An international review of building standards and guidelines on thermal comfort and ventilation for School buildings

Natalie Bain-Reguis
Edinburgh Napier University
n.reguis@napier.ac.uk

Dr Andrew Smith
Edinburgh Napier University
A.Smith7@napier.ac.uk

This paper reviews and discusses thermal comfort and ventilation standards and guidelines in educational buildings in selected countries around the World, alongside the guidelines from the World Health Organization (WHO), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the Chartered Institution of Building Services Engineers (CIBSE) and the Federation of European Heating, Ventilation and Air Conditioning (REHVA). Standards and guidelines are first defined followed by the inclusion and exclusion criteria of the selected countries. The chosen specific indoor elements scrutinised are detailed before the values of their standards and guidelines in educational buildings are summarised per country and for the different organisations. The values show a significant disparity in standards and guidelines about indoor elements in classrooms around the World. Some countries don't have a whole-country approach. The WHO, ASHRAE, CIBSE and REHVA have stricter guidelines. These findings highlight the heterogeneity of national guidelines or enforceable regulations related to the indoor environment of educational buildings around the World. Future research should focus on exploring the impact of these different standards and guidance on the indoor climate of various educational settings around the World.

1 - Introduction

People are spending 90% of their time indoors. Healthy indoor environments are therefore important, as they impact the health and well-being of workers (World Green Building Council, 2020). Workers mostly complain about poor Indoor Air Quality (IAQ) (International Institute of Refrigeration, 2016) and inadequate indoor temperature (Edem, Akpan and Pepple, 2017). Schools are workplaces where pupils and teachers spend hours in overcrowded enclosed spaces (Cutler, 2010) often with poor ventilation (Chatzidiakou, Mumovic and Summerfield, 2012; Bain-Reguis *et al.*, 2022) and where viruses can spread easily from noroviruses to the seasonal flu (Barker, Stevens and Bloomfield, 2001). The COVID-19 pandemic, with SARS-COVID-19 being an airborne virus (World Health Organization, 2020; CDC, 2022), has challenged the governments to provide adequate ventilation in classrooms (Scottish Government, 2021) while maintaining acceptable thermal comfort for the occupants (Alonso *et al.*, 2021; Miranda *et al.*, 2022).

The scope of this review is to explore the different regulations and recommendations in Scotland and other countries around the World. As there is a distinction between regulations and recommendations, the following paragraphs define each term.

Standards (or regulations) are legally binding rules or directives made and maintained by a government authority. They have the force of law and are enforceable. They are often specific, and detailed, and provide clear requirements that must be followed. Failure to comply with standards can result in legal consequences, such as fines, penalties, or other enforcement actions. Standards are designed to standardise behaviour and ensure adherence to established standards.

Guidelines (or recommendations) are non-binding documents that provide advice, or best practices on how to interpret and comply with laws, regulations, or standards. They do not have the force of law. Guidelines are usually issued by regulatory agencies or other authoritative bodies. While it may reflect the agency's interpretation of the law, it does not create new legal requirements on its own. Unlike regulations, guidelines are not legally enforceable. However, organisations may choose to follow guidelines as a means of aligning with industry best practices or demonstrating compliance.

In summary, regulations are legally binding and enforceable rules that carry the weight of law, while recommendations or guidance are advisory, providing recommendations and interpretations without the force of law. Organisations and individuals are typically obligated to follow regulations, but they may choose to follow guidelines for informational or best practices purposes. Countries have regulations, guidelines or both.

This paper aims to review and discuss thermal comfort and ventilation standards and guidelines in educational buildings in selected countries around the World, alongside the guidelines from the World Health Organization (WHO), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the Chartered Institution of Building Services Engineers (CIBSE) and the Federation of European Heating, Ventilation and Air Conditioning (REHVA).

2 - Methodology

2.1 - Selected countries and their characteristics

The chosen method of selection has been to look at the countries with similar economic development as the United Kingdom. It has been assumed that countries with developed economies have a fair and robust legislative system. Table 1 shows all the countries with developed economies.

Table 1: Developed economies, from Country Classification (UN, 2014)

Europe			Other countries	Major Developed economies (G7)
Europe Union	Non-EU member States	Other Europe		
EU-15	Bulgaria	Iceland	Australia	Canada
Austria	Croatia	Norway	Canada	Japan
Belgium	Cyprus	Switzerland	Japan	France
Denmark	Czech Republic		New Zealand	Germany
Finland	Estonia		United States	Italy
France	Hungary			United Kingdom
Germany	Latvia			United States
Greece	Lithuania			
Ireland	Malta			
Italy	Poland			
Luxembourg	Romania			
Netherlands	Slovakia			

Portugal	Slovenia			
Spain				
Sweden				
United Kingdom				

The indoor and outdoor climates are interlinked, therefore it seemed essential to take the countries' climates into consideration. Therefore, for each of the countries listed in Table 1, the Köppen–Geiger climate classification has been used to identify their specific climate. The Köppen-Geiger climate classification (recently updated) uses the type of ecosystem of a specific location using the annual atmospheric temperature (Kottek *et al.*, 2006). The Köppen-Geiger climate classification divides climates into five main climate groups, with each group being divided based on patterns of seasonal precipitation and temperature (Table 2).

Table 2: Köppen climate classification scheme symbols description table (Kottek et al.*, 2006)*

Climate Group	Precipitation	Temperature
A (Tropical)	• f (Rainforest) • m (Monsoon) • w (Savanna, dry winter) • s (Savanna, dry summer)	
B (Dry)	• W (Arid Desert) • S (Semi-Arid Steppe)	• h (Hot) • k (Cold)
C (Temperate)	• w (Dry winter) • f (No dry season) • s (Dry summer)	• a (Hot summer) • b (Warm summer) • c (Cold summer)
D (Continental)	• w (Dry winter) • f (No dry season) • s (Dry summer)	• a (Hot summer) • b (Warm summer) • c (Cold summer) • d (Very cold winter)
E (Polar)		• T (Tundra) • F (Ice cap)

Atmospheric temperature depends on solar radiation, humidity, wind, and altitude. The United Kingdom has a moderate climate (Cfb).

The new EU member states and the countries named "Other Europe" in Table 1 have been discarded because either their climate was not temperate or the standards have not been found.

Table 3 shows the countries selected with their population, surface area and main climate.

Table 3: Selected countries with characteristics

Name	Population[1]	Area (2021)[1]	Main climate[2]
Units	Thousand	km^2	Koppen-Geiger
Austria	8,970	82,520	Dfb/ET
Belgium	11,618	30,280	Cfb
Denmark	5,877	40,000	Dfb but Cfb in main cities
Finland	5,541	338,460	Dfc
France	67,656	547,557	Cfb
Germany	83,001	349,380	Cfb/Dfb
Greece	10,605	128,900	Csa
Ireland	5,060	68,890	Cfb
Italy	58,936	297,730	Csa/Cfa
Luxembourg	646	2,430	Cfb
Netherlands	17,567	33,670	Cfb
Portugal	10,267	323,250	Csa/Csb
Spain	47,277	499,603	Bsk
Sweden	10,472	407,310	Dfb/c
United Kingdom	66,800	241,930	Cfb
- England and Wales	59,440	149,011	Cfb
- Scotland	5,466	78,789	Cfb
- Northern Ireland	1,894	14,130	Cfb
Canada	38,557	8,965,590	Dfb/Dfc
Japan	125,105	364,500	Cfa/Dfb
United States	333,730	9,147,420	Cf/Dfa
Australia	26,010	7,692,020	Bwh but Cfa and Cfb for main cities
New Zealand	5,160	263,310	Cfb

[1]https://databank.worldbank.org

[2]http://koeppen-geiger.vu-wien.ac.at

Due to no information nor experts found in Finland, Greece, and Luxembourg, these countries have not been studied. Despite Austria, Spain, Sweden and Canada having different climates than the UK, the standards and guidelines for these countries have been reviewed as they are either close geographically or economically.

2.2 - Selection of the parameters to review

This paper aims to review and discuss the standards and guidelines for “thermal comfort” and “ventilation” in educational buildings. Therefore, it is necessary to choose the related parameters.

Thermal comfort is a subjective measure as it is defined as *“that condition of mind which expresses satisfaction with the thermal environment”* in the ASHRAE Standard 55 (ASHRAE, 2004). There is a wide range of factors that directly and indirectly influence thermal comfort. Indoor temperature and Relative humidity are commonly measured to assess thermal conditions. Indoor air temperature is considered the best indicator of thermal comfort as it usually changes the perceived comfort levels of occupants (Wyon, Andersen and Lundqvist, 1979; de Dear *et al.*, 2015). Measuring indoor temperature in relation to other factors allows for a comprehensive analysis of the indoor environment, taking into account the preferences and needs of occupants, as well as the dynamics of the environment (Bluyssen, 2019). Relative Humidity (RH) can be defined as the ratio between the quantity of water vapour present in the air and the maximum quantity of water vapour that the air can contain at a given temperature (CIBSE, 2015b). RH in buildings does not change significantly and unlike indoor air temperature, occupants are less sensitive to changes in humidity levels (CIBSE, 2015b). However, RH can have an impact on virus transmission (Verheyen and Bourouiba, 2022) and mould propagation (Qin *et al.*, 2020)

The ventilation rates and/or air change rates define if a room has adequate ventilation. They can be calculated using the CO_2 concentration levels, the number of occupants, the dimensions of the room, their age, sex and activity levels (Persily, 2016).

Therefore, the following indoor parameters are reviewed per country:

- the ventilation rate,
- the air change rate,
- the CO_2 concentration levels,
- the minimum surface area,
- the minimum volume per person,
- the minimum and maximum indoor temperature,
- and the minimum and maximum relative humidity.

However, it is outside the scope of this work to analyse in detail the differences and the rationale of different countries to select specific values.

2.3 – Method

To find the relevant information, an extensive review of the regulations and guidelines has been completed for each country. For countries with documents written in a language other than English or French, the use of an online translator application has been necessary: Google Translate. Once collated, all findings have been checked by experts.

3 - Results

Table 4 gives the national regulations and/or guidelines for the selected countries alongside the recommended threshold drawn by the WHO, ASHRAE, CIBSE and REHVA. The information shown in **BOLD are standards** while the other ones are guidelines.

Name	CO_2 in schools	Ventilation Rates	Indoor Temperature	Indoor Relative Humidity	Min surface area	Min volume	Max occupancy
Units	ppm	l/s per person	°C	%	m^2	m^3	children/adults
Austria (*RIS - Ordinance of the Upper Austrian State Government concerning the construction and furnishing of public compulsory schools (Upper Austrian School Construction and Furnishing Ordinance 1994)*, 1994; *RIS - School Construction and Facilities Ordinance - State Law consolidated Burgenland*, 2024)	<1900 ppm (In naturally ventilated) < 800 ppm (In mechanically ventilated rooms)		about 20°C		>1.60m^2 /pupil. Classrooms >50 m^2 (primary, secondary schools or polytechnic) > 40 m^2 (Special ed)	>5 m^3 per pupil. Clear height of classrooms>3,20 m.	
Belgium (*Annexe C3 de la PEB: dispositifs de ventilation des immeubles non résidentiels*, 2008; *Cadre légal pour la qualité de l'air intérieur*, 2022)	**<900ppm**	**6 l/s i.e. 22m^3/h per person**	**20°C min (winter) 27°C max (summer)**	**20%-70%**	**4m^2/person**		
Denmark ('Executive Order No. 1615 of 13 Dec. 2017 (in force) BR18 22 Section 447 Ventilation', 2017)	**<1000ppm**	**>= 5 l/s per person + 0.35 l/s/m^2**	**23-26°C (summer), 20-24°C (winter) >= 20°C monthly average** all year.			**>6m^3/person**	50

France (‘Arrêté du 27 décembre 2022 fixant les conditions de réalisation de la mesure à lecture directe de la concentration en dioxyde de carbone dans l’air intérieur au titre de l’évaluation annuelle des moyens d’aération - Légifrance’, 2022)	**<800ppm**	**15 m^3/h per person i.e. 4l/s per person**			2 m^2 per child 60 m^2 min. in total		
Germany 7a and 7b (*DGUV Regel 102-601 „Branche Schule“*, 2019)	<1000 ppm		20-24°C		2.8 to 3.4m^2/pupil		
Ireland (HSE, 2023)	<1000ppm	8 l/sec per person	18°C-23°C	40-70%			
Italy (‘Norme tecniche aggiornate relative all’edilizia scolastica, ivi compresi gli indici minimi di funzionalità didattica, edilizia ed urbanistica da osservarsi nella esecuzione di opere di edilizia scolastica.’, 1975; *Linee guida sulle specifiche tecniche in merito all’adozio ne di dispositivi mobili di purificazione e impianti fissi di aerazione e agli standard minimi di qualità dell’aria negli*	<1000ppm	10l/s per person 2.5 ACH in elementary schools	20°C+/-2°C in winter	45-55% in winter	153m^2/class and 6.11m^2/pupil min in elementary schools	300cm height min	

ambienti scolastici e in quelli confinati degli stessi edifici., 2022; Settimo *et al.*, 2022)							
Netherlands (*Netherland Program requirements Fresh Schools 2021*, 2021)	**1200ppm**	**6l/s per person**	**18-25°C (Winter)** **<27°C (summer)**			**2.6m (height)**	
Portugal ('Portugal_Portaria n.º 138-G_2021', 2021)	**<1250ppm (2013)**						
Spain ('Real Decreto 486/1997, de 14 de abril, por el que se establecen las disposiciones mínimas de seguridad y salud en los lugares de trabajo', 1997; 'LA VENTILACIÓNCOMO MEDIDA PREVENTIVA FRENTE AL CORONAVIRUS SARS-CoV-2', 2021)	<500 ppm + outdoor	12.5l/s per person	23-25°C (Spring-Summer) 21-23°C (Autumn-Winter)	40-50% (Spring-Summer) 45-60% (Autumn-Winter)	2 m^2/person >3 meters high from the floor to the ceiling	>10 m^3/person	25
Sweden (*Sweden - FoHMFS 2014:18 Folkhälsomyndighetens allmänna råd om ventilation*, 2014; *Sweden - The Design of the Workplace*, 2020)	<1000ppm	7 l/s per person + 0.35 L/s per m^2	20 -24°C (Heating season) 19-26°C (Cooling season)	<75%			
England and Wales (DfE, 2018a, 2018b)	**<1000 ppm, 1500 ppm for more than 20 consecutive minutes each day (Mechanical ventilation)**	**2.3 l/s/m^2** i.e. **8 l/s per person**	**20-25°C (heating season)**		2.9m^2/pers (primary) 4.5m^2/pers (Secondary)		

	< 1500 ppm (Natural ventilation)						
Scotland (The Scottish Government, 1967, 2004, 1990; The Scottish Government, 2016; The Scottish Governement, 2017)	**<1500ppm**	**2 ACH**	**>17°C**		Consultation: Primary: Up to 231 8.5m^2 232-462 7.5m^2 463+ 6.5m^2 Secondary: Up to 400 13m^2 401-800 12m^2 801-1200 11m^2 1201+ 10m^2		
Northern Ireland (UK Government, 2018; Department of Education Northern Ireland, 2020)	<1550ppm	8l/s per person	18°C		all should be of 60m^2	minimum of 2.9m height	
Canada (National Research Council Canada, 2020; Ontario Society of Professional Engineers, 2022)	<900ppm in Ontario since 2022			35-50%	7.5m^2/person		
Japan (Ministry of Education, Culture, Sports, Science and Technology of Japan, 2018)	**<1500ppm**	**Air flow: 0.5m/s**	**18-28°C**	**30-80 %**			
United States (CDC, 2020; ASHRAE, 2022, 2023a, 2023b)	<800ppm (CDC) <outside+750ppm (ASHRAE)	5l/s per person	19-26°C (winter) 25-28°C (summer)	< 85% (winter); <65% (summer) 40-60%			

Australia (Standard Australia, 2024; Standards Australia, 2024)	**<850 ppm**	**12l/sec per person if mechanically ventilated**			**2m² per student**		
New Zealand (Education, 2022)	<800ppm target **<1250ppm daily average** **<2000ppm peak**	**8l/s per person**	**min: 19˚C (+/-1°C) Max: 25°C (no more than 80 occupied hours), 28°C (no more than 40 occupied hours)**	**30 to 60% ideally**			**50p/100m²**
WHO (WHO, 2022)	<1000ppm <800ppm in case of severe epidemic	6-7l/s per person			2m² per student		
ASHRAE (ASHRAE, 2023a)	Recommended limits: Outside air level +750 ppm for 90 minutes	5l/sec per person	Winter: 22 C Summer: 24 C	Winter: 40-50% RH Summer: 50%-60% RH			
CIBSE (CIBSE, 2015a, 2021)	800-1000ppm	10l/sec per person	16 C				
REVHA (REHVA, 2023)	<1000ppm		Winter: 20-24 C Summer: 23-26 C	>20%			

4 - Discussion

There is a significant disparity in regulations and guidelines about ventilation and thermal comfort in classrooms around the World. 9 out of 20 countries have standards on one or more parameters, the other 11 countries have guidelines.

Some countries do not have a whole-country approach (USA, Canada) where regulations and guidelines may differ between areas of the same country. In the USA, both the CDC and ASHRAE have produced guidelines, which slightly differ. The ASHRAE standards are not regulations per se and therefore not necessarily enforceable. Some countries have strict enforceable rules (Australia, Belgium, Denmark, France, Netherlands, Portugal, UK) while others have recommendations (Germany, Ireland, Italy, Spain, Sweden).

In the UK, the regulations related to education are devolved to each region. Therefore, England and Wales, Scotland and Northern Ireland all have different regulatory texts.

Looking at the individual regulated parameters of interest, the maximum CO_2 levels acceptable in classrooms are lower when recent guidance or standards have been published. This can be assumed to be a consequence of the COVID-19 pandemic. The stricter maximum CO_2 value is 800ppm in the classrooms of France, then 900ppm in Belgium, 1000ppm in Denmark, 1200ppm in the Netherlands and in Sweden and in mechanically ventilated classrooms of England and Wales, and 1500ppm in naturally ventilated classrooms of England and Wales. New Zealand has three values: 800ppm as a recommendation target, 1200ppm as a maximum daily average and 2000ppm as the maximum peak value. In Scottish classrooms, the latest regulation imposes CO_2 levels to be less than 1500ppm in classrooms and 800ppm in music rooms and gym halls (Scottish Government, CERG, 2020).

The guidelines of the independent organisations are stricter than the standards in place in the countries (apart from the new Legislation in France 2023). The WHO gives two thresholds including one in case of severe epidemic. ASHRAE standards did not give a CO_2 threshold but rather a minimum ventilation rate. According to Persily, CO_2 levels are not a good indicator of ventilation or IAQ (Persily, 2021). However, since the pandemic, they recommend CO_2 levels to be 750ppm above the outside level. The Chartered Institute of Building Services Engineers (CIBSE) has published a new guide with CO_2 thresholds needing to be between 800 and 1000 ppm.

The minimum ventilation rates are ranging from 4l/s per person (France) to 12.5l/s per person (Spain), with an average of 8l/s per person.

Some countries have regulations for the minimum/maximum temperatures in classrooms. The values span from 17ºC to 27ºC. In Scotland, keeping the indoor temperature at an acceptable comfort level, especially in winter, is primordial. The indoor temperature in Scottish classrooms should be kept above 17ºC, according to the current regulations (Scottish Government, 2020), which is the lowest temperature threshold in classrooms found in the present literature.

Belgium, Japan and New Zealand are imposing strict limits to control RH in classrooms (between 20 and 80%). Other countries have guidance levels (Ireland, Italy, Spain, Sweden, Canada, USA), which are between 30 and 80%. In Scotland, there is currently no mandatory legal requirement to control RH and the relative risk posed by this parameter alone has not yet been fully ascertained in research. Nevertheless, numerous studies have identified an RH 'sweet spot' between 40% and 60% adding that air which was too dry would allow viruses to thrive and be more active (Azuma et al., 2020) and mould would develop when the air is too high in humidity.

The regulations or the guidance related to the surface areas, the volume of the classrooms or the maximum capacity are heterogeneous. When values are given, they are different from one country to another. Belgium, Denmark and Australia have regulations in place either for the minimum surface area (2 to $4m^2$ per student) or for the minimum volume ($6m^3$ per student). The Netherlands has set a minimum height of 2.6 meters for classrooms.

5 – Conclusion

This review aimed to explore the existing standards and guidelines related to thermal comfort and ventilation in educational buildings. The review revealed a significant disparity in regulations and guidelines about ventilation and thermal comfort in classrooms around the World. Most countries have standards or guidance related to the maximum level of CO_2 or the minimum ventilation rates or both. But the limits can vary from 800ppm to 2000ppm. Almost all countries have the minimum and maximum indoor temperature acceptable in a classroom, spanning from 17°C to 28°C. The Relative Humidity standards or guidance vary from 20 to 80%RH. The minimum surface area, the minimum volume per student needed in a classroom and the maximum occupancy guidance are heterogeneous and only three countries have regulated values. The international bodies have guidelines on most elements studied with a smaller range of values.

Future research should focus on exploring the impact of these different standards and guidance on the indoor environment of various educational settings around the World. This review was limited by the accessibility of related documents due to language barriers or experts found in the field.

Acknowledgements

We are grateful to the following experts who have provided feedback and comments for this review:

Austria: Hubert Meszaros (OIB); Belgium: Geoffrey Van Moeseke (Louvain); Denmark: Pawel Wargocki (DTU); France: Corinne Mandin (IRSN); Italy: Andrea Cattaneo (Insubria) and Gaetano Settimo (ISS); Netherlands: Dadi Zhang (Delft); Portugal: Joana Madureira; Spain: Florentina Villanueva García (Castilla-La Mancha); Canada: Joey Fox (OSPE); Japan: Kenichi AZUMA (Kindai); United States: Richard Corsi (UC Davis); Australia: Lidia Morawska (Queensland).

References

Alonso, A. *et al.* (2021) 'Effects of the COVID-19 Pandemic on Indoor Air Quality and Thermal Comfort of Primary Schools in Winter in a Mediterranean Climate', *Sustainability*, 13(5), p. 2699. Available at: https://doi.org/10.3390/su13052699.

Annexe C3 de la PEB: dispositifs de ventilation des immeubles non résidentiels (2008). Available at: https://energieplus-lesite.be/reglementations/ventilation9/annexe-c3-de-la-peb-dispositifs-de-ventilation-des-immeubles-non-residentiels/ (Accessed: 8 July 2024).

‘Arrêté du 27 décembre 2022 fixant les conditions de réalisation de la mesure à lecture directe de la concentration en dioxyde de carbone dans l’air intérieur au titre de l’évaluation annuelle des moyens d’aération - Légifrance’ (2022). Available at: https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000046830005 (Accessed: 8 July 2024).

ASHRAE (2004) ‘ASHRAE Standard 55’.

ASHRAE (2022) ‘ANSI/ASHRAE Standard 62.1-2022’.

ASHRAE (2023a) ‘Design Guidance for Education Facilities: Prioritization for Advanced Indoor Air Quality’.

ASHRAE (2023b) ‘Standard 55 – Thermal Environmental Conditions for Human Occupancy’. Available at: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy (Accessed: 10 July 2024).

Bain-Reguis, N. *et al.* (2022) ‘Indoor CO2 and Thermal Conditions in Twenty Scottish Primary School Classrooms with Different Ventilation Systems during the COVID-19 Pandemic’, *Pollutants*, 2(2), pp. 180–204. Available at: https://doi.org/10.3390/pollutants2020014.

Barker, J., Stevens, D. and Bloomfield, S.F. (2001) ‘Spread and prevention of some common viral infections in community facilities and domestic homes’, *Journal of applied microbiology*, 91(1), pp. 7–21. Available at: https://doi.org/10.1046/J.1365-2672.2001.01364.X.

Bluyssen, P.M. (2019) ‘The need for understanding the indoor environmental factors and its effects on occupants through an integrated analysis’, *IOP Conference Series: Materials Science and Engineering*, 609(2), p. 022001. Available at: https://doi.org/10.1088/1757-899X/609/2/022001.

Cadre légal pour la qualité de l’air intérieur (2022). Available at: https://www.health.belgium.be/fr/vers-un-cadre-legal-pour-la-qualite-de-lair-interieur (Accessed: 8 July 2024).

CDC (2020) *Community, Work, and School*, *Centers for Disease Control and Prevention*. Available at: https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html (Accessed: 8 July 2024).

CDC (2022) *COVID-19 and Your Health*, *Centers for Disease Control and Prevention*. Available at: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html (Accessed: 3 August 2023).

Chatzidiakou, L., Mumovic, D. and Summerfield, A.J. (2012) ‘What do we know about indoor air quality in school classrooms? A critical review of the literature’, *Intelligent Buildings International*, 4(4), pp. 228–259. Available at: https://doi.org/10.1080/17508975.2012.725530.

CIBSE (2015a) *CIBSE Guide A Environmental design*.

CIBSE (2015b) ‘Guide A: Environmental design.’ The Chartered Institution of Building Services Engineers. Available at: https://www.cibse.org/knowledge-research/knowledge-portal/guide-a-environmental-design-2015?id=a0q20000008I79JAAS (Accessed: 11 February 2024).

CIBSE (2021) ‘CIBSE COVID-19 Ventilation Guidance version 5’.

Cutler, R. (2010) ‘Promoting hygiene in schools: Breaking the chain of infection’, *British Journal of School Nursing*, 5(4), pp. 187–190. Available at: https://doi.org/10.12968/BJSN.2010.5.4.48002.

de Dear, R. *et al.* (2015) ‘Adaptive thermal comfort in Australian school classrooms’, *Building Research & Information*, 43(3), pp. 383–398. Available at: https://doi.org/10.1080/09613218.2015.991627.

Department of Education Northern Ireland (2020) ‘Section 3a Primary Schools Building Handbook’. Available at: https://www.education-ni.gov.uk/sites/default/files/publications/education/Section%203a%20Primary%20Schools%20Building%20Handbook.pdf (Accessed: 8 July 2024).

DfE (2018a) ‘BB 101: Ventilation, thermal comfort and indoor air quality 2018’. Available at: https://www.gov.uk/government/publications/building-bulletin-101-ventilation-for-school-buildings (Accessed: 7 July 2023).

DfE (2018b) ‘BB 103 Area guidelines and net capacity’. Available at: https://www.gov.uk/government/publications/area-guidelines-and-net-capacity (Accessed: 8 July 2024).

DGUV Regel 102-601 „Branche Schule“ (2019).

Edem, M.J., Akpan, E.U. and Pepple, N.M. (2017) ‘Impact of Workplace Environment on Health Workers’, *Occupational Medicine & Health Affairs*, 05(02), pp. 1–5. Available at: https://doi.org/10.4172/2329-6879.1000261.

Education, N.Z.M. of (2022) *Designing Quality Learning Spaces-Indoor Air Quality & Thermal Comfort Designing Quality Learning Spaces (DQLS)*. Available at: https://assets.education.govt.nz/public/Documents/Primary-Secondary/Property/Design/Indoor-Air-Quality-and-Thermal-Comfort-V2-v2.0-2022.pdf.

‘Executive Order No. 1615 of 13 Dec. 2017 (in force) BR18 22 Section 447 Ventilation’ (2017).

HSE (2023) *Code of Practice of Indoor Air Quality*. Available at: https://www.hsa.ie/eng/publications_and_forms/publications/codes_of_practice/code_of_practice_for_indoor_air_quality.pdf (Accessed: 8 July 2024).

International Institute of Refrigeration (2016) *In UK, 70% of office workers complain of poor IAQ, International Institute of Refrigeration*. Available at: https://iifiir.org/en/news/in-uk-70-of-office-workers-complain-of-poor-iaq (Accessed: 30 August 2023).

Kottek, M. *et al.* (2006) ‘World Map of the Köppen-Geiger climate classification updated’, 15(3), pp. 259–263. Available at: https://doi.org/10.1127/0941-2948/2006/0130.

‘LA VENTILACIÓNCOMO MEDIDA PREVENTIVA FRENTE AL CORONAVIRUS SARS-CoV-2’ (2021). Available at: https://www.insst.es/documents/94886/712877/La+ventilaci%C3%B3n+como+medida+preventiva+frente+al+coronavirus+SARS-CoV-2.pdf/7d80e9f3-2b44-7e37-8af2-7ab105621070?t=1626298548369 (Accessed: 8 July 2024).

Linee guida sulle specifiche tecniche in merito all’adozio ne di dispositivi mobili di purificazione e impianti fissi di aerazione e agli standard minimi di qualità dell’aria negli ambienti scolastici e in quelli confinati degli stessi edifici. (2022).

Ministry of Education, Culture, Sports, Science and Technology of Japan (2018) 'School Environmental Hygiene Management Manual'.

Miranda, M.T. *et al.* (2022) 'Ventilation conditions and their influence on thermal comfort in examination classrooms in times of COVID-19. A case study in a Spanish area with Mediterranean climate', *International Journal of Hygiene and Environmental Health*, 240, p. 113910. Available at: https://doi.org/10.1016/j.ijheh.2021.113910.

National Research Council Canada (2020) 'National Building Code of Canada 2020'. Available at: https://nrc-publications.canada.ca/eng/view/ft/?id=515340b5-f4e0-4798-be69-692e4ec423e8 (Accessed: 8 July 2024).

Netherland Program requirements Fresh Schools 2021 (2021).

'Norme tecniche aggiornate relative all'edilizia scolastica, ivi compresi gli indici minimi di funzionalità didattica, edilizia ed urbanistica da osservarsi nella esecuzione di opere di edilizia scolastica.' (1975).

Ontario Society of Professional Engineers (2022) 'Core recommendations for Safer Indoor Air'. Available at: https://ospe.on.ca/wp-content/uploads/2023/01/Safer_Indoor_Air_Nov22_Final.pdf (Accessed: 8 July 2024).

Persily, A. (2021) 'Don't Blame Standard 62.1 for 1,000 ppm CO2', *ASHRAE Journal* [Preprint].

Persily, A.K. (2016) 'Field measurement of ventilation rates', *Indoor Air*, 26(1), pp. 97–111. Available at: https://doi.org/10.1111/ina.12193.

'Portugal_Portaria n.º 138-G_2021' (2021).

Qin, M. *et al.* (2020) 'Precise humidity control materials for autonomous regulation of indoor moisture', *Building and Environment*, 169, p. 106581. Available at: https://doi.org/10.1016/j.buildenv.2019.106581.

'Real Decreto 486/1997, de 14 de abril, por el que se establecen las disposiciones mínimas de seguridad y salud en los lugares de trabajo' (1997).

REHVA (2023) 'Proposed modifications and guidelines for implementation of Article 11a "Indoor environmental quality" in EPBD draft'. Available at: https://www.rehva.eu/fileadmin/user_upload/2023/EPBD_IEQ_Guidance.pdf (Accessed: 8 July 2024).

RIS - Ordinance of the Upper Austrian State Government concerning the construction and furnishing of public compulsory schools (Upper Austrian School Construction and Furnishing Ordinance 1994) (1994). Available at: https://www.ris.bka.gv.at/Dokumente/Lgbl/LGBL_OB_19940915_80/LGBL_OB_19940915_80.html (Accessed: 8 July 2024).

RIS - School Construction and Facilities Ordinance - State Law consolidated Burgenland (2024). Available at: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrBgld&Gesetzesnummer=10000209 (Accessed: 8 July 2024).

Scottish Government (2021) ‘Coronavirus (COVID-19): guidance on reducing the risks in schools’. Available at: http://www.gov.scot/publications/coronavirus-covid-19-guidance-on-reducing-the-risks-in-schools/ (Accessed: 7 July 2023).

Settimo, G. *et al.* (2022) *Rapporti ISTISAN 20/3 ISTITUTO SUPERIORE DI SANITÀ Qualità dell’aria indoor negli ambienti scolastici: strategie di monitoraggio degli inquinanti chimici e biologici*.

Standard Australia (2024) ‘AS 1668.4:2024 The use of ventilation and airconditioning in buildings, Part 4: Natural ventilation of buildings’. Available at: https://store.standards.org.au/product/as-1668-4-2024 (Accessed: 8 July 2024).

Standards Australia (2024) ‘AS 1668.2:2024 The use of ventilation and airconditioning in buildings, Part 2: Mechanical ventilation in buildings’. Available at: https://store.standards.org.au/product/as-1668-2-2024 (Accessed: 8 July 2024).

Sweden - FoHMFS 2014:18 Folkhälsomyndighetens allmänna råd om ventilation (2014).

Sweden - The Design of the Workplace (2020).

The Scottish Governement (1967) ‘The School Premises (General Requirements and Standards) (Scotland) Regulations’. King’s Printer of Acts of Parliament. Available at: https://www.legislation.gov.uk/uksi/1967/1199/contents/made (Accessed: 22 February 2024).

The Scottish Governement (1990) ‘Technical Standards For Compliance With The Building Standards (Scotland) Regulations’.

The Scottish Governement (2004) ‘The Building (Scotland) Regulations’. King’s Printer for Scotland. Available at: https://www.legislation.gov.uk/ssi/2004/406/contents/made (Accessed: 28 February 2024).

The Scottish Governement (2017) ‘Updating of the School Premises (General Requirements and Standards)(Scotland) Regulations 1967: consultation response analysis’. Available at: http://www.gov.scot/publications/updating-school-premises-general-requirements-standards-scotland-regulations-1967-analysis/pages/3/ (Accessed: 20 February 2024).

The Scottish Government (2016) ‘Technical Handbooks 2016 Non-Domestic - Complete’. Scottish Government, St. Andrew’s House, Regent Road, Edinburgh EH1 3DG Tel:0131 556 8400 ceu@scotland.gsi.gov.uk. Available at: https://webarchive.nrscotland.gov.uk/20180104105433oe_/http://www.gov.scot/Topics/Built-Environment/Building/Building-standards/techbooks/techhandbooks/th2016nondom (Accessed: 28 February 2024).

UK Government (2018) *BB 101: Ventilation, thermal comfort and indoor air quality 2018*. Available at: https://www.gov.uk/government/publications/building-bulletin-101-ventilation-for-school-buildings (Accessed: 8 July 2024).

Verheyen, C.A. and Bourouiba, L. (2022) ‘Associations between indoor relative humidity and global COVID-19 outcomes’, *Journal of the Royal Society Interface*, 19(196). Available at: https://doi.org/10.1098/RSIF.2021.0865.

WHO (2022) ‘Measures to reduce risks for children’s health from combined exposure to multiple chemicals in indoor air in public settings for children with a focus on schools, kindergartens and day-care centres’, in. Available at:

https://iris.who.int/bitstream/handle/10665/354225/9789289057974-eng.pdf?sequence=1 (Accessed: 25 June 2024).

World Green Building Council (2020) 'World Green Building Council 2020 Schools Briefing Notes -IAQ.pdf'. Available at: https://www.worldgbc.org/sites/default/files/Better Places for People-Schools Briefing Notes -IAQ.pdf (accessed on 28 May.

World Health Organization (2020) *WHO Director-General's opening remarks at the media briefing on COVID-19*. Available at: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020 (Accessed: 15 February 2024).

Wyon, D.P., Andersen, I. and Lundqvist, G.R. (1979) 'The effects of moderate heat stress on mental performance.', *Scandinavian Journal of Work, Environment & Health*, 5(4), pp. 352–361. Available at: https://doi.org/10.5271/sjweh.2646.