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2024 IAS Keynote Lecture

The CO_2 Problem: Climate Models vs. Field Measurements

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ABSTRACT:

Developed countries (e.g., USA, Germany, and France) have the unfair advantage over developing countries (e.g., Republic of the Congo, Republic of Kenya, and Sri Lanka) in imposing climate rules that enforce the use of expensive renewable energy based on flawed climate models with inflated CO_2 concentrations. This review attempts to bring attention to this irregular practice by amassing empirical data from field measurements on CO_2 that contradict climate models. The content is presented in two parts, (1) the "PhanDA" model and (2) the CO_2─1,000 ppm limit.

The "PhanDA" model-derived CO_2 value by Judd et al. (2024) for the Present is ~220 ppm, which does not match the measured value of 420 ppm at the Mauna Loa Observatory in Hawaii for the Present in the Keeling Curve. During the past 50 years, the Keeling Curve shows a rapidly increasing CO_2 trend, whereas the PhanDA model shows a rapidly decreasing trend.

Equally important, the PhanDA model is inapplicable for the Mesozoic era ((252 Ma-66 Ma), which represents 35% of the Phanerozoic eon (539 Ma-0). There is no correlation between Temperature and CO_2 during the Mesozoic, which is the underpinning of the model. Therefore, the PhanDA model and the associated assertion on the importance of CO_2 on Climate Change are problematic.

During a Trump-Musk Conversation on X (2024), Elon Musk claimed that when Atmospheric CO_2 goes past 1,000 ppm from the current value of nearly 400 ppm at a rate of 2 ppm per year increase, it would cause headaches and nausea in humans. This is a consequential claim to human health. In addressing this vital issue, a rigorous examination of 80,302 empirical data points from 25 countries on CO_2 concentration values available from direct measurements and from publications related to classrooms, conference rooms, dwellings, and aircraft cabins was carried out. This robust dataset (i.e., 46 figures and 13 tables) suggests that humans are able to function normally without adverse health effects even when CO_2 concentration levels reach between 2,000 and 6,000 ppm. Further, the U.S. Government (USDA, 2024) does not consider the CO_2─1,000 6limit as a health threat. In fact, the CO_2 5,000 ppm is the U.S. Government's Permissible Exposure Limit (PEL) of the daily workplace exposure. For basic physiological reasons, the concentration of **CO_2** in ambient air is almost irrelevant as long as it is much smaller than about 40,000 ppm, where it is in equilibrium with the optimum **CO_2** concentration of human blood. According to NRC (2007), 20,000 ppm is an appropriate sub chronic NOAEL (No Observed Adverse Effect Level) for headaches. Therefore, the notion that headaches supposedly associated with the 1.000 ppm limit of CO_2 is a fallacy. There is no need for concern about indoor CO_2 levels in classrooms, conference rooms, dwellings, and aircraft cabins.

KEYWORDS:

CO_2, The "PhanDA" climate model, The Keeling Curve, Phanerozoic, Mesozoic, Climate Change, The Net Zero, "Climate: The Movie (The Cold Truth)", William Happer, Richard Lindzen, Patrick Moore, Steve Koonin, John Christy, Roy Spencer, Freeman Dyson, Fred Singer, Bjorn Lomborg, John Clauser, Judith Curry, Anthony Watts, Willie Soon, Alex Epstein, Martin Durkin, Tom Nelson, John Robson, The CO_2 Coalition, The Heartland Institute

CONTENTS:

INTRODUCTION:

This review is based on a Keynote Lecture, which was the third consecutive Indian Association of Sedimentologists (IAS) Keynote Lectures given by G. Shanmugam (Fig. 1).

a. 2022: University of Jammu: Sedimentary Basins (Shanmugam, 2022).

b. 2023: Annamalai University: Scientific Journey (1962-2023) (Shanmugam, 2024a).

c. 2024: Birbal Sahni Institute of Palaeosciences: The CO_2 Problem (The Keynote). The goal is to address the issue of the hegemonic western countries and their Environmental, Social, and Governance (ESG) (Fig. 2) over Developing Countries (e.g., Sri Lanka) through Climate models and CO_2 (Shanmugam, 2024a, b).

Fig. 1 Three consecutive IAS keynote Lectures by G Shanmugam

Contrary to popular belief that natural CO_2 is the primary controlling factor of Climate Change, hegemonic superpower, such as the United States, and other developed countries are the true powers, which not only manipulate climate models to exhibit

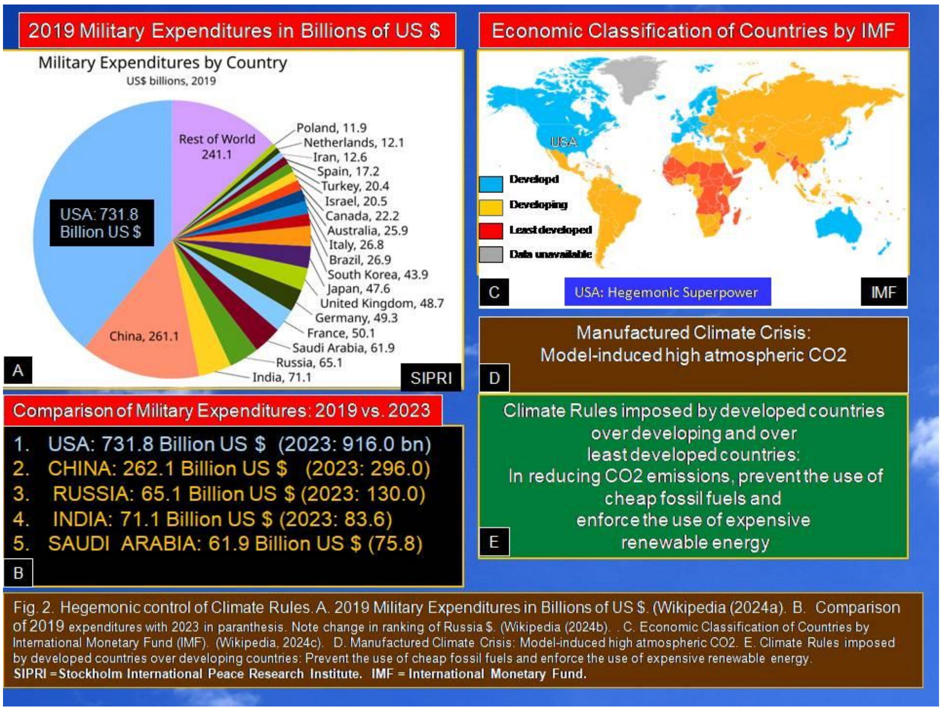


Fig. 2. Hegemonic control of Climate Rules. A. 2019 Military Expenditures in Billions of US $. (Wikipedia (2024a). B. Comparison of 2019 expenditures with 2023 in paranthesis. Note change in ranking of Russia $. (Wikipedia (2024b). . C. Economic Classification of Countries by International Monetary Fund (IMF). (Wikipedia, 2024c). D. Manufactured Climate Crisis: Model-induced high atmospheric CO2. E. Climate Rules imposed by developed countries over developing countries: Prevent the use of cheap fossil fuels and enforce the use of expensive renewable energy. **SIPRI = Stockholm International Peace Research Institute. IMF = International Monetary Fund.**

inflated CO_2 concentrations but also impose Climate Rules over developing countries unfairly (Fig. 2). The objective of this review is to illustrate the fallacy of climate models based on empirical data from field measurements on two fronts, namely (1) the

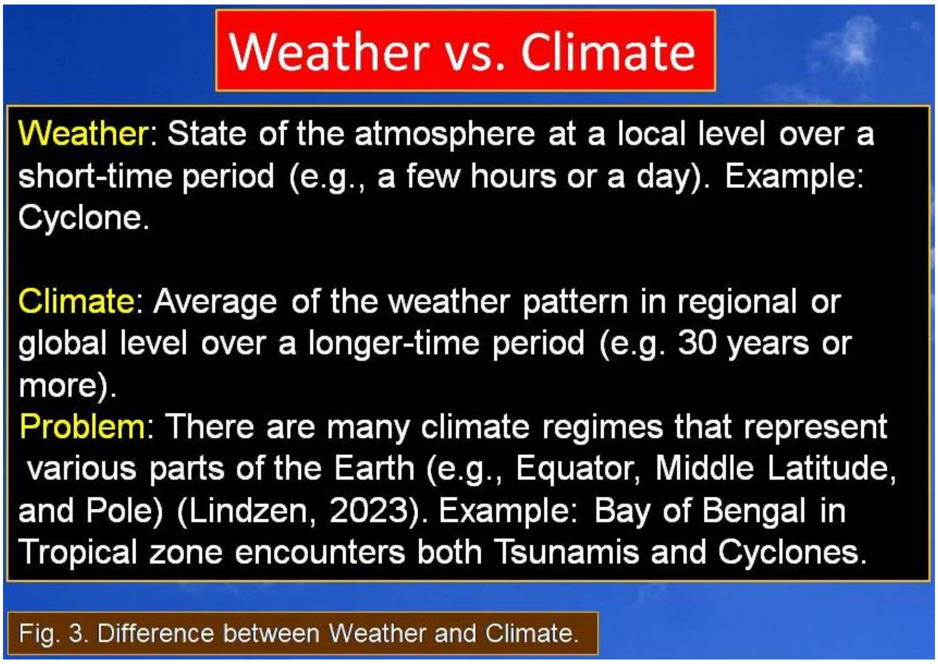


Fig. 3. Difference between Weather and Climate.

“PhanDA” model, and ((2) the CO_2 1000-ppm limit.

WEATHER VS. CLIMATE

In this discussion, it is imperative that we clarify the difference between Weather and Climate (Fig. 3).

1. Weather represents the state of the atmosphere at a local level over a short-time period (e.g., a few hours or a day). Example: Cyclone. Climate represents the average of the weather pattern in regional or global level over a longer-time period (e.g. 30 years or more). Example: Tropical climate. The problem is that there are many climate regimes that represent various parts of the Earth (e.g., Equator, Middle Latitude, and Pole) (Lindzen, 2023). For exam[le, Bay of Bengal is located in a Tropical zone, which encounters both Tsunamis (triggered by earthquakes) and Cyclones (triggered by seven meteorological factors) (Fig. 4).

2. Cyclones are meteorological phenomenon (AOML, 2007a, b, c; Shanmugam, 2008), not man-made events. For example, Cape Verde Island (a small country with minimum CO_2 emissions) triggers largest number of Cyclones in the North Atlantic (Fig. 5).

3. There is a major disparity in frequency of cyclones between Arabian Sea and Bay of Bengal with India in the middle (Fig. 6). Clearly, the Indian population in has nothing to do with triggering of Cyclones.

Importantly, there is a tendency to attribute a plethora of natural events, such as Tsunamis, Cyclones, Meteorite impacts, Wildfires, etc. to Climate Change (Fig. 7). This is false.

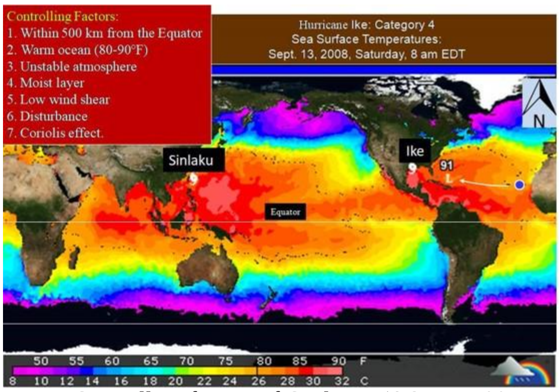


Fig 4. Controlling factors of Cyclones (AOML, 2007 a, b, c; Shanmugam 2008

Fig 5. Origin of North Atlantic Cyclones. Cape Verde Is. 177th in CO_2 emissions. Image credit Nilfanion NHC. NASA. Wikipedia. Public domain

Fig 6. Disparity in frequency of cyclones between Arabian Sea and Bay of Bengal image credit: Hurricane Alley

Fig 7. Climate (Consequence) cannot cause diverse weather and impacts events

PART 1: THE "PHANDA" MODEL

In understanding the role of CO_2 on Climate Change, Judd et al. (2024) published a model called "PhanDA" on September 20, 2024 in *Science*. This model is a reconstruction of Global Mean Surface Temperature (GMST) for the past 485 million years (Fig. 8A). Previously, Scotese et al., 2021) published similar temperature curves (Fig. 8B). However, the model by Scotese et al. (2021) did not predict the extreme high temperatures for the Early Paleozoic.

The PhanDA model was created using **Data Assimilation**, a method that statistically integrates

Geological data with climate model simulations. PhanDA indicates that Earth's Temperature has varied between 11° and 36°C over the past 485 million years. This range is larger than previous reconstructions. Judd et al. (2024) claim that CO_2 is the dominant driver of Phanerozoic climate, emphasizing the importance of this greenhouse gas in shaping Earth history. However, there are basic problems that are still unresolved. The purpose of this review is to bring attention to these fundamental issues.

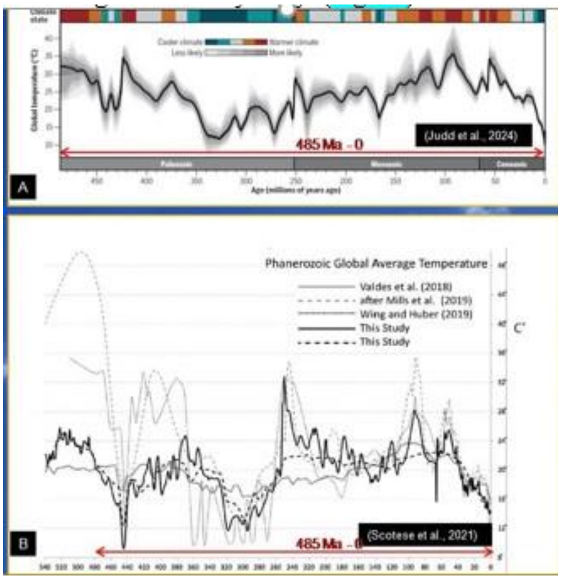


Fig 8. Comparison of global temperature curves, A). Temperature curve by Judd et al., 2024, B). Temperature curve by Scotese et al. Red arrow shows the interval covered in Fig. 8A (485 Ma-0). Note that the model by Scotese et al., did not predict the extreme high temperatures for the early Paleozoic

THE CO_2 PROBLEM

1.The "PhanDA" model shows a decreasing Temperature trend during the past 20 Ma (Fig. 9), whereas observations illustrate an increasing Temperature for the past 50 years (Fig. 10).

2. Christy (2022) noted out that IPCC model predicts a greater Global Warming than the measured Temperature data suggest (Fig. 10).

3. IPCC AR6 (2021) Climate model is problematic for three reasons (Fig. 11):

   a. Temperature anomaly is used, not absolute Temperature.

   b. Temperature varies with different baseline.

   c. The model has a large uncertainty range (Fig. 11).

Phanerozoic temperature history

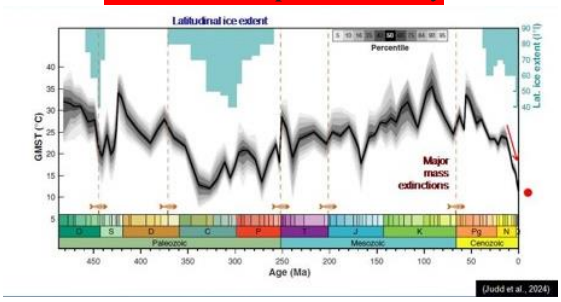


Fig 9. Phanerozoic temperature history. PhanDA constructed GMST for the past 485 Million years. Black line shows the median, shading corresponds to the ensemble percentile. Blue rectangles show the maximum latitudinal ice extent, and orange dashed lines show the timing of the five major mass extinctions of the Phanerozoic. Source Judd et al., (2024). Red arrow shows decline in temperature, which contradicts measured temperature data (see Christy, 2022).

Temperature Predictions vs. Observations

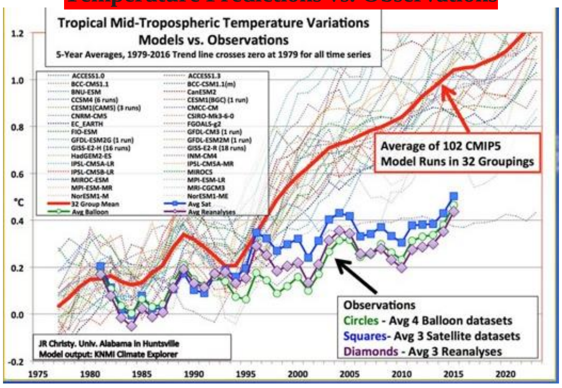


Fig 10. Exaggerated temperature prediction (Red line) vs Actual data by observation. Diagram source: Christy, (2022).

4. Contrary to the claim by Judd et al. (2024), here is no correlation between Temperature and CO_2 trends (Fig. 12) (Epstein, 2022).

5. In the PanDA models also, there is an absence of correlation between

Problems with Prediction of Global Surdace Air Temperature by IPCC AR6 (2021)

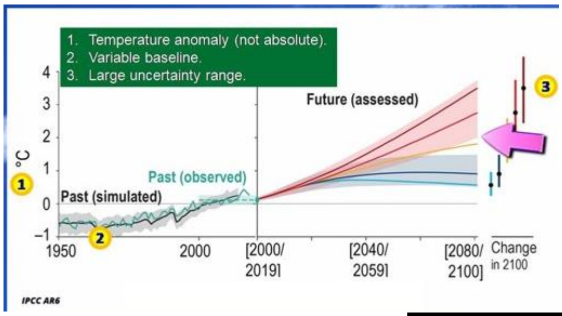


Fig 11. Three problems with IPCC Model. Source: IPCC AR 6 (2021). https://ipcc.ch/report/ar6/wg1/figures/technical-summary

Temperature and CO_2 during the Mesozoic era(Fig. 13C).

6. The high-altitude Mauna Loa site in Hawaii, used in constructing the Keeling Curve for atmospheric CO_2 concentrations (NOAA, 2024), is considered the Gold Standard for measured CO_2 concentrations in climate studies. The current measured value of CO_2 is 420 ppm in the Keeling Curve (Fig. 13A and B), but the PhanDA –reconstructed value is ~220 ppm (Fig. 13C). Judd et al. (2024) are conspicuously silent in explaining this discrepancy.

7. During the past 50 Years, CO_2 concentration has been steadily increasing in field observations ((Fig. 13A and B), but CO_2 concentration is decreasing in reconstructed values in the PhanDA model for the past 10 Ma (Fig. 13C). Judd et al. (2024) need to address this discrepancy.

8. In explaining the inapplicability of the PhanDA model to Mesozoic era, Judd et al. (2024) concede that "Although this may represent a true decoupling of CO_2 and GMST, it could also result from an incomplete knowledge of how different proxies encode past CO_2 information (11). Further work exploring both the CO_2 and temperature proxies is needed to resolve this "Mesozoic Conundrum." This is a major problem because the Mesozoic era ((252 Ma-66 Ma) represents 35% of the Phanerozoic eon (539 Ma-0).

9. From a critical scientific perspective, it makes no sense to claim that CO_2 is the primary control knob of climate for reasons ranging from lots of contradictory geological/climatological evidence (Berner, 2004; Dyson, 2007; Singer et al., 2009;

Watts, 2009; Soon et al., 2015; Christy, 2022; Epstein, 2022; Koonin, 2022; Curry, 2023; Lindzen, 2023; Moore, 2023; Plimer, 2023, Shanmugam, 2023, Durkin and Nelson, 2024) to basic radiation transfer physics (van Wijngaarden and Happer, 2020; Happer, 2022), which shows that radiation forcing from CO_2 is heavily saturated so huge changes, like "instantaneously" doubling CO_2, only diminish Earth's cooling radiation to space by about 1%.

Distribution of CO_2 and Temperature during the past 600 Million Years

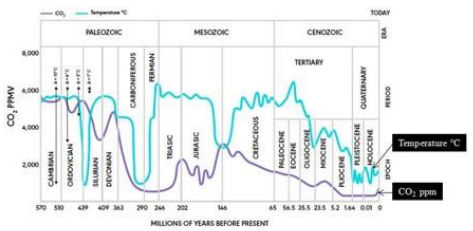


Fig 12. Absence of correlation between CO_2 and Temperature. Source: Epstein (2022). ***Additional labels by G. Shanmugam***

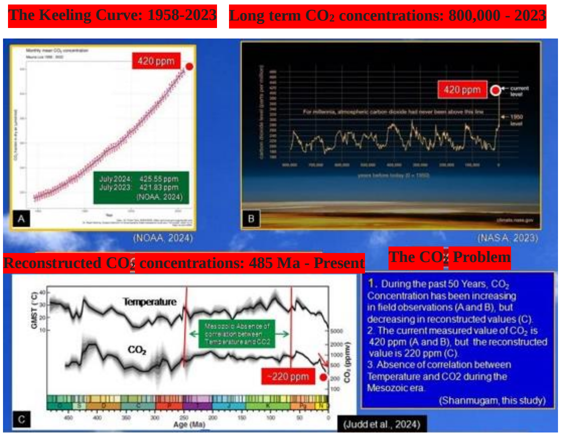


Fig 13. Problems with Climate Model ©. Red arrow in C shows declining CO_2 trend., which contradicts measurements (A & B)

PART 2: THE CO_2 1,000-PPM LIMIT

During a two-hour Trump-Musk Conversation on X (2024), Elon Musk claimed that when Atmospheric CO_2 goes past 1,000 ppm, it would cause headaches and nausea in humans. His conversation on August 12, 2024 was viewed by 1 Billion on Platform X (formerly known as Twitter). The current difference in CO_2 concentration between outdoor (atmospheric 420 ppm) and indoor (classroom 1,000 ppm) is 580 ppm.

DONALD JOHN TRUMP (born June 14, 1946) is an American politician, media personality, and businessman who served as the 45th President of the United States from 2017 to 2021. On November 5, 2024, Trump was elected as the 47th President of the United States.

ELON REEVE MUSK (born June 28, 1971) is a businessman and investor known for his key roles in the space company Space X and the automotive company Tesla, Inc. Other involvements include ownership of X Corp., the company that operates the social media platform X (formerly known as Twitter), and his role in the founding of The Boring Company, xAI, Neuralink, and OpenAI. He is one of the wealthiest individuals in the world; as of August 2024, *Forbes* estimates his net worth to be US$241 billion (Wikipedia, 2024).

Musk's influence and his Platform have the power to significantly affect public opinion. Although Musk was careful in making his comment with enough caveat (Fig. 14), some might overreact and believe that when the level of CO_2 goes past 1,000-ppm limit, it can have serious negative effects on people's health. I am particularly concerned about students and other followers of Musk who may be influenced by the Musk's magnetic message.

Trump – Musk Conversation on X August 12, 2024

Musk states that:
[01:09:35] "But I think if you just keep increasing the plus per million in the atmosphere long enough, eventually it actually simply gets uncomfortable to breathe. People do not realize this. If you go past 1000 parts per million of CO_2 you start getting Headaches and nausea. We are now in the 400 range. We are adding, I think, about roughly two parts per million per year. It still gives us, what it means is we still have quite a bit of time."

Fig 14. Trump – Musk Conversation on X August 12, 2024
Source: Trump – Musk Conversation on X, 2024

In preventing this false narrative, the purpose of this article is to present empirical data from real-world examples, such as classrooms, conference rooms, aircraft cabins, and other indoor environments that already have over 1,000 ppm of

CO_2, without anticipated ill effects. I have considered a total of 80,302 empirical data points from 25 countries (Fig. 15), which include 79,372 classroom data points. I have also examined data from three U.S. conference rooms (i.e., Iowa, Georgia, and Florida) and 179 U.S. domestic flights among 770 global flights. Importantly, I provide the necessary geological and physiological details in establishing a sound scientific framework. Finally, I reiterate the U. S. Government policies, established by USDA, NRC, and OSHA, on this matter.

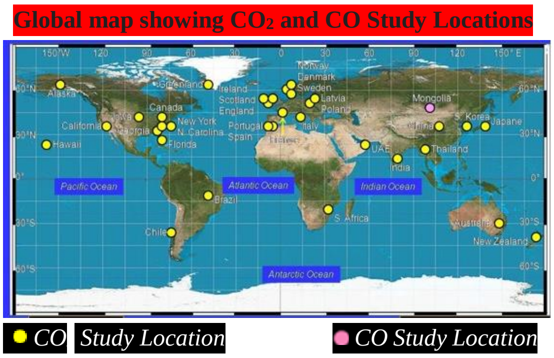


Fig 15. Global map showing CO_2 and CO Study Locations. *Data compiled by G. Shanmugam*

THE U.S. CO_2 STANDARD: 1,000 PPM LIMIT

The U.S. Guideline: ASHRAE (*American Society of Heating, Refrigerating and Air-Conditioning Engineers) (CO_2meter) considers that 1,000 ppm of CO_2* is the typical maximum value for indoor air quality (Table 1). In a recent article, Stumm (2022, p. 20) stated "…the indoor CO_2 level of 1,000 ppm reappears as a sensible, time—honored upper limit…"

Table 1. ASHRAE Carbon Dioxide Levels in the Classroom. From CO_2 meter (2024)

Serial Number	CO_2 (ppm)	Comments	Source
1	400	Normal outdoor air	ASHRAE
2	400-1,000	Typical CO_2 levels found indoors	ASHRAE
3	1,000-2,000	Common complaints of drowsiness or poor air quality	ASHRAE
4	2,000-5,000	Associated with headaches, fatigue, stagnant, stuffiness, poor concentration, loss of focus, increased heart rate, nausea	ASHRAE
5	> 5,000	Toxicity or oxygen deprivation may occur. This is the permissible exposure limit of the daily workplace exposure	ASHRAE
6	> 40,000	Immediately harmful due to oxygen deprivation	ASHRAE

ASHRAE = *American Society of Heating, Refrigerating, and Air-Conditioning Engineers*

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) have developed ventilation guidelines that should maintain a comfortable environment for most occupants. The amount of fresh air that should be supplied to a room depends on the type of facility and room. For example, in elementary school classrooms, ASHRAE recommends 15 cubic feet per minute person of outdoor air (for a 1,000 square foot room occupied by 35 people). In office spaces, ASHRAE recommends 17 cubic feet per minute person (for a 1,000 square foot occupied by 5 people). In addition, a Minnesota Department of Labor and Industry (MNDOLI) Rule states that "outside air shall be provided to all indoor workrooms at the rate of 15 cubic feet per minute per person (MN Rule, 5205.110)".

These rates of ventilation should keep carbon dioxide concentrations below 1,000 ppm and create indoor air quality conditions that are acceptable to most individuals (MNDOH, 2024).

Carbon dioxide is not generally found at hazardous levels in indoor environments. The MNDOLI has set workplace safety standards of 10,000 ppm for an 8-hour period and 30,000 ppm for a 15-minute period. This means the *average* concentration over an 8-hour period should not exceed 10,000 ppm and the *average* concentration over a 15-minute period should not exceed 30,000 ppm. It is unusual to find such continuously high levels indoors and extremely rare in non-industrial workplaces. These standards were developed for healthy working adults and may not be appropriate for sensitive populations, such as children and the elderly.

Satish et al. (2012) have reviewed the Direct Effects of Low-to-Moderate CO_2 Concentrations on Human Decision-Making Performance. Although typical outdoor CO_2 concentrations are approximately 380 ppm, outdoor levels in urban areas as high as 500 ppm have been reported (Persily 1997). Concentrations of CO_2 inside buildings range from outdoor levels up to several thousand parts per million (Persily and Gorfain 2008). Prior research has documented direct health effects of CO_2 on humans, but only at concentrations much higher than those found in normal indoor settings. CO_2 concentrations > 20,000 ppm cause deepened breathing; 40,000 ppm increases respiration markedly; 100,000 ppm causes visual disturbances and tremors and has been associated with loss of consciousness; and 250,000 ppm CO_2 (a 25% concentration) can cause death (Lipsett et al. 1994). Maximum recommended occupational exposure limits for an 8-hr workday are 5,000 ppm as a time-weighted average, for the Occupational Safety and

Health Administration (OSHA 2012) and the American Conference of Government Industrial Hygienists (ACGIH 2011).

The UK Guideline: Maximum CO_2 level is 2,000 ppm (Air Gradient, 2024a).

The Netherlands Guideline: Maximum CO_2 level is 1,200 ppm (Air Gradient, 2024a).

In short, there is no agreement among countries on the threshold limit of CO_2. For reference, I have inserted the ASHRAE's maximum indoor value of 1,000 ppm of CO_2 as the "U. S. Standard" in figures for reference purposes.

WHAT ARE THE SYMPTOMS OF DIFFERENT LEVELS OF CO_2 EXPOSURE?

According to the U.S. Government (USDA, 2024), the following are the symptoms of exposure to CO_2:

CO_2 is considered to be minimally toxic by inhalation. The primary health effects caused by CO_2 are the result of its behavior as a simple asphyxiant. A simple asphyxiant is a gas which reduces or displaces the normal oxygen in breathing air.

Symptoms of mild CO_2 exposure may include headache and drowsiness. At higher levels, rapid breathing, confusion, increased cardiac output, elevated blood pressure and increased arrhythmias may occur.

Breathing oxygen depleted air caused by extreme CO_2 concentrations can lead to death by suffocation.

5,000 ppm (0.5%) OSHA Permissible Exposure Limit (PEL) and ACGIH Threshold Limit Value (TLV) for 8-hour exposure

10,000 ppm (1.0%) Typically no effects, possible drowsiness

15,000 ppm (1.5%) Mild respiratory stimulation for some people

30,000 ppm (3.0%) Moderate respiratory stimulation, increased heart rate and blood pressure, ACGIH TLV-Short Term

40,000 ppm (4.0%) Immediately Dangerous to Life or Health (IDLH)

50,000 ppm (5.0%) Strong respiratory stimulation, dizziness, confusion, headache, shortness of breath

80,000 ppm (8.0%) Dimmed sight, sweating, tremor, unconsciousness, and possible death.

The response to CO_2 inhalation varies greatly even in healthy individuals. The seriousness of the symptoms is dependent on the concentration of CO_2 and the length of time a person is exposed. Since CO_2 is odorless and does not cause irritation, it is considered to have poor warning properties. Fortunately, conditions from low to moderate exposures are generally reversible when a person is removed from a high CO_2 environment.

CO_2 CONCENTRATION IN CLASSROOMS

As mentioned before, ASHRAE has established Carbon Dioxide Levels in the Classroom (Table 1).

CALIFORNIA, USA

In a comprehensive study of CO_2 concentrations in California schools, Chan et al. (2020) visited 104 classrooms from 11 schools that had recently been retrofitted with new heating, ventilation, and air-conditioning (HVAC) units. CO_2 concentration, room and supply air temperature and relative humidity, and door opening were measured for four weeks in each classroom. Field inspections identified HVAC equipment, fan control, and/or filter maintenance problems in 51% of the studied classrooms. Across 94 classrooms with valid data, average CO_2 concentrations measured during school hours had a mean of 895 ppm and a standard deviation (SD) of 263 ppm. However, in all 11 schools, measured CO_2 concentration in classrooms exceeded 1,100 ppm (Fig. 16).

Indoor CO_2 concentrations measured during school hours in 94 classrooms indicate classrooms frequently had $\mathbf{CO_2}$ at or above the sensor limit of 2,000 ppm (Fig. 17). There is no evidence that these students had suffered adverse health problems from exposure to excess $\mathbf{CO_2}$.

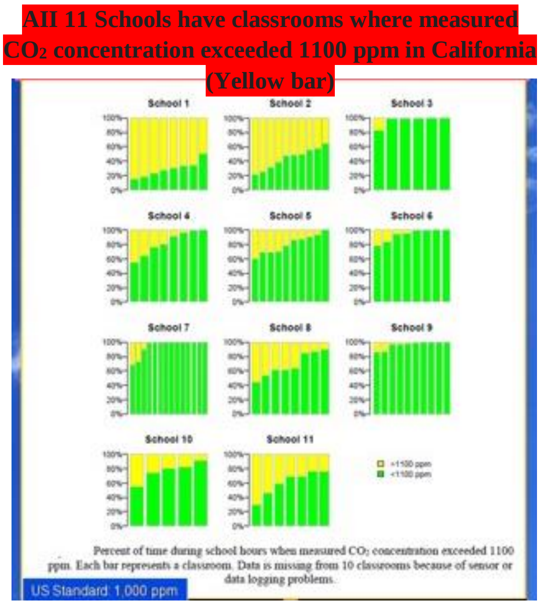


Fig 16 Source: Chan et al., (2020)
Additional labels by G. Shanmugam

Classrooms with CO_2 concentrationat or above2000 ppm in California (Yellow bar)

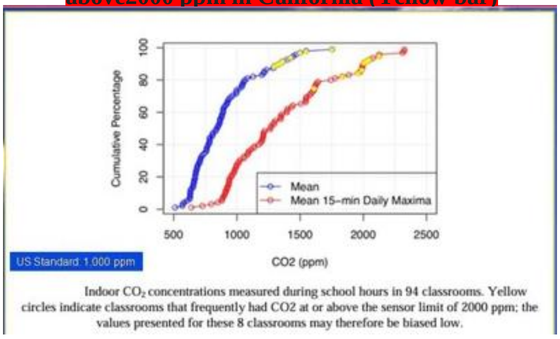


Fig. 17 CO_2>2000 ppm in California
Source: Chan et al., (2020) *Additional labels by G. Shanmugam*

NEW YORK, USA

Muscatiello et al. (2015) studied Classroom conditions and **CO_2** concentrations in 10 New York State Schools. They assessed the relationship between teacher-reported symptoms and classroom carbon dioxide (**CO_2**) concentrations. Previous studies have suggested that poor indoor ventilation can result in higher levels of indoor pollutants, which may affect student and teacher health. Ten schools (9 elementary, 1 combined middle/high school) in eight New York State school districts were visited over a 4-month period in 2010. Carbon dioxide concentrations were measured in classrooms over 48-h, and teachers completed surveys assessing demographic information and self-reported symptoms experienced during the current school year. Data from 64 classrooms (ranging from 1 to 9 per school) were linked with 68 teacher surveys (for four classrooms, two surveys were returned). Overall, approximately 20% of the measured classroom CO_2 concentrations were above 1,000 parts per million (ppm), ranging from 352 to 1,591 ppm.

Happer (2014) reported that in classrooms of colleges and universities, **CO_2** Levels average about 1,000 ppm.

NORTH CAROLINA, USA

Wilson (2022) reported that Higher than normal levels of CO_2 detected in a classroom in Wake County in North Carolina. Using a chart, she pointed out that how the carbon dioxide levels go up and down throughout the day. At 9:00 am the reading shows the CO_2 levels around 800 ppm but then climbs throughout the day, reaching the highest level of CO_2 around 2:00 pm at 3,200 ppm (Fig. 18).

CO_2 concentrationat measured at 3200 ppm in North Carolina Classroom

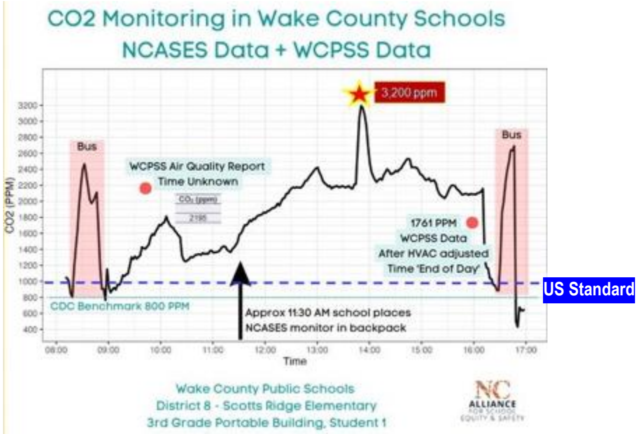


Fig. 18 CO_2 3200 ppm in North Carolina Classroom
Source: Wilson (2022) *Additional labels by G. Shanmugam*

HAWAII, USA

HIDOE (2022) reported that three classrooms out of 1,339 in Hawaii measured over 2,000 ppm of CO_2 (Table 2).

Table 2. Measured Maximum CO_2 concentration of over 2000 ppm in three classrooms in Hawaii

Tier	No. of Rooms
1 (< 800 ppm)	337
2 (800 - 1100 ppm)*	525
3 (1100 - 1500 ppm)	304
4 (1500 - 2000 ppm)	70
5 (> 2000 ppm)	3

US Standard

*1100 ppm approximates ASHRAE 62.1 HVAC design guidelines for 700 ppm above ambient carbon dioxide; ASHRAE 62.1 is used to guide the improvement of indoor air quality in existing buildings

Source: HIDOE (2022) *Additional labels by G. Shanmugam*

CANADA

The Quebec Government has released data from 76,122 classrooms across 3,246 schools in Quebec, Canada (CBC News, 2023). In the week before Christmas, 5,090 classrooms (6.7 per cent) exceeded the 1,500 ppm threshold. The most recent data also shows nearly a third of classrooms (33.2 per cent) recorded an average weekly CO_2 concentration of more than 1,000 ppm — the optimal limit according to Health Canada.

LONDON, ENGLAND, UK

Hama et al. (2023) studied CO_2 concentrations in 30 classrooms of primary schools in London, England, UK. Their study showed that CO_2 Concentrations exceeded the U.S. Standard of 1,000 ppm in many London classrooms (Fig. 19).

CO_2 Concentrations Exceed the US Standard of 1000 ppm in London Classroom, UK

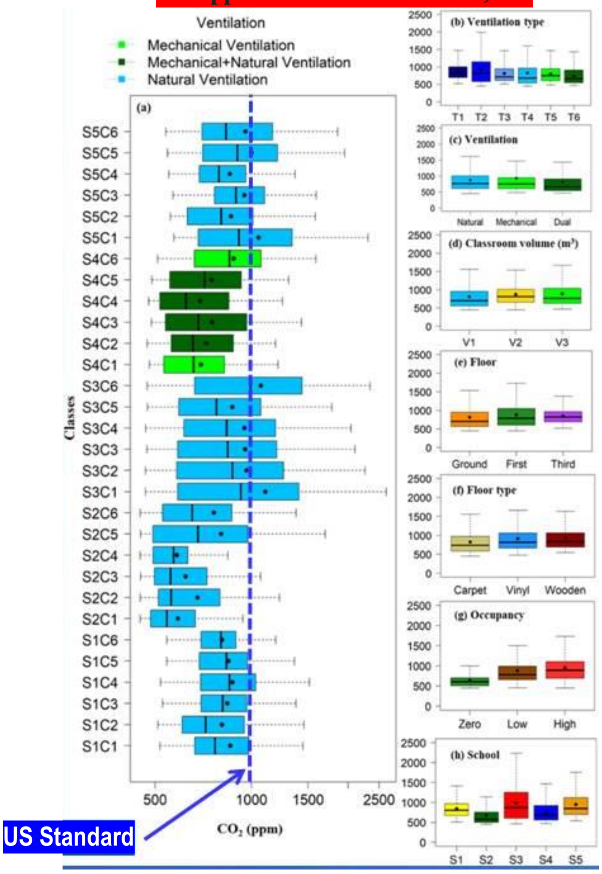


Fig. 19 Source: Hama et al., (2023)
Additional labels by G. Shanmugam

A LECTURE ROOM, UK

Greene et al. (2022) described the effects of high CO_2 concentration on the thermal comfort and academic performance of students during winter and summer in a large occupied lecture room. A large lecture room was chosen as the sample. This room was typical of other lecture rooms on the university's campus and similar to the other Universities within the UK. The results showed that CO_2 Concentrations exceeded 2,500 ppm in a Lecture Room for December 5th, 2008, UK (Fig. 13). This study also revealed that there is a positive correlation between the number of participants and the level of CO_2 concentration (Fig. 20).

On Wednesday May 6th, 2009, this study confirmed that high CO_2 concentration did affect the student's academic performance from 10am to 11am, when only 51%obtained higher than the passing 50% score on the test with CO_2 concentration ranging from 2,500 to 3,000 ppm.

SCOTLAND, UK

Bain-Reguis et al. (2022) studied indoor CO_2 and Thermal Conditions in 20 Scottish Primary School Classrooms with different ventilation systems during the COVID-19 Pandemic.

These classrooms are labeled A1, A2, A3, A4, A5, B1, B2, B3, B4, B5, C1, C2, C3, C4, C5, D1, D2, D3, D4, and D5. The recommended thresholds for room occupancy as provided by Scottish Government advice were 1,500 ppm for normal teaching classrooms. By comparison, the U.S. has 1,000 ppm limit. Surprisingly, CO_2 Concentrations exceed the Scottish Standard of 1,500 ppm in 11 out of 19 classrooms during the COVID-19 Pandemic in Scotland (Fig. 21). This observation is perhaps the most convincing evidence that humans can and do function normally when the CO_2 concentration exceeds the 1,000 ppm limit.

CO_2 Concentrations Exceed 2500 ppm in a Lecture Room, UK

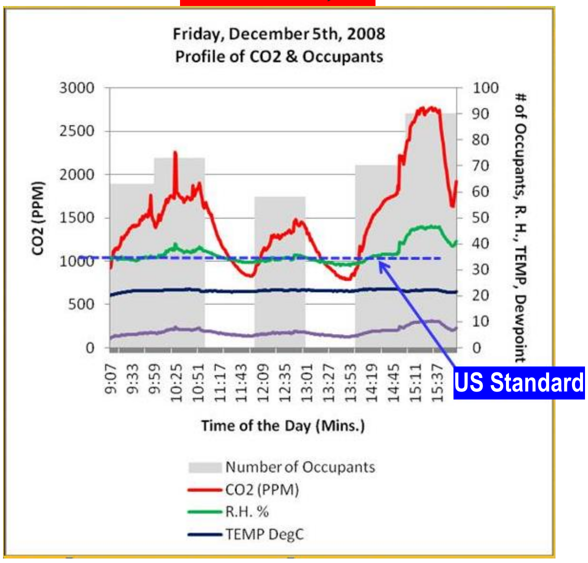


Fig. 20 Source: Greene et al., (2012)
Additional labels by G. Shanmugam

CO_2 Concentrations Exceed Scottish standard of 1500 ppm in 11out of 15 Classrooms during school hours in Scotland

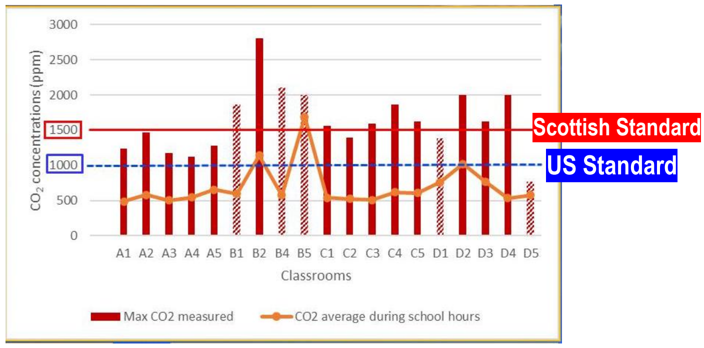


Fig. 21 Source: Bain-Reguis et al., (2022)
Additional labels by G. Shanmugam

IRELAND

As part of the AMBER (Assessment Methodology for Building Energy Rating) project, IES (2024) has developed a monitoring and control system for ensuring adequate ventilation in spaces to minimize the risk and spread of COVID-19 in Ireland. The project had already identified the importance of monitoring CO_2 and had highlighted a number of serious issues with respect to the CO_2 levels in both homes and schools. In some instances, the CO_2 levels in schools were rising <u>to over 6,000 ppm. This is the highest value reported among 80,302 classrooms considered from 25 countries in this study.</u>

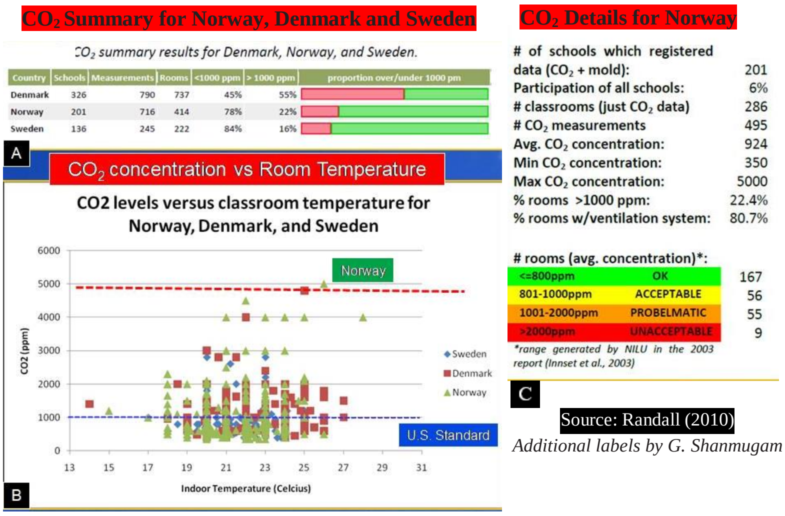


Fig. 22 A). CO_2 Summary for Norway, Denmark abd Sweden, B). CO_2 concentration vs Room Temperature, C). CO_2 Details for Norway from Randall (2010)

NORWAY, DENMARK, AND SWEDEN

Randall (2010) studied CO_2 concentration in 1,373 classrooms from Norway, Denmark, and Sweden in 2009.

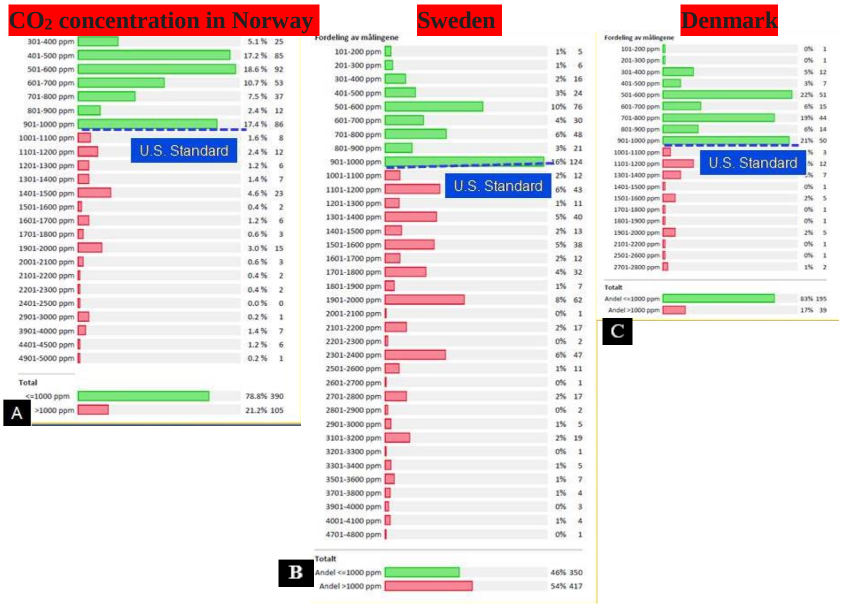


Fig. 23 Norway, Denmark and Sweden Source: Randall (2010) *Additional labels by G. Shanmugam*

<u>Summary</u>

Project: 2009 Scandinavian student-based research campaign Institution: Institute for Air Research (NILU) Countries: Norway, Denmark, and Sweden

Total Number of Classrooms: 1,373

Total Number of students: 12,000

Maximum CO_2 concentration measured: 5,000 ppm in Norw (Fig. 22B)

Maximum % rooms with CO_2 concentration: >1000 ppm: 54% Denmark (Fig. 23B)

LATVIA

Zemitis et al. (2021) studied 9 classrooms Latvia. They reported that CO_2 concentration lev averages of about 2,380 ppm and the absolu maximum of 4,424 ppm. The field results show th >3,000 ppm level of CO_2 is common (Fig. 24A), ar that the CO_2 concentration (blue line) consistently above 1500 and reaches 2,500 ppm (Fig. 24B).

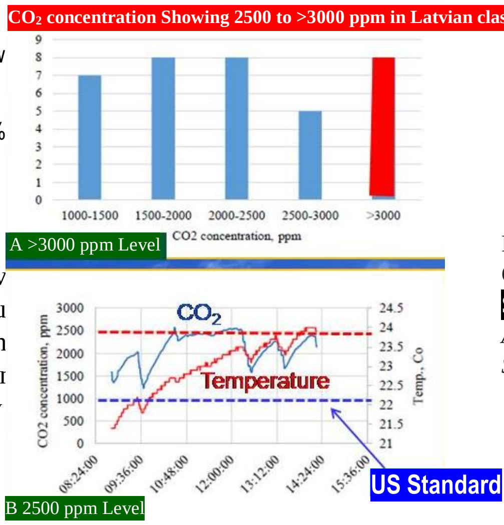


Fig. 24 > 3000ppm in Latvian Classroom
Source: Zemitis et al., (2021)
Additional labels by G. Shanmugam

At the start of the year 2019, there were 707 educational institutions and 214,002 pupils in Latvia, according to information from the Ministry of Education and Science. Bogdanovica et al. (2020) documented CO_2 concentration values above 2,000 ppm in a Latvian classroom (Fig. 25). They have also reported a weak positive correlation between CO_2 concentration and the percentage of pupils with headache. The correlation coefficient is r = 0.31 (Fig. 26b) The results of the survey show that indoor IEQ, overheating and fatigue ratings, as well as headaches per hour, have a moderate correlation with CO_2 concentration in the classroom, so CO_2 concentration may have the potential to influence student well-being at school, but the correlation is not strong because well-being is affected by many other factors. The occurrence of headaches in the learning process is not direct evidence of their correlation with the increase in CO_2 concentration in the room, as the period of non-compliance with the CO_2 concentration standard may be too small for pupils to suffer from headaches. Headaches can also be caused by other factors, such as sickness or sleep deprivation in students, and difficulties in understanding the class subject.

CO_2 concentration values above 2000 ppm in Latvian classroom

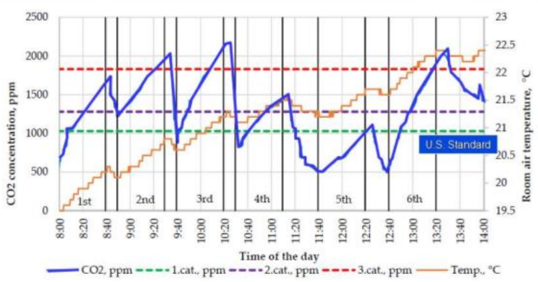


Fig. 25 > 2000ppm in Latvian Classroom

Source: Bogdanovica et al., (2020) *Additional labels by G. Shanmugam*

A weak positive correlation between CO_2 concentration and the percentage of pupils with headache in a Latvian classroom. The correlation coefficient is r = 0.31

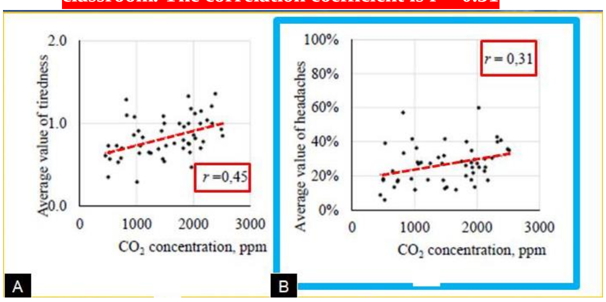


Fig. 26 A weak positive correlation between CO_2 concentration and the percentage of pupils with headache in a Latvian classroom. The correlation coefficient is r = 0.31.

Source: Bogdanovica et al., (2020) *Additional labels by G. Shanmugam*

COIMBRA, PORTUGAL

Ferreira and Cardoso (2013) studied air quality in 51 elementary schools (81 classrooms) in the city of Coimbra, Portugal, both inside and outside of the rooms was evaluated during the four seasons, from 2010 to 2011. In 47 schools, the average CO_2 concentrations were above the maximum reference concentration (984 ppm) mentioned in Portuguese legislation. The maximum concentration values found inside the rooms were critical, especially in the fall/winter (5,320 ppm). This is the second highest value reported among 80,302 classrooms considered from 25 countries in this study.

POLAND AND SPAIN

Krawczyka et al. (2016) compared CO_2 concentration values in 8 classrooms from Poland and Spain. Carbon dioxide concentration was in the range between +0 and +5,000 ppm with precision ±50 ppm (±2%); between5,000 ppm and 10,000 ppm with precision ±100 ppm (±3%); and atmospheric pressure was in the range between +600 and +1150 hPa with precision ±5 hPa. (Krawczyka et al. (2016) compared CO_2 concentration values in 8 classrooms from Poland and Spain. Carbon dioxide concentration was in the range between +0 and +5,000 ppm with precision ±50 ppm (±2%); between5,000 ppm and 10,000 ppm with precision ±100 ppm (±3%); and atmospheric pressure was in the range between +600 and +1150 hPa with precision ±5 hPa. Concentration of CO_2 in classroom 2 in Białystok (Poland) exceeds the U.S. Standard (Fig. 27A). Concentration of CO_2 in classroom 5 in Belmez (Spain) is below the U.S. Standard (Fig. 27B).

CO_2 concentration in Poland and Spain with reference to US Standard

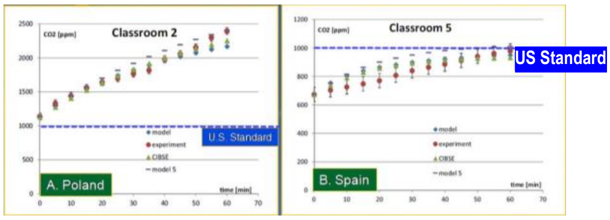


Fig. 27 CO_2 concentration in Poland and Spain.

Source: Krawczyka et al., (2016) *Additional labels by G. Shanmugam*

FRANCE

Canha et al. (2016) reported that the French Departmental Health Regulations mandate that concentrations do not exceed 1,300 ppm at any time in rooms in which smoking is prohibited. However, the studied classrooms presented CO_2 concentration above 1000, 1300, and 1500 ppm during 65%, 46%, and 35% of the occupied period, respectively.

Table 3. Distribution of the CO_2 concentrations (ppm) in French Classrooms.

Distribution of the CO_2 concentrations (ppm) during the occupied period over the sampling week (n = 50 classrooms)

CO_2 concentration (ppm)	Mean	Min	P5	P25	Median	P75	P95	Max
Weekly mean	1290	530	730	970	1250	1670	1900	2220
Minimum	440	360	380	410	430	460	570	600
Maximum	2440	580	1080	1880	2320	3180	3890	4310

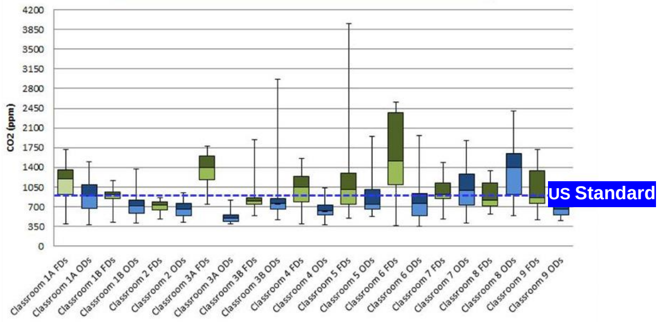
Source: Source: Canha et al. (2016) *Additional labels by G. Shanmugam*

They also documented the overall results of the CO_2 concentration measurements for the studied Classrooms during the period of occupancy. The mean CO_2 concentration in the 50 studied classrooms was 1,290 ppm during the occupied period, with a median of 1,250 ppm and a maximum of 2,220 ppm. The absolute measured maximum was 4,310 ppm (Table 3).

ITALY

Di Gilio et al. (2021) studied CO_2 concentration inside 9 schools (11 classrooms) located in Apulia Region (South of Italy) during the reopening of schools after the lockdown due to COVID-19 pandemic. Although, during the first evaluation stage, air ventilation through the opening of windows and doors was guaranteed, 6 (54%) classrooms showed mean values of CO_2 higher than 1,000 ppm and almost all classrooms exceeded the recommended CO_2 concentration limit value of 700 ppm (Fig. 28). In one case, CO_2 concentration exceeded 2,300 ppm (Fig. 28).

CO_2 concentration value exceeds 2300 ppm in an Italian classroom



First Stage evaluation (FDs green color | Second Stage evaluation (Other days blue

Fig. 28. > 2300 ppm in an Italian Classroom.

Source: Di Gilio et al., (2021) *Additional labels by G. Shanmugam*

UNITED ARAB EMIRATES

In their annual indoor air quality assessment for the Abu Dhabi National Oil Company (ADNOC) Schools, the Abu Dhabi Education Council has reported hazardous levels (~3000 ppm) of carbon dioxide in 15 classrooms. In their study of indoor air quality in 15 classrooms in the United Arab Emirates, Abu-Rahmah et al. (2021) reported that CO_2 concentration ranged between 2,625 and 3,382 ppm under "Precleaning AC filters" conditions (Table 4). Even after cleaning of AC filters, CO_2 concentration exceeded 1,000 ppm in these 15 classrooms (Table 4).

Table 4. Measured CO_2 concentrations in 15 schools in the United Arab Emirates

: Indoor air-quality parameters precleaning and postcleaning the AC filters.

Location	Code	Vol. (m^3)	No. of occupants	Grade level	Precleaning AC filters: CO_2 levels (ppm)	T (°C)	RH (%)	CO_2 indoor/ outdoor	Postcleaning AC filters: CO_2 levels (ppm)	T (°C)	RH (%)	CO_2 indoor/ outdoor
Arabic classroom	G138	238	12	9	2,893	27	63	6.90	1,048	25	38	2.50
Arabic classroom	G132	238	17	7	3,098	26	67	7.40	1,318	24	42	3.15
Math classroom	G009	253	7	12	2,897	25	63	6.91	1,189	24	37	2.84
English classroom	G008	156	8	12	3, 311	25	64	7.90	1,308	24	38	3.12
Chemistry lab	G123	140	10	10	2,792	24	69	6.66	1,033	23	43	2.47
Cafeteria	G106	756	44	6–12	3,381	25	66	8.00	1,087	24	41	2.60
Physics lab	G083	349	13	12	2,778	25	65	6.63	971	24	39	2.32
Hum. classroom	G074	196	10	8	3,009	24	65	7.18	1,272	23	41	3.00
Hum. classroom	G075	196	13	8	2,625	25	62	6.26	1,330	24	34	3.17
Arabic classroom	G134	238	17	7	3,117	25	61	7.44	1,286	24	32	3.07
Art lab	G087	349	21	10	3,107	25	65	7.42	1,046	24	39	2.50
Math classroom	G014	253	9	11	2,822	25	60	6.74	920	24	32	2.20
Physics lab	G080	349	19	11	2,897	25	61	6.91	1,167	24	32	2.80
Hum. classroom	G072	196	19	6	3,275	24	60	7.82	1,014	23	31	2.42
English classroom	G020	156	20	10	2,993	25	61	7.14	763	24	34	1.82
Time-based averages					~3000	~25	~63	~7.2	~1,117	~24	~37	~2.7

Source: Abu-Rahmah (2021) *Additional labels by G. Shanmugam*

INDIA

Soomro et al. (2018) studied five classrooms in Hyderabad City in India. Three of them had CO_2 concentration over 1,000-ppm limit (Table 5).

SOUTH AFRICA

van der Walt et al. (2024) studied CO_2 and temperature every 11 min in 24 classrooms at two schools in Stellenbosch, South Africa. Container classrooms with and without insulation, mobile (prefabricated) classrooms, and brick classrooms of different configurations were included. Measurements were concurrently sampled over

Table 5. Measured CO_2 concentrations over 1,000 ppm in 3 schools in Hyderabad City in India

Institute	Time	Average Temperature (°C)	Average Humidity (%)	Average atmospheric pressure (hpa)	Average wind speed (m/s)	CO_2 concentration (ppm)	Occupancy	Gender	
								Male	Female
CR1	9:30	36	23	1012	4.44	1378	40	40	00
	10:00	32	24	1012	4.44	1231	40	40	00
	10:30	38	22	1012	4.44	1298	40	40	00
CR2	9:30	36	32	1013	4.44	478	20	10	10
	10:00	32	24	1012	4.44	498	20	10	10
	10:30	34	20	1012	4.44	518	20	10	10
CR3	8:00	33	15	1012	3.88	1058	37	22	15
	8:30	34	16	1012	4.16	1178	37	22	15
	9:00	35	11	1012	4.16	1198	37	22	15
CR4	5:30	35.5	30	1012	2.22	798	14	8	6
	6:00	35.5	28	1013	4.16	848	14	8	6
	6:30	35.5	20	1012	4.16	896	14	8	6
CR5	5:30	30.4	42.6	1010	2.22	1318	53	53	00
	6:00	32	45	1011	2.77	1413	53	53	00
	6:30	33	40	1012	4.16	1428	53	53	00

Source: Soomto et al., (2018) *Additional labels by G. Shanmugam*

twelve months, across multiple seasons with relevant metadata, including ambient weather conditions. They analyzed temperature and CO_2 concentrations for classroom types and classroom categories and compare school days with non-school days. The results show that temporary classrooms (container and mobile) have substantially worse thermal environments, even when air conditioning is available. The CO_2 concentrations in container classrooms were substantially worse with CO_2 concentration values above 1,000 ppm during all seasons (Fig. 29).

CO_2 concentration value aboves 1000 ppm in Container schools during all seasons in South African Primary School classrooms

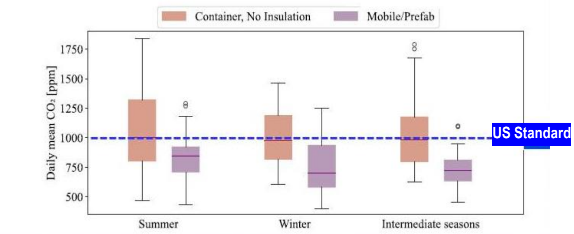


Fig. 29 South Africa Source: Van der Wall et al., (2024)
Additional labels by G. Shanmugam

SOUTH KOREA

Han et al. (2022) studied CO_2 concentration in Elementary School Classrooms in Seoul, South Korea. They published an example of CO_2 concentration changes over time in three classrooms, one each with no air cleaner, one air cleaner and two air cleaners, used for 27–28 students in the second grade at S school. Regardless of the presence of an air cleaner, the initial CO_2 concentration in all three classrooms was approximately 500 ppm, and it increased to 2,500–3,000 ppm during class, decreased by approximately 100–700 ppm during playtime, and then increased again to 3,000 ppm (Fig. 30). During lunchtime, the initial CO_2 concentration decreased to 1,500–2,000 ppm and then increased again to 3,000 ppm during afternoon class. Most of the classrooms were closed environments because measurements were taken during early winter, and thus CO_2 levels continued to increase during class time due to lack of ventilation. Nevertheless, students attended these classes during class hours with >1,000 ppm of CO_2.

Increase in CO_2 concentration to 3000 ppm during class hours in Elementary School Classrooms, Seoul, South Korea

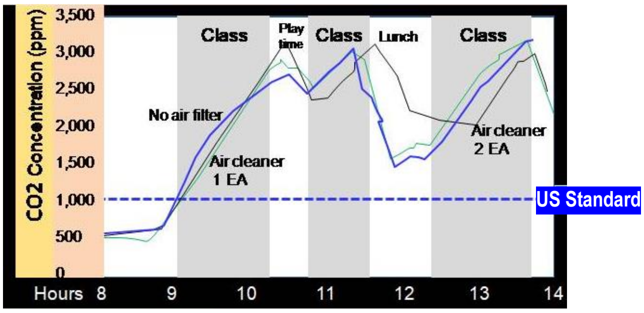


Fig. 30 Increase in CO_2 concentration to 3000 ppm during class hours in Elementary School Classrooms, Seoul, South Korea

Redrawn from Han et al.,) *Additional labels by G. Shanmugam*

AUSTRALIA

Andamon et al. (2023) reported on pre-pandemic field measurements of CO_2 concentration levels conducted for an academic year in 10 classrooms from four primary and a secondary schools in Victoria, Australia. Measured CO_2 concentrations across the 10 classrooms which were operated with a mix of intermittent natural ventilation and air-conditioning for cooling or heating, on average ranged between 657 ppm and 2,235 ppm during school hours with median over 1,000 ppm in 70% of classrooms.

Across the four seasons, which approximately corresponds to the four school terms, all classrooms exceeded 1,000 ppm for the median peak concentration levels and showed similar median levels ranging from a narrow band of 1169 ppm–1,359 ppm for average CO_2 concentration levels, exceeding 2500 ppm with wider range of 2655 ppm–3558 ppm for peak median maximum CO_2 concentrations and 2121 ppm–2,397 ppm for the 95% of 15-min moving average. The maximum values for peak maximum CO_2 concentrations ranged from 3,799 ppm to 5,000 ppm recorded in 3 classrooms (Fig.31). During all seasons, maximum measured concentrations of CO_2 range between 2,000 and 4,200 ppm (Fig. 31).

Peak Maximum CO_2 concentration values range from 3799 ppm to 5000 ppm in three Australian Schools

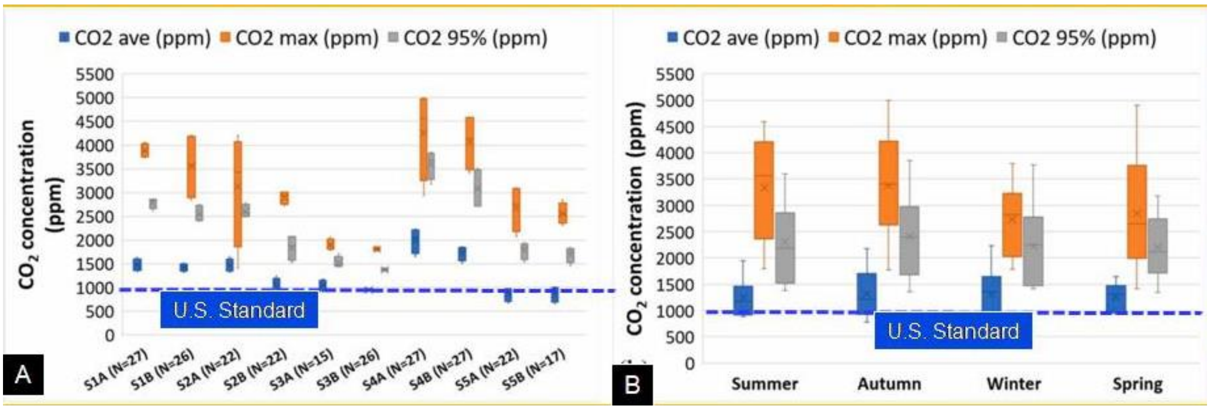


Fig. 31 Peak Maximum CO_2 concentration values range from 3799 ppm to 5000 ppm in 3 Australian School Classrooms

Source: Andamon Rajagopalan & Woo (2023) *Additional labels by G. Shanmugam*

NEW ZEALAND

BRANZ (2019) conducted a study of air quality in 28 classrooms in 10 schools in New Zealand. In New Zealand new school buildings, the Ministry of Education requires that the average concentration of CO_2 should not exceed 1,500 ppm. By comparison, the U.S. Standard is 1,000 ppm.

- Inside the Wellington classroom, the CO_2 average concentration in school hours was almost 900 ppm.
- In the Auckland schools of the SKOMOBO trial, CO_2 in one classroom exceeded 1,000 ppm for 66% of school time and 1,500 ppm for 40% of the day in winter. In spring, CO_2 rates were mostly below 1,000 ppm.
- In Hawke's Bay, weekly average CO_2 measurements were consistently over 1,000 ppm year round. Students in one classroom experienced high CO_2 levels the whole year, with summer levels around 2,000 ppm. Windows were not being opened.
- In Christchurch, over half of the averages were above 1,200 ppm, with one room reaching 2,800 ppm in winter and another 3,800 ppm in autumn. In one classroom, students were exposed to CO_2 levels of 2,000–3,000 ppm for a whole week in winter. In another, CO_2 levels were above 2,000 ppm for most of the year.
- In Dunedin, 53% of the weekly averages were below (or around) 1,000 ppm. No students were exposed to CO_2 above 2,000 ppm.

According to BRANZ (2019), these CO_2 concentrations, although exceeds 1,000 ppm in some cases, are unlikely to be a significant health risk but are more likely to have a temporary impact on performance.

JAPAN

Senseair (2024) studied CO_2 concentrations in 13 classrooms on a daily basis at Tagoura Junior High School in Japan. CO_2 concentrations exceeded the U.S. Standard limit of 1,000 ppm (Fig. 32).

CO_2 concentration in 13 Classrooms at Tagoura Junior High School, Japan

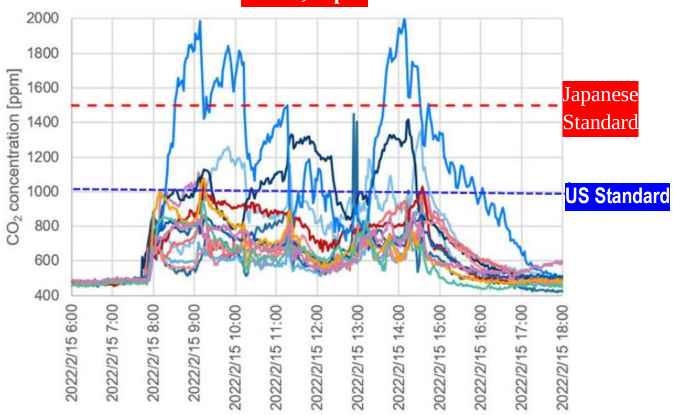


Fig. 32 CO_2 concentration in 13 Classrooms at Tagoura Junior High School, Japan

Source: Senseair (2024) *Additional labels by G. Shanmugam*

CHINA

Lee and Chang (2000) examined five classrooms in Hong Kong (HK), air-conditioned or ceiling fans ventilated, for indoor and outdoor air quality. They found that maximum indoor CO_2 level reached 5,900 μl/l during class at the classroom with cooling tower ventilation.

The subsample of the CIEHS 2018 study was performed in 66 classrooms of 22 primary schools nationwide in China by Zhu et al. (2021). This study found that CO_2 levels exceeded the recommended limit of CO_2. All these examples suggest that students worldwide are attending schools where CO_2 concentration values are often above 1,000 ppm.

THAILAND

AirGradient (2024b) studied CO_2 levels in 30 classrooms in the city of Chiang Mai in Northern Thailand. They analyzed the high CO_2 values of 2,000 to 3,000 ppm as follows (Fig. 33).

- When the school opens at 8 am, CO_2 levels began to rise from the initial amount of 1,000ppm (and not the typical outside CO_2 of around 400ppm).
- By 10 am, CO_2 levels skyrocket to over 2,000ppm.
- By 12 pm, the amount of CO_2 peaks beyond 3,000ppm.
- After 12 pm, CO_2 levels drop by a normal rate. This is perhaps due to students going out of the room for their lunch break, allowing fresh air to circulate.
- By 3 pm, CO_2 levels drop below 1,000ppm as students go home

The average during the school day in this particular classroom is approximately 2,080 ppm CO_2. But there are no observed effects of high CO_2 levels on students from this study.

CO_2 concentration exceeds 3000 ppm in Classrooms in the city of Chiang Mai Northern Thailand

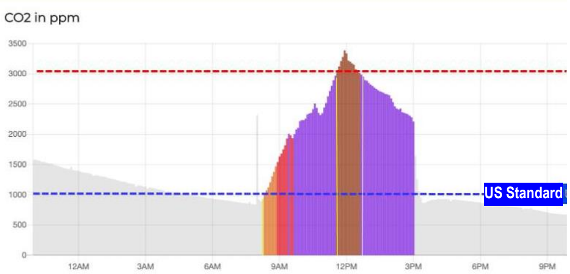


Fig. 33 CO_2 concentration exceeds 3000 ppm in Classrooms in the city of Chiang Mai Northern Thailand

Source: AirGradiant (2024b) *Additional labels by G. Shanmugam*

BRAZIL

Jurado et al. (2014) evaluated the indoor air quality in Brazilian universities by comparing thirty air-conditioned (AC) (*n* = 15) and naturally ventilated (NV) (*n* = 15) classrooms. The levels of CO_2 in the AC rooms were significantly higher than CO_2 in the NV rooms (1,433.62 ± 252.80 and 520.12 ± 37.25 ppm, respectively).

CONCEPCIÓN, CHILE

Rivera (2020) conducted field studies in 9 schools and 28 classrooms in the city of Concepción, Southern Chile. CO_2 concentrations average 1600 ppm in fall and 1900 ppm in winter, exceeding the maximum threshold of 1,000 ppm in densely occupied spaces according to EPA and ASHRAE Standard 62.1-2016. Indoor Air quality profile measurements of CO_2, during one school day school in the fall, shows a maximum of 5,000-ppm

CO_2 concentration reaches 5000 ppm during one school day in the fall in Chile

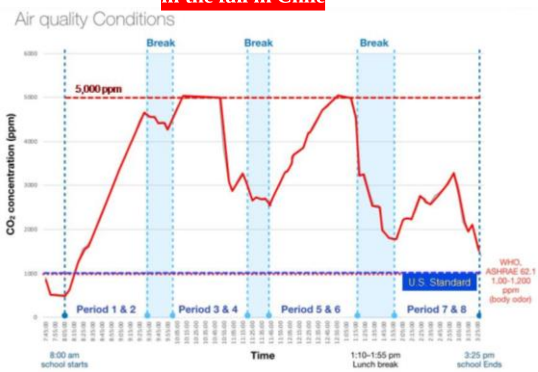


Fig. 34 CO_2 5000 ppm in Chile

Source: Rivera (2020) *Additional labels by G. Shanmugam*

concentration value (Fig. 34)

Data gathered for this study show that in indoor classrooms and other settings, CO_2 concentration commonly range between 2,000 and

Maximum measured concentration of CO_2 in ppm

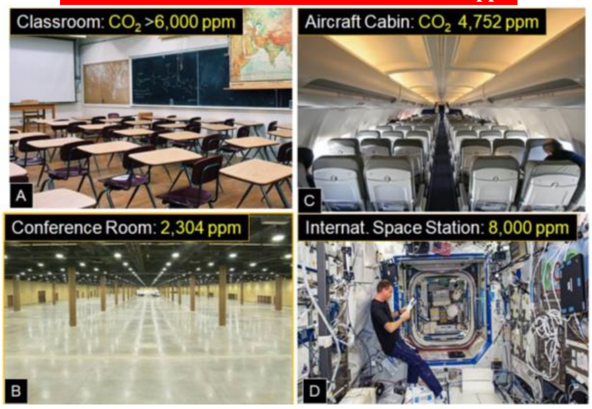


Fig. 35 Maximum measured concentration of CO_2 in ppm in various settings. A). Clasroom CO_2 >6000 ppm (IES, 2024) B). Conference room 2304 ppm (Teleszewski et al., 2019) C). Aircraft Cabin 4752 ppm (COT, 2022) D). International Space Station 8000 ppm (Moser 2023).

6,000 ppm (Fig. 35).

CO_2 CONCENTRATION IN CONFERENCE ROOMS, USA

We have examined data from three conferences held in three different States in the US, namely Iowa, Georgia, and Florida in 2024 (Fig. 29). The 2024 Florida Homeschool Convention was the largest of the three in terms of attendees with measured value of CO_2 at 1,248 ppm (Fig. 36). There is no evidence that these conference attendees had suffered from exposure to excess **CO_2**.

We found that there is a general increase in **CO_2** concentration values with increasing number of attendees (Table 6).

Increase in CO_2 concentration in ppm with increase in number of Conference Attendees

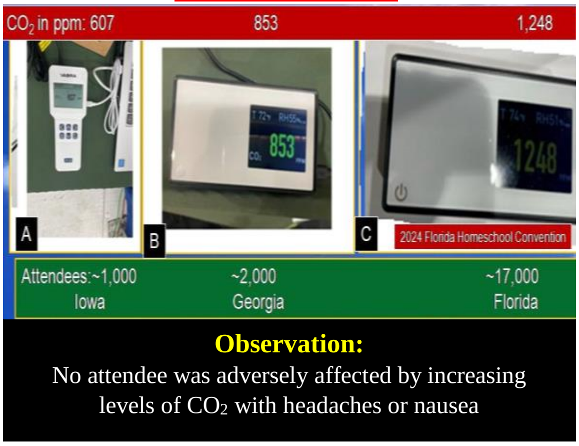


Fig. 36 Increase in CO_2 concentration in ppm with increase in number of Conference Attendees in the US

Table 6. Number of attendees and measured CO_2 in three conferences in the USA (Fig. 29). Courtesy of Angela Wheeler, The CO_2 Coalition

Serial Number	State (USA)	Number of Attendees	Measured CO_2 (ppm)
1	The Homeschool Iowa Convention West Des Moines, Iowa June 14 and 15, 2024	~1,000	107
2	The Southeast Homeschool Convention Atlanta, Georgia July 26 and 27, 2024	~2,000	853
3	The Florida Homeschool Convention Kissimmee, Florida May 23-25, 2024	~17,000	1,248

CO_2 CONCENTRATION IN A CONFERENCE ROOM, POLAND

Carbon dioxide levels were measured in a conference room in the building of the Faculty of Civil and Environmental Engineering at Białystok University of Technology by Teleszewski et al. (2019). This building is located in the city of Białystok, Poland, Maximum CO_2 concentration was 2,304 ppm (Table 7).

Table 7. Measured maximum CO_2 concentration of 2304 ppm in a Conference room at Bialstok University technology, Poland

Series no.	Date	Number of persons n	$\gamma = n/V$	Average relative humidity	Initial concentration of CO_2	Air change rate m	Time of prior airing with open windows
–	–	person	person/m^3	%	ppm	h^{-1}	min
1	12/04/2017	53	0.17	44.46	607	0.1	720
2	17/05/2017	48	0.16	48.82	457	0.001	720
3	05/07/2017	54	0.17	55.71	754	6.7	60
4	15/11/2017	59	0.19	45.84	553	2	720
5	13/12/2017	53	0.17	41.73	536	1	720
6	17/01/2018	56	0.18	42.90	1658	8.2	0
7	14/02/2018	53	0.17	40.15	549/2304	0/7.5[a]	720

Source: Teleszewski et al,. (2019) *Additional labels by G. Shanmugam*

CO_2 CONCENTRATION IN A CONFERENCE ROOM, CHINA

Wang et al. (2022) studied four conference rooms in China using both measurements and simulations of CO_2 concentration (Fig. 37). Measured values exceeded 1,800 ppm (Fig. 30A). In simulations, with the doors and windows closed, in winter the peak value of CO_2 concentration in ROOM D could reach 3200 ppm, while in summer, was up to 3500 ppm (Fig. 37 B). The CO_2 concentration at 12:00 (three hours after the meeting) reduced to 1000 ppm in winter.

Measured and Simulated CO_2 concentration values in Conference Rooms China

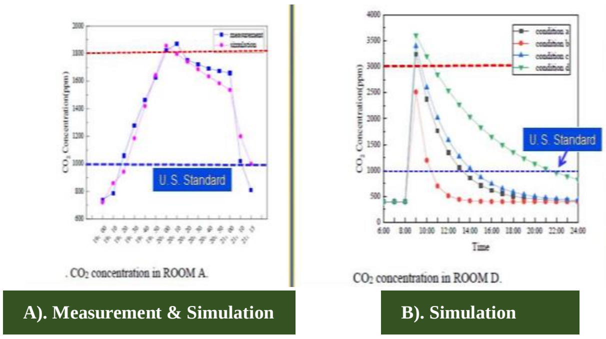


Fig. 37 Conference Rooms, China Source: Wang et al., *Additional labels by G. Shanmugam*

CO_2 CONCENTRATION IN GREENLANDIC DWELLINGS

A comprehensive study of indoor air quality was performed by Kotol et al. (2014) in Sisimiut, Greenland in 2011/2012. A cross sectional study in 79 dwellings was performed. In summer, the average CO_2 concentrations ranged from 467 ppm to 877 ppm and in winter from 438 ppm to 2368 ppm. The highest concentrations appeared in bedrooms with the absolute measured maximum of 4,687 ppm. The CO_2 concentrations were above 1370 ppm for 2% of time in the summer and for 30% of time in the winter. The CO_2 concentrations we measured in Greenlandic bedrooms were generally higher compared to CO_2 concentrations measured in other studies conducted in Denmark and Alaska. This may likely be due to lower ventilation rates in Greenlandic dwellings.

CO_2 CONCENTRATION IN STUDENT HOUSES, FAIRBANKS, ALASKA

Kotol (2014) studied four student houses for indoor air quality in Fairbanks, Alaska. He reported thatCO_2 concentration reached a maximum of 2,500 ppm (Fig. 38).

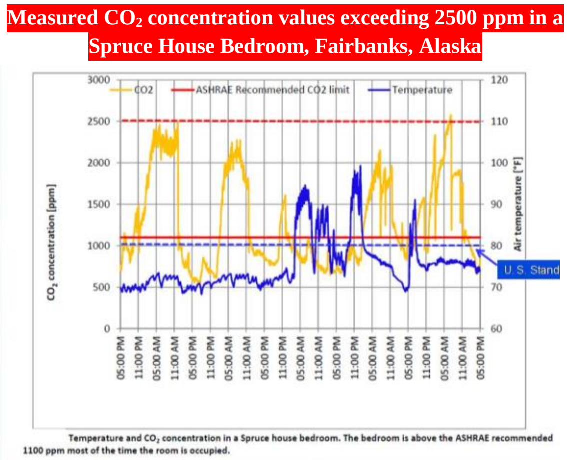


Fig. 38 Spruce House Bedroom, Fairbanks, Alaska

Source: Kotol (2014) *Additional labels by G. Shanmugam*

CO CONCENTRATION IN MONGOLIAN HOUSEHOLDS

Cowlin et al. (2006) studied CO concentration, but not CO_2, in 58 households in Ulaanbaatar, Mongolia (Fig. 39). In homes with all stove types, the average level of indoor concentrations of PM and CO exceeded Mongolian national standards for 24-hour concentrations, and in the case of PM, the excess exposure was large. The Mongolian national standard for 24-hour CO is 2.6 parts per million (ppm), and the average of 24-hour CO concentrations over all households was 9.5 ppm. The Mongolian national standard for 24-hour average total suspended particles is 150–200 micrograms per cubic meter (µg/m3), and the average 24-hour observed PM concentration was 730 µg/m3 over all households.

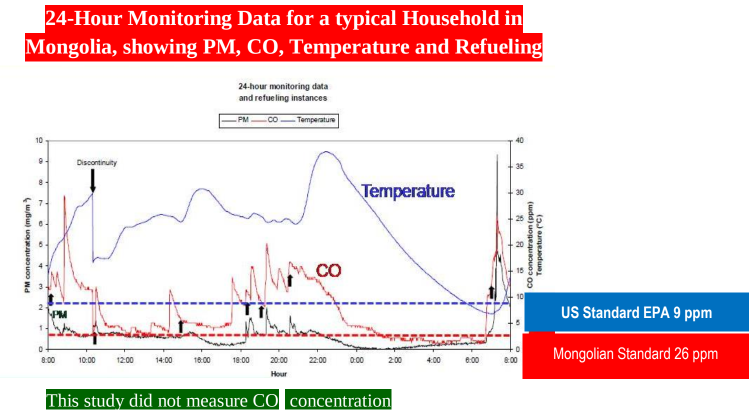


Fig. 39 24-Hour Monitoring Data for a typical Household in Mongolia, showing PM, CO, Temperature and Refueling

Source: Cowlin et al,. (2006) *Additional labels by G. Shanmugam*

CO_2 CONCENTRATION IN AIRCRAFT CABINS

U.S. DOMESTIC AND INTERNATIONAL FLIGHTS

COT (Committee on the Toxicity) (2022) reviewed approximately 770 U,S. Domestic and International flights for in-flight cabin air quality.

REVIEW SUMMARY

- The highest mean value of CO_2 reported in aircraft was 1903 ppm and the maximum value was 4,752 ppm (Table 8, Fig. 40).
- Levels of CO and CO_2 in aircraft were collated and compared with regulatory values in aircraft, air quality standards as well as levels that cause adverse health effects.
- For CO_2 measured in aircraft worldwide, many mean and maximum concentrations exceed the ASHRAE aircraft standard (1100 ppm) and maximum concentrations exceed values indicating poor air quality for residential and non-residential (1750 ppm) and the acceptable maximum indoor air quality in schools (1500 ppm).
- In EU flights, maximum concentrations also exceed values indicating poor air quality for residential and non-residential (1750 ppm) and the acceptable maximum indoor air quality in schools (1500 ppm), but mean and maximum concentrations are lower than CS aircraft standards (5000 ppm).
- For CO, mean and maximum concentrations measured in aircraft worldwide are below all regulatory values for aircraft and air quality standards, with the exception of the World Health Organization (WHO) Air Quality Guideline (AQG) of 4 mg/m^3 (2.2 ppm). No mean data are available for EU flights but maximum concentrations are below regulatory values for aircraft and air quality standards, with the exception of the WHO AQG.
- Following the ban on smoking in commercial flights in 1997, CO_2 and CO concentrations showed a slight decreased

trend or appeared largely unaffected, respectively.

- All concentrations of CO_2 and CO reported are below levels that are reported to cause adverse health effects. Therefore, no adverse health effects are anticipated following exposure to the reported levels of CO and CO_2 in aircraft.

Table 8. Mean, minimum and maximum concentrations of Co 2 in Airbus 330 and Boeing 747 -400

Flight	Mean conc. (ppm)	Min conc. (ppm)	Max conc. (ppm)
A	1.170	629	2195
B	906	612	1565
C	686	642	1492
D	1557	855	2900
E	1052	1052	2368
F	1097	863	2043
G	716	479	1826
H	728	423	1911
I	967	760	1491
J	701	538	1347
K*	884	418	4752
L*	868	530	4088
M	683	509	2303
N	733	427	1489
O*	1024	624	1994
P	1000	702	1946

**Flight in which smoking was permitted. It should be noted that smoking was prohibited in all flights in 1997*

Source: COT (2022) *Additional labels by G. Shanmugam*

Mean and maximum concentration of CO_2 in aircraft flying worldwide compared with aircraft standards. X-axis shows data from 1987 (left) to 2021 (right)

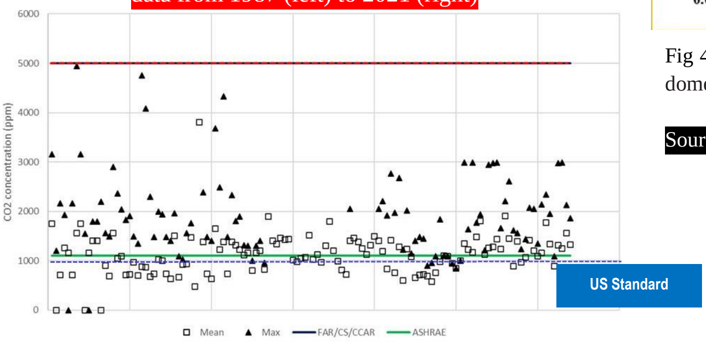


Fig 40. Mean and maximum concentration of CO_2 in aircraft flying worldwide compared with aircraft standards. X-axis shows data from 1987 (left) to 2021 (right)

Source: COT (2022) *Additional labels by G. Shanmugam*

A CASE STUDY OF THE U.S. DOMESTIC FLIGHTS

Cao et al. (2019) measured real-time CO_2 concentrations, an indicator of ventilation rates, and cabin pressure in the passenger cabins of 179 U.S. domestic flights from boarding through deplaning. This dataset was considered by COT (2022). The average CO_2 concentrations were 1,353 ± 290 ppm (mean ±SD) and the estimated outside airflow rates were 5.77 ±2.09 L/s/p across all flights (Fig. 41). The results indicated that 96% of observations met the minimum recommended outside airflow rates for acceptable air quality (3.5 L/s/p), but only 73% met the rate required in FAA design requirements (4.7 L/s/p), during flying phases. The CO_2 levels on all flights were well below the occupational exposure limit of 5000 ppm. However, all maximum and most mean and median CO_2 concentration values are more than 1,000 ppm (Table 9). There is no data on passengers who had suffered from exposure to excess **CO_2**.

According to COT Meeting (2023), "Most aircraft and occupational standards for CO_2 are set

Measured CO_2 Concentration and pressure during a typical flight

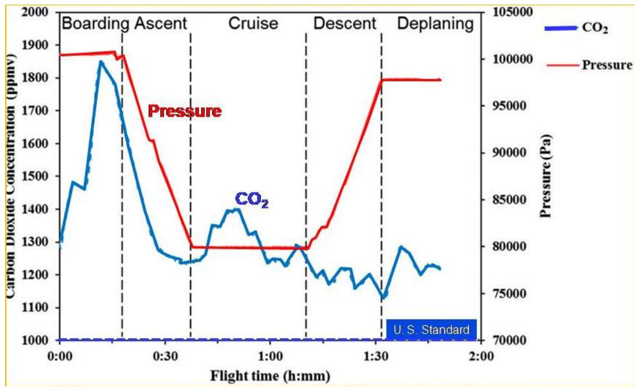


Fig 41. Measured CO_2 Concentration and pressure during a typical domestic flight in the US

Source: Cao et al., (2019) *Additional labels by G. Shanmugam*

at 5,000 ppm" (Table 10), The Committee on Toxicity (COT) is an independent scientific committee that advises the UK government on the toxicity of chemicals in food, consumer products, and the environment. Clearly, this UK government entity does not consider even the 5,000 ppm of CO_2 is harmful to humans.

Measured CO_2 Concentration and estimated outside air flow rates on all the flights

Measured CO_2 concentrations and estimated outside airflow rates on all the flights. US Standard: 1,000 ppm

Aircraft series	Aircraft types	Aircraft numbers	CO_2 concentration (ppmv) Min	Max	Mean	Median	SD	Outside ventilation rate (L/s/p) Min	Max	Mean	Median	SD
Airbus 319/320	A319	2	1003	1635	1228	1211	112	4.05	8.19	6.11	6.13	0.82
	A320	3	682	2990	1175	1235	382	1.94	17.08	8.15	5.95	4.04
Boeing 737	B737-300	4	1032	1773	1479	1497	111	3.64	7.83	4.68	4.55	0.54
	B737-400	1	1656	1937	1808	1804	65	3.26	3.98	3.56	3.57	0.16
	B737-500	1	1000	1220	1124	1142	49	6.06	8.23	6.88	6.69	0.49
	B737-700	7	850	2947	1261	1272	188	1.97	10.90	6.05	5.71	1.40
	B737-800	6	661	2976	1288	1355	316	1.95	18.38	6.73	5.22	3.62
Boeing 757	B757	67	703	2992	1438	1421	284	1.94	15.95	5.19	4.88	1.52
Boeing 767	B767-300	5	756	1662	1234	1238	160	3.96	13.66	6.25	5.93	1.65
Bombardier	CR-7	1	1094	2209	1903	1911	160	2.77	7.14	3.38	3.32	0.48
	CR-9	5	658	2616	1451	1427	265	2.27	18.59	5.04	4.86	1.32
	CRJ-100	2	620	1620	889	878	160	4.10	21.60	10.61	10.25	2.91
	CRJ-140	1	1264	1566	1398	1384	79	4.28	5.76	5.02	5.07	0.39
	CRJ-150	1	793	1233	969	976	127	5.97	12.42	9.07	8.58	1.88
	CRJ-200	2	721	1442	1070	1049	173	4.79	15.09	7.90	7.63	2.14
Embraer	E-135	1	1143	2077	1417	1381	185	2.99	6.68	5.04	5.08	0.79
	E-145	1	682	2054	1201	1070	403	3.03	17.08	7.86	7.40	3.85
	E-170	1	855	1352	1097	1083	160	5.23	10.78	7.49	7.25	1.73
	E-175	8	686	2137	1162	1120	200	2.89	16.85	6.91	6.89	1.69
	E-190	1	1392	2340	1771	1717	233	2.59	5.03	3.75	3.80	0.60
MD	DC-9	3	934	1951	1340	1159	320	3.23	9.23	5.82	6.54	1.59
	MD-80	1	659	1094	897	891	111	7.14	18.52	10.41	10.01	2.45
	MD-88	53	514	2979	1321	1318	264	1.95	39.50	5.89	5.42	1.98
	MD-90	2	656	2993	1251	1265	416	1.94	18.72	6.97	5.75	2.83
Summary		179	514	2993	1353	1333	290	1.94	39.50	5.77	5.34	2.09

Note: All maximum and most mean and median CO_2 concentration values are more than 1,000 ppm

Source: Cao et al., (2019) *Additional labels by G. Shanmugam*

Table 10. Aircraft regulatory values for CO_2 in Europe, US, and China. Source: COT Meeting (2023). (Cited in Chen et al., 2021).

Serial Number	Allowed CO_2 (ppm)	Aircraft/Workplace	Country / Continent
1	5,000	FAR (Federal Aviation Regulations)	US
2	1,000	ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, withdrawn)	US
3	30,000	JAR (Joint Airworthiness Requirements)	EU
4	5,000	EASA (European Aviation Safety Authority} CS (Certification. Specifications}	EU
5	20,000; 15 min 5,000; peak 2,000	BS-EN4618 on Aerospace series (withdrawn)	EU
6	5,000	CCAR (Chinese Civil. Aviation Regulations)	China
7	5,000; 8-hour PEL (Permissible Exposure Limit) (Workplace exposure limit.)	EH40/2005 Workplace exposure limits	

Since 1970, I have taken hundreds of international flights, some lasting 15 hours, around the world. I have never had any incidents of adverse health effects caused by CO_2 exposure during flights. I must conclude that the 1,000-ppm CO_2 concern is unwarranted.

CO_2 CONCENTRATION IN SUBMARINE NAVAL VESSELS AND INTERNATIONAL SPACE STATION

Data collected on nine nuclear-powered ballistic missile submarines indicate an average CO_2 concentration of 3,500 ppm with a range of 0-10,600 ppm, and data collected on 10 nuclear-powered attack submarines indicate an average CO_2 concentration of 4,100 ppm with a range of 300-11,300 ppm (Hagar 2003).

It is also worth mentioning that astronauts operate in the International Space Station (ISS) for a period of 3 years under **CO_2** levels of 8,000 ppm (Fig. 35) (Moser, 2023). Almost all of the CO_2 on board the ISS is produced by the astronauts' breathing. Carbon dioxide levels are monitored and controlled on the ISS (International Space Station) by the Atmosphere Revitalization (AR) subsystem of the Environmental Control and Life Support System **(ECLSS)**. NASA has set the maximum allowable 24-hour average CO_2 on board the ISS at 5,250 ppm (4.0 mmHg). Let's Talk Science (2024). Although ISS is an unusual environment, the fact that these astronauts operate for a period of three years with CO_2 concentrations much higher than 1,000 ppm is worth emphasizing in this response to Musk, who founded Space X. On September 15, 2021, SpaceX made history when Elon Musk launched four private passengers into orbit on the first mission to space with an all-civilian crew.

CO_2 DISTRIBUTION (FORECAST) IN 2100

Forecast values of CO_2 concentration in 2,100 varies from 672 to 1,142 ppm (Fig. 42 and Table 11). As mentioned before, ASHRAE (*American Society of Heating, Refrigerating and Air-Conditioning Engineers) (2010, 2023) has established that 1,000 ppm of CO_2* is the typical value for indoor air quality in the USA. Therefore, there is no need for health concerns due to 1,000 ppm of CO_2 in 2100.

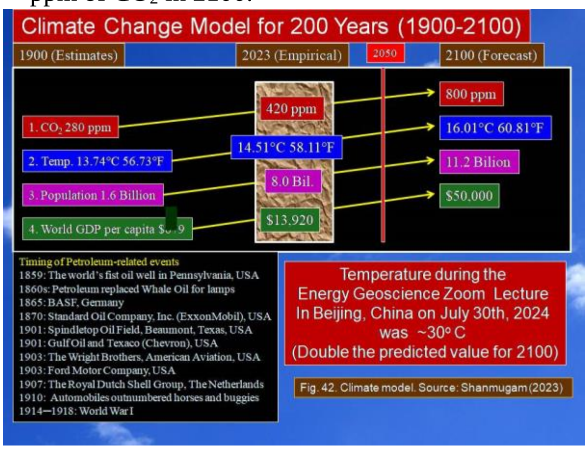


Fig. 42. Climate model. Source: Shanmugam (2023)

Table 11. Forecast values of CO_2 concentration in 2100.			
Serial Number	**Forecast levels of CO_2 (ppm) in 2100**	**Method**	**Source**
1	572	By calculating CO_2 in 2100 by estimating at 2 ppm, increase in CO_2 per year from 2024 to 2100 (using 76 years and 152 ppm and 420 ppm for 2024). At this rate, 1,000 ppm will be reached by 2314.	This study
2	800	Forecast	Lindsey (2022); Happer and Lindzen (2022); Scripps CO_2 Program (2023). van Wijngaarden and Happer (2020)
3	1,000	~Forecast	IPCC (2000) Meehl et al. (2007)
4	1,142	Forecast	AWI (2019)

CO_2 AND HUMAN PHYSIOLOGY

Finally, the above discussion on CO_2 must be framed into a coherent human physiological network. For basic physiological reasons, the concentration of **CO_2** in ambient air is almost irrelevant as long as it is much smaller than about 40,000 ppm, where it is in equilibrium with the optimum **CO_2** concentration of human blood. According to Messina and Patrick (2022) of the U.S. National Institute of Health (NIH), "The partial pressure of carbon dioxide (PCO_2) is the measure of carbon dioxide within arterial or venous blood. It often serves as a marker of sufficient alveolar ventilation within the lungs. Generally, under normal physiologic conditions, the value of PCO_2 ranges between 35 to 45 mm Hg or 4.7 to 6.0 kPa." To put this into perspective, the partial pressure of CO_2 at sea level is 0.3 mm Hg. The difference in **CO_2** between inhaled (0.3 mm Hg) and exhaled air (40 mm Hg) confirms the fact that the inside of our lungs has 100 times more CO_2 than the air going into our lungs (Fig. 43). Our lungs have to keep breathing out this excess **CO_2** to avoid **CO_2** build up in our lungs. Normally, our lungs have about 40,000 ppm of CO_2 by comparison to the atmospheric CO_2 of about 400 ppm.

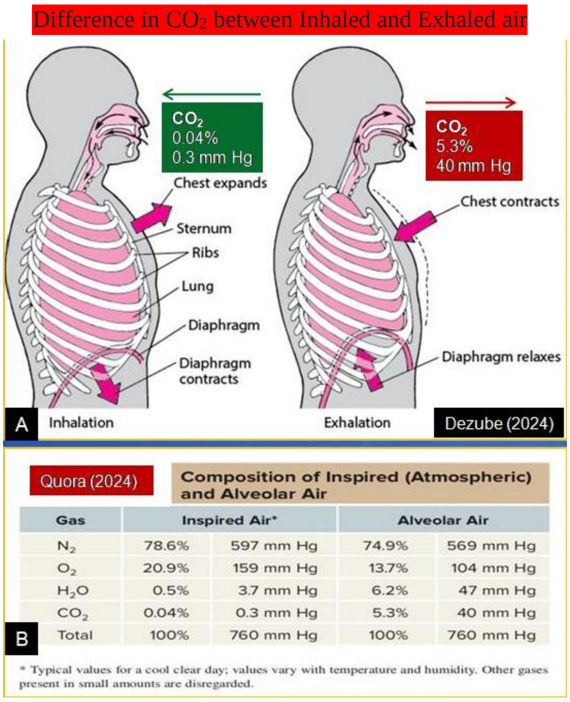


Fig 43. A). Diagram showing difference [n CO_2 between Inhaled and Exhaled Air during breathing. Diagram without CO_2 values from Dezube (2024). Merck Manual. Consumer Version. Additional CO_2 values from Quora (2024) added by G. Shanmugam. B). Composition of Inspired (Atmospheric) and Alveolar Air (Quora, 2024). *Additional labels by G. Shanmugam*

Our breathing reflex is driven by the **CO_2** concentration in the blood, not by a lack of blood oxygen. Our blood becomes too acidic when it has too much **CO_2** and it becomes too alkaline with too little **CO_2**. Our breathing rate adjusts automatically to maintain the optimum **CO_2**

In this context, we must discuss two related phenomena; one on alkalosis (too little **CO_2** in the blood) and one on the breathing reflex (triggered by too much **CO_2** in the blood). Respiratory alkalosis is caused by a low carbon dioxide level in the blood (MedlinePlus, 2024). This can be due to:

- Fever
- Being at a high altitude
- Lack of oxygen
- Liver disease
- Lung disease, which causes you to breathe faster (hyperventilate)
- Aspirin poisoning.

Breathing is usually automatic, controlled subconsciously by the respiratory center at the base of the brain (Dezube, 2024). Breathing continues during sleep and usually even when a person is unconscious. People can also control their breathing when they wish, for example during speech, singing, or voluntary breath holding. Sensory organs in the brain and in the aorta and carotid arteries monitor the blood and sense oxygen and carbon dioxide levels. Normally, an increased concentration of carbon dioxide is the strongest stimulus to breathe more deeply and more frequently. Conversely, when the carbon dioxide concentration in the blood is low, the brain decreases the frequency and depth of breaths. During breathing at rest, the average adult inhales and exhales about 15 times a minute.

EFFECTS IN HUMANS DUE TO HIGH LEVELS OF CO_2

The U. S. National Research Council (NRC, 2007) has documented the effects in humans due to high levels of CO_2. Selected examples are as follows:

- Dyspnea (i.e., shortness of breath) is a commonly reported end point and can be induced by acute exposures to CO_2 at >30,000 ppm (NRC 1996). Hyperventilation without dyspnea occurs at exposure concentrations as low as 10,000 ppm (NRC 1996). Dyspnea attributable to CO_2 is aggravated by increasing the level of exertion.

- White et al. (1952) studied humans exposed to CO_2 at 60,000 ppm for 16 minutes and reported that 19 of 24 subjects exhibited slight or moderate dyspnea and 5 of 24 exhibited severe dyspneic sensations. At 40,000-50,000 ppm for 17-32 minutes, 16 subjects reported dyspnea (Schneider and Truesdale 1922). In contrast, no dyspnea was reported in five subjects exposed at 32,000 ppm or at 25,000-28,000 ppm for several hours (Brown 1930).

- In the most modern protocol to examine dyspnea, Menn et al. (1970) reported that eight subjects exposed to CO_2 at 11,000 ppm exhibited no increase in dyspnea or intercostal pain during 30 minutes of maximal exercise. The same study reported that exposure to CO_2 at 28,000 ppm during 30 minutes of maximal exercise produced increased dyspnea in three of eight subjects and intercostal pain in two of eight subjects, but subjects did not show increased dyspnea at one-half or two-thirds maximal exercise. Sinclair et al. (1971) reported that a 1-h exposure to CO_2 at 28,000 ppm in four subjects caused no dyspnea or intercostal pain during steady strenuous exercise. Thus, the bulk of the data indicate a no-observed-adverse-effect level (NOAEL) for CO_2 of about 28,000 ppm on the basis of the findings on dyspnea and intercostal pain.

- Neither dyspnea nor intercostal pain occurred in four subjects exposed to CO_2 at 28,000 ppm for 15-20 days and made to do 45 minutes of exercise twice daily at up to a heavy level, although the chronic portion of this protocol was not fully described (Sinclair et al. 1971). Similarly, there were no symptoms reported in six subjects exposed to CO_2 at 20,000 ppm for 30 days or 29,000 ppm for 8 days and made to do 10 minutes of exercise twice a week at a workload of 150 watts (Guillerm and Radziszewski 1979; Radziszewski et al. 1988). Thus, 28,000 ppm is an appropriate chronic NOAEL for dyspnea and intercostal pain.

- Headaches are commonly associated with increased CO_2 concentrations in inspired air, but there is conflicting data on the concentrations reliably associated with that end point. There may also be an effect of exertion, because CO_2 seems to cause more headaches at lower concentrations during exercise than it does during rest. In particular, Schneider and Truesdale (1922) reported that for 16 resting subjects exposed to CO_2 at 10,000-80,000 ppm for 17-32 minutes, headaches developed only at concentrations that were ≥50,000 ppm; however, the headache could be intense. At 28,000 ppm for 1 h of strenuous steady-state exercise, occasional mild headaches were noted among four subjects (Sinclair et al. 1971). At 39,000 ppm for 30 minutes of exercise at two-thirds maximal exertion, Menn et al. (1970) found mild-to-moderate frontal headaches in six of eight subjects near the end of the exposure period. The headaches resolved after about an hour. At 28,000 ppm and 11,000 ppm for 30 minutes of exercise, no headaches were reported (Menn et al. 1970). Thus, there is inconsistent modern evidence for mild headaches resulting from CO_2 exposures at 28,000 ppm during exercise. Some level of increased exertion among submarine crew might be likely during 1-24 h emergency episodes; however, headaches induced by CO_2 are both mild and reversible and therefore were not used as a primary end point for setting the 1-h and 24-h EEGLs.

- Sub chronic CO_2 exposures at 30,000 ppm or higher are known to produce headaches. Glatte et al. (1967) reported that CO_2 at 30,000 ppm for 5 days led to mild to moderate throbbing frontal headaches on the first day in four of seven subjects. The headaches disappeared on day 3 and were not severe enough to interfere with normal activities, including 1 h of moderate exercise daily, although three of the four subjects with headaches requested analgesics. During 30-day exposures at 20,000 ppm, six subjects rarely developed headaches, and exposures at 29,000 ppm led to slight headaches (Radziszewski et al. 1988). Eight subjects, four exposed to CO_2 at 28,000 ppm for 15-30 days and four exposed to CO_2 at 39,000 ppm for 11 days, reported occasional mild headaches during exertion that disappeared after the first day of exposure (Sinclair et al. 1969, 1971). Thus, 20,000 ppm is an appropriate sub chronic NOAEL for headaches.
- In summary, it takes an exposure concentration of at least 10,000 ppm to increase minute-volume after a plateau in the hyperventilatory response has been reached, usually after a few hours. It is not clear from the data whether the hyperventilatory response diminishes with time, although in a study at 10,000 ppm, it resolved completely after 8 days of a 44-day exposure (Pingree 1977). Data from Radziszewski et al. (1988) showed a 60% increase in minute-volume during a 2-h exposure at 20,000 ppm. The increase was reduced to 45% after 24 h. There is no indication in the literature that hyperventilation constitutes an adverse response.

CONCLUDING REMARKS

We really do not know what will happen when the Atmospheric CO_2 exceeds 1,000 ppm limit in 2314 (Table 11). However, we do know that the "Evolution" in itself creates / modifies / erases the living being with appropriate physiology that is suited to such new atmospheric conditions. This global study, with robust datasets from 25 countries, has revealed that we can indeed adapt to hiher levels of CO_2 exposure (Table 12).

The U.S. Government (USDA, 2024) does not consider the CO_2─1,000 limit as a health threat (Fig. 44). A total of 80,302 empirical indoor data points from 25 counties (i.e., classrooms, conference rooms, and aircraft cabins) suggest that humans are able to function normally without adverse health effects even when CO_2 concentration levels reach between 2,000 and 6,000 ppm (Table 12). Although the authors of research articles are willing to advocate the adverse health risks associated with the artificial CO_2─1,000 ppm limit, they are conspicuously silent in documenting empirical evidence for headaches associated with the 1.000 ppm limit of CO_2. Also, there is no experimental evidence for such a relationship. According to NRC (2007), 20,000 ppm is an appropriate sub chronic NOAEL (No Observed Adverse Effect Level) for headaches. All datasets lead to the conclusion that humans can function normally without adverse health effects even at 10,000 ppm of CO_2 (Fig. 44). Therefore, the notion that headaches supposedly associated with the 1.000-ppm limit of CO_2 is a fallacy.

Table 12. Summary of empirical data points showing that millions of humans can and do function normally everyday under CO_2 concentrations much higher than 1,000 ppm worldwide in classrooms, conference rooms, dwellings in cold climate, aircraft cabins, submarine naval vessels, and International Space Station.

Serial Number	CO_2 (ppm)	Setting	Data Points	Location / Country / Region	Reference
1	>1,100	Classroom	104	California, USA	Chan et al. (2020)
2	1,591 Max	Classroom	64	New York, USA	Muscatiello et al. (2015)
3	3,200 Max	Classroom	1	North Carolina USA	Wilson (2022)
4	>2,000 in 3 Classrooms	Classroom	1,239	Hawaii, USA	HIDOE (2022)
5	>1,500 (6.7%)	Classroom	76,122	Canada	CBC News (2023)
6	>1,000	Classroom	30	London, England, UK	Hama et al. (2023)
7	>2,500	Lecture Room	1	UK	Greene et al. (2022)
8	>1,500	Classroom	20	Scotland, UK	Bain-Roguis et al. (2022)
9	>6,000 (Highest)	Classroom	1	Ireland	IES (2024)
10	5,000 Max (Norway)	Classroom	1,373	Norway, Denmark, and Sweden	Randall (2010)
11	2,500 Max	Classroom	10	Latvia	Zemitis et al. (2021)
12	5,320 Max (2nd Highest)	Classroom	81	Portugal	Ferreira and Cardoso (2013)
13	>1,000 (Poland) <1,000 (Spain)	Classroom	8	Poland and Spain	Krawczyka et al. (2016)
14	4,310 Max	Classroom	50	France	Canha et al. (2016)

15	>2,300	Classroom	11	Italy	Di Gilio et al. (2021)
16	~3,000	Classroom	15	United Arab Emirates	Abu-Rahmah et al. (2021)
17	>1,000	Classroom	5	India	Soomro et al. (2018)
18	>1,000	Classroom	24	South Africa	van der Walt et al. (2024)
19	3,000 Max	Classroom	3	South Korea	Han et al. (2022)
20	4,200 Max	Classroom	10	Australia	Andamon et al. (2023)
21	3,000 Max	Classroom	28	New Zealand	BRANZ (2019)
22	>1,000	Classroom	13	Japan	Senseair (2024)
23	>1,000	Classroom	71	China	Zhu et al. (2021)
24	>3,000	Classroom	30	Thailand	AirGradient (2024b)
25	1,433 Max	Classroom	30	Brazil	Jurado et al. (2014)
26	5,000 Max	Classroom	28	Chile	Rivera (2020)
27	1,248 Max	Conference Rooms	3	Iowa, Georgia, and Florida. USA	Angela Wheeler, The CO_2 Coalition
28	2,304 Max	Conference Room	1	Bialystok University of Technology, Poland	Teleszewski et al. (2019)
29	>1,800	Conference Room	4	China	Wang et al. (2022)
30	4,687 Max	Dwellings	79	Greenland	Kotol et al. (2014)
31	2,500 Max	Student houses	4	Fairbanks, Alaska, USA	Kotol (2014)
32	CO exceeded Mongolian Standard. CO_2 not measured .	Households	58	Mongolia	Cowlin et al. (2006)
33	4,752	Aircraft Cabins	770	U.S. Domestic and International	COT (2022)
34	11,300	Submarine Naval Vessels	10	Global	Hagar (2003)
35	8,000	International Space Station	1	Global	Moser (2023)
SUMMARY	**2,000-5,000 Common**	**—**	**80,302**	**25 Countries**	—

In all indoor air-quality case studies considered in this review, CO_2 concentration is not a problem. In fact, other studies have also illustrated with empirical data that there is no climate crisis (Shanmugam, 2024a) (Fig. 45).

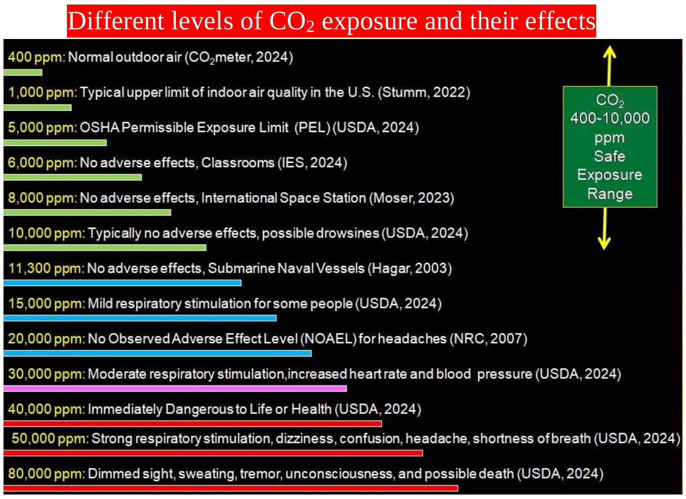


Fig 44. Different levels of CO_2 exposure and their effects
Data compiled by G. Shanmugam

Fig 45. Conclusions Source: *G. Shanmugam (2024b* *Image Credit: NASA*

Finally, the developing countries should be allowed freely to flourish by using cheap fossil fuels without the "Climate Scam" exerted by the hegemonic western countries (Fig. 46).

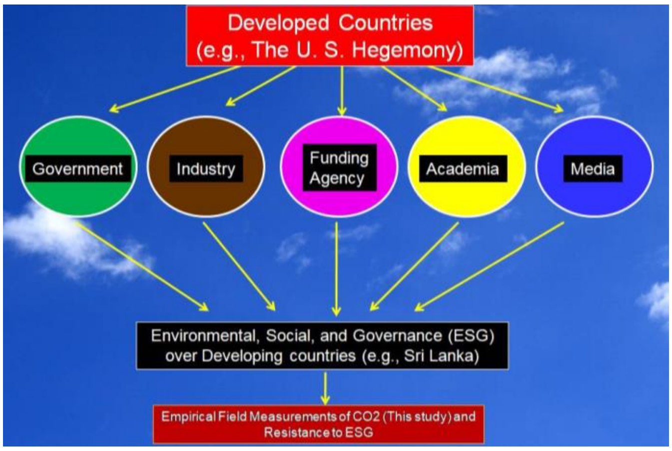


Fig 45. Implications of this study for ESG and Developing countries

Table 13. Problems associated with CO_2 and Temperature concerning Climate Change.

Serial Number	Problem	Detail	Reference
1	Conceptual	Absence of extreme high Temperatures for Early Paleozoic (Fig. 8B)	Scotese et al. (2021)
2	Conceptual	Absence of correlation between Temperature and CO_2 during the Mesozoic era (Fig. 13C)	Judd et al. (2024)
3	Conceptual	Absence of correlation between Temperature an CO_2 during the Phanerozoic (Fig. 12)	Berner (1991, 2004); Epstein (2022)
4	Conceptual and Empirical	Contradiction between PanDA model and the Keeling Curve on CO_2 trends (Fig. 13)	Judd et al. (2024)
5	Conceptual	Exaggerated Temperature Prediction (Climate models) vs. Actual Field Observation (Fig. 10)	Christy (2022)
6	Conceptual	Use of Temperature anomaly, not absolute Temperatures in Climate models (Fig. 11)	IPCC AR6 (2021)
7	Conceptual	Use of baseline in Climate models (Fig. 11)	IPCC AR6 (2021)
8	Conceptual	Use of large uncertainty range in Climate models (Fig. 11)	IPCC AR6 (2021)
9	Empirical	Tsunamis are oceanographic phenomena, not anthropogenic (Fig. 7)	Shanmugam (2006, 2008, 2012)
10	Empirical and meteorological	Cyclones are meteorological phenomena, not anthropogenic (Figs. 4, 5, 6, and 7)	Shanmugam (2008)
11	Empirical	Field measurements of CO_2 defy conventional model of 1,000 ppm upper limit (Fig. 44)	This study
12	Empirical	There is no Climate Crisis (Figs. 42 and 45)	Shanmugam (2024b)
13	Empirical, and political	Field measurements of CO_2 undermine the power of hegemonic western countries over developing countries (Fig. 46)	This study
14	Physiological	Breathing and CO_2 (Fig. 43)	Dezube (2024)
15	Empirical	Wind and solar energy options are unreliable and expensive	Epstein (2022)
16	Empirical, and political	Problems with EV	Robson (2024)
17	Political	Destruction of Nord Stream pipeline in the Baltic Sea	Putin (2024)
18	Hypocritical	Global Elites arrived at Davos in Switzerland (January, 2023) to attend the World Economic Forum In Private Jets, by emitting enormous amounts of CO_2 from burning Jet fuels, to discuss Climate Change.	Shanmugam (2024b)
19	Analytical	Unsettled: What Climate Science Tells Us, What It Doesn't, and Why It Matters	Koonin (2021)
20	Analytical	Climate Uncertainty and Risk: Rethinking Our Response	Curry (2023)
21	Physical	Dependence of Earth's Thermal Radiation on Five Most Abundant Greenhouse Gases	Van Wijngaarden, and Happer (2020)
22	Analytical	Bridging the Gap Between Data and Climate Policy.	Lindzen (2023)
23	Analytical	Is Climate Change Fake?	Moore (2021)
24	Analytical	Cool It: The Skeptical Environmentalist's Guide to Global Warming	Lomborg (2007)
25	Analytical	Freeman Dyson on Global Warming 1of 2 Bogus Climate Models.	Dyson (2007)
26	Political	Net Zero emissions	Fankhauser et al. (2022)
27	Analytical	200 Years of Fossil Fuels and Climate Change (1900-2100)	Shanmugam (2023)
28	Analytical	). Fossil fuels, climate change, and the vital role of CO_2 plays in thriving people and plants on planet Earth	Shanmugam (2024b)
29	Analytical	The "Climate: The Movie (The Cold Truth)"	Durkin and Nelson (2024)
30	Analytical	"CO_2 , The Gas of Life"	Happer (2023)
31	Analytical	Climate Change Reconsidered: The Report of the 1368 Nongovernmental International Panel on Climate Change (NIPCC)	Singer and Ids (2009)
32	Empirical	Is the US surface temperature record reliable?	Watts (2009)
33	Analytical	Reevaluating the role of solar variability on Northern Hemisphere temperature trends since the 19th century	Soon (2015)
34	Empirical	Declining tropical cyclone frequency under global warming	Chand et al. (2022)
35	Analytical	The NZE tamasha and the CoP	Chandrasekharam (2021)

Despite the vast number of contributions on Climate Change, critical problems are yet to be solved (Table 13).

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My research interests cover not only Climate Change but also other domains, such as Landslides, Submarine fans, Seismites, Hyperpycnites, among others (Shanmugam, 2024b). This article is an expanded version of the manuscript entitled "Elon Musk's cautionary claim "When Atmospheric CO_2 concentration exceeds 1,000 ppm limit, it would cause headaches and nausea": All the 76,874 empirical data points of CO_2 from classrooms (>6,000 ppm), conference rooms, and aircraft cabins, assuage such a claim." My sincere thanks to Dr. S. Asokan (Ph.D., University of Cambridge, UK) for his insightful review. I thank William Happer (Cyrus Fogg Bracket Professor of Physics, Emeritus, Princeton University, and a Co-Founder of **CO_2** Coalition), for providing helpful comments on CO_2 and human physiology. I also thank Angela Wheeler, Vice President Marketing and Multimedia, The CO_2 Coalition, for providing images of **CO_2** meters used in this article (Fig. 36). As always, I am grateful to my wife, Jean Shanmugam, for her general comments.

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Aviation Safety Authority)

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BS-EN4618 on Aerospace series

CBC (The Canadian Broadcasting Corporation) News

Chinese Civil. Aviation Regulations (CCAR)

CO_2 Coalition

CO_2meter

Committee on the Toxicity (COT)

Donald Trump

European Aviation Safety Authority (EASA)

EH40/2005 Workplace exposure limits

Elon Musk

FAR (Federal Aviation Regulations)

Florida Homeschool Convention

Gaylord Palms Resort & Convention Center, Kissimmee, Florida

George devries Klein

Ghulam Bhat

Greg Wrightstone

Homeschool Iowa Convention

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International Monetary Fund (IMF)

Jean Shanmugam

Joint Airworthiness (JAR)

MedlinePlus

Merck Manual

Minnesota Department of Health (MINDOH)

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National Institute of Health (NIH)

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