliminary results are reported, analysing different measurement periods, to give the reader consistency with the method. Hence, Figure 1 analyses the identified CO_2 concentration trends during the different citizen science measurement steps, taking four classes from two other schools as an example. Three separate trends are identified. Classes (a) and (b) show significant improvements that progress over time – in those cases, we can see an improvement and a reduction in the number of hours in which the LEDs are active for both the methodological steps 4 and 6; in case (a) even greater improvements arrive after the initial restitution. Class (c) is interested in a visible improvement in IAQ and maintaining the level reached throughout the school year. Class (d) has a different trend: in the first period, the IAQ improves, while in the long run (step 6), the air quality worsens even compared to the reference period. The IAQ rising trend (cases a to c) is underlined in 55% of the classes. Additionally, higher IAQ levels are reached in those classes where methodological step 3 is given (in the presence of lecturing and direct student activation). If only these latter cases were considered, the IAQ rising trends would arrive at 75% of classes in steps 4 and 6 (long-run).



(a) (b)

(c) (d)

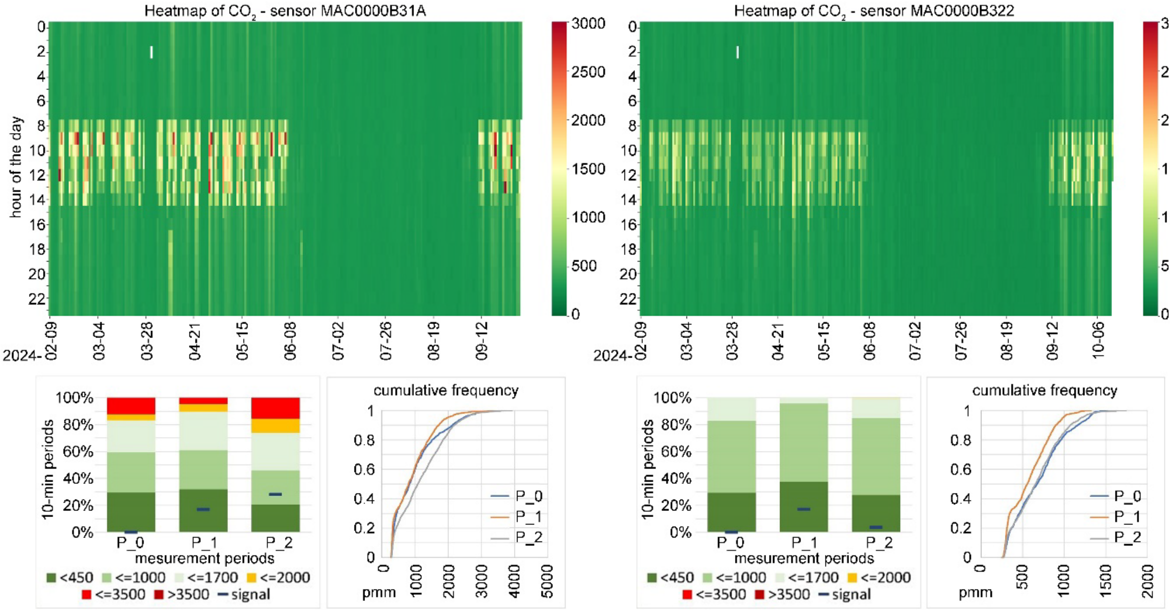
Figure 1. Four sample measured classes – P_0 is step 2 of the methodology (background), P_1 is step 4 (short-term citizen science), and P_2 is step 6 (long-term citizen science), analysing the ability of students in pursuing self-actuation (School Year 2023-4).

4. Discussion

In addition to the single-class analysis, the study also aims to discuss the ability of the proposed self-actuation citizen science methodology to guarantee IAQ levels compared to actuator-controlled systems. Figure 2 compares the impact of the citizen science self-actuation on CO_2 IAQ levels in a classroom where students are actively participating versus a classroom in the same school where a mechanical ventilation system with sensor-driven control guarantees the CO_2 IAQ levels (1000 ppm) – for MV details, see [4]. Results demonstrate how an active involvement of occupants in activating CNV under alerting requests can guarantee the fulfilment of IAQ requirements within safe limits without mechanical assistance, eliminating installation and maintenance costs and the identified critical issues correlated to MV noises for room-installed detached machines. The research group is developing additional studies on this point.

5. Conclusions

The proposed study underlines how alert-based citizen science actions may support, when adequately implemented, the maintenance of IAQ levels within the comfort domains via self-actuation action (CNV) without requiring MV assistance. This is particularly useful for all schools and buildings where MV solutions may not be installed due to space limitations or budget constraints.



(a) (b)

Figure 2. CO$_2$ concentration per domain during the occupation: (a) in a classroom without MV, but supported by the citizen-science self-actuation approach and (b) in a classroom with MV (85% of the time, CO$_2$ is below 1000 ppm).

Furthermore, the study underlined how continuous work is needed to maintain a high level of students' attention and involvement, identifying two leading suggestions:

- It is crucial to guarantee the involvement of the most representative teachers within the school, allowing citizen science to be attractive for students;
- Since the obtained results are considerably higher in those classes where a lecture is given to students, it is essential to program recurrent informative moments with occupants to activate the process and present results involving end-users directly.

Finally, the potential use of more invasive types of alerting solutions, such as more prominent lighting signals (e.g. external lamps such as the red ones for fire alerts) or acoustic ones for higher CO$_2$ concentrations, can be considered in future to reach the desired results also in those cases in which self-actuation and involvements, of both teachers and students, are less evident. Results and the high interest collected by the involved schools and additional institutes that are candidates to enter the project suggest that greater attention must be given to this topic at the institutional level in territories where a national standard is absent. Results also indicate the need to develop new smart measuring and alerting solutions, as the ones available on the market are still limited or very expensive to support smart building development. Additional work is under development, including using graphical user interfaces and analysing the longer-term impact of citizen science, extending the KPIs and using self-developed middleware for multi-sensor integration and reducing costs.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 958345 (PRELUDE project).

References

[1] WHO Europe 2009 *WHO Guidelines for Indoor Air Quality: Dampness and Mould* (Copenhagen, WHO)
[2] EPA 1998 EPA 402-K-98-001 *Building Air Quality: Action Plan* (Washington: EPA)

[3] Ding E, Zhang D and Bluyssen PM 2022 *Building and Environment* **207** 108484
[4] Chiesa G and Vigliotti M 2024 *Energy & Buildings* **322** 114665
[5] Chiesa G, Heiselberg PK and Kolokotroni M 2021 *Innovations in Ventilative Cooling* (Cham: Springer)
[6] Chen Y, Tong Z, Wu W, Samuelson H, Malkawi A and Norford L 2019 *Applied Energy* **235** 1141-52
[7] Fiorentini M, Kokogiannakis G, Jackson W, Ma Z and Cooper P 2016 *Proc. 12th REHVA World Congress* (Aalborg: Aalborg Un.) 7669.
[8] Stabile L, Dell'Isola M, Frattolillo A, Massimo A and Russi A 2016 *Building and Environment* **98** 180-9.
[9] Ackerly K and Brager G 2013 *Building Research & Information* **41** 342-60
[10] Grosso M 2017 *Il raffrescamento passivo degli edifici* IV (Sant'Arcangelo di Romagna: Maggioli)
[11] O'Sullivan P and O'Donovan A 2018 *Ventilative cooling case studies IEA EBC Annex 62* (Aalborg: Aalborg Un.)
[12] Zivelonghi A and Kumar P 2024 *Energy & Buildings* **303** 113621
[13] Ferrari S, Blazquez T, Cardelli R, De Angelis E, Puglisi G, Escandon R and Suarez R 2023 *Helyon* **9** e19120
[14] Draghi M, Speranza R and Bianchi P 2022 DPCM 26 July 22A04476 *GU Serie Generale* **180**
[15] Mysen M, Berntsen S, Nafstad P and Schild PG 2005 *Energy and Buildings* **37** 1234-40
[16] Bako-Biro Zs, Clements-Croome DJ, Kochhar N, Awbi HB and Williams MJ 2012 *Building and Environment* **48** 215-23
[17] Ribéron J, Ramalho O, Derbez M, Berthineau B, Wyart G, Kirchner S and Mandin C 2016 *Pollution Atmospherique* **228** 5466