Requirements for Building Thermal Conditions and Indoor Air Quality under Emergency Operations in Cold Climates.

Alexander Zhivov, Ph.D., M.B.A., FASHRAE, ISIAQ
Senior Research Engineer, U.S. Army Engineer Research and Development Center (ERDC)
Champaign, IL 6122, U.S.A.
Corresponding email: Alexander.M.Zhivov@usace.army.mil

ABSTRACT

Requirements for thermal environmental conditions (temperature, relative humidity) and indoor environmental quality (e.g., carbon dioxide [CO_2] concentration, particulate matter [PM] concentration) are set to achieve the following purposes:

- To perform required activities in a building in a safe and efficient manner
- To support processes housed in the building, and
- To provide conditions required for the long-term integrity of the building and building materials.

Typically, buildings are designed to meet these requirements, which are specified by national codes (e.g., ASHRAE Standard 55, ASHRAE Standard 62) under **normal (blue skies) operating conditions**. Buildings with specialized processes (e.g., spaces with information technology [IT] and communications equipment, critical hospital areas, painting facilities, printing facilities, etc.) may have broader or narrower air temperature and relative humidity ranges than areas designed primarily for human comfort. Under normal operation conditions, environmental requirements based on sustainability of building envelope assemblies and furnishings are not a limiting factor given that the building envelope air barrier and vapor protection are designed to avoid mold growth and water accumulation within the building assembly (for cold and arctic climate requirements for the building envelope, see (Axelarris et al. 2021).

During an emergency (black skies) situation, requirements of thermal parameters for different categories of buildings or even parts of buildings may change. When the operation of normal heating, cooling, and humidity control systems becomes limited or unavailable, mission-critical areas can be conditioned to the level of thermal parameters required to support the agility of personnel who perform mission-critical operations, but not to the level of their optimal comfort conditions. Beyond these threshold (habitable) levels, effective execution of critical missions is not possible, and mission operators must be moved to a different location. Although the threshold limits of thermal parameters in a black skies' situation may occupy a broader range than those required for thermal comfort in blue skies operating conditions, they should still not exceed levels of heat and cold stress thresholds. In a black skies' situation, facilities that house activities with special or more stringent process requirements (e.g., IT and communication equipment, critical hospital spaces, etc.) should be prioritized to maintain conditions that do not exceed those critical thresholds.

In a black skies' situation, building spaces surrounding mission-critical areas may use broader ranges of air temperatures and humidity levels, but those levels must still be limited to prevent excessive thermal losses/gains and moisture transfer through walls and apertures not designed with thermal, air, or vapor barriers. Under such conditions noncritical standalone buildings can be hibernated, but necessary measures should be taken, and when possible, a

sufficient thermal environment should be maintained to prevent significant damage to these buildings so they can be returned back to their normal operation. The *Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates* (Zhivov 2021) provides detailed information on thermal requirements for blue and black skies operations.

In cold and arctic climates, building envelope assemblies are not a limiting factor when considering how indoor climate must be maintained during short- or long-term outages of indoor climate control unless water piping cannot be drained or otherwise protected against freezing damage.

Ventilation. Recent research (Wargocki et al. 2000) has shown that adequate ventilation in a building increases productivity and reduces sick leave. The amount of ventilation air that should be supplied to the building is regulated by national and international codes, e.g., by ASHRAE Standard 62. In cold climates, it requires more energy to heat the outside air brought into the building to the room air temperature than is required to heat the building. During emergency situations when there is a shortage of available energy/fuel, it may be safe to reduce outdoor air rates and to filter the return air, to maintain the indoor air quality at habitable conditions that are sufficient to maintain occupants' alertness at a level required for mission fulfillment.

The closest situation parallel to the emergency operation in buildings are those of NASA spacecrafts and Navy submarines. In 2004, the U.S. National Research Council (NRC) proposed Continuous Exposure Guidelines (CEGLs) and Emergency Exposure Guidelines (EEGLs) for the U.S. Navy. Similarly, in 2008 the NASA Toxicology Group, in cooperation with another subcommittee of the NRC, revised Spacecraft Maximum Allowable Concentrations (SMACs) for a 1000-day exposure limit [John James et al. 2009].

Before 1968, U.S. submarines were allowed to operate at CO_2 levels in the range of 0.8% to 1.2% (8000 – 12000 ppm), levels that were later associated with an increased risk of respiratory diseases and ureteral calculi. After 1968, improved scrubbers were able to maintain CO_2 levels at 0.5% (5000 ppm), which resulted in an "abrupt" decline in respiratory illness and the incidence of ureteral calculi. In 2007 a subcommittee of the NRC Committee on Toxicology, based on scanty evidence, recommended a continuous exposure guidance level for a 90-day patrol of 8,000 ppm (6.1 mmHg); however, to our knowledge the U.S. Navy did not adopt this value for operations. In 2003 the Institute of Naval Medicine of the UK recommended a level of 0.7% (7000 ppm 5.3 mmHg) as a health-based ceiling limit, not to be exceeded during a 90-day patrol.

These data show that the CO_2 concentration level allowed by NASA and the Navy is 5 times higher than the level adopted by ASHRAE for buildings. This indicates that the outside airflow rate can be significantly reduced in emergency situations. The outdoor airflow rate can be further reduced by operation the heating, ventilating, and air-conditioning (HVAC) system in recirculation mode when gas air scrubbers are installed along with MERV 14 particle filters

Relative humidity. Cold outside air holds little moisture, even though its relative humidity in winter may be as high as 80 or 90%. When cold outside air is brought inside the building and is heated to room temperature, e.g., 70 °F (21 °C), the relative humidity of the air inside the building becomes only between 5 and 15%. ASHRAE Standard 55 "Thermal Environmental Conditions for Human Occupancy" establishes a range of temperatures and humidity levels that are considered comfortable by 80% or more of the test subjects. The Standard requires that systems designed to control humidity must be able to maintain a dewpoint temperature of 62.2°F (16.8°C). ASHRAE Standard 55 does not specify a minimum humidity level. However, relative humidity affects non-thermal comfort factors, e.g., dryness of the skin and eyes and dehydrated mucous membranes in the nose and throat which irritates these membranes and leaves them more vulnerable to infections from colds and flu (Health Canada). Sterling et al. (1985) cites multiple epidemiological studies that show a statistically significant reduction in respiratory infections and absenteeism in occupants of buildings with mid-range humidity levels compared to occupants of buildings with low humidity level. More recent studies (Guarnieri et al. 2023) show that relative humidity below and above the optimal range impacts the immune system, facilitates infectious transmission, and exacerbates respiratory diseases. Extremes of humidity are most detrimental to human comfort, productivity, and health. Sterling et al. (1985) showed that a relative humidity range between 30 and 60% (at normal room temperatures) provides the best conditions for human occupancy.

While most thermal comfort recommendations for relative humidity in commercial and residential buildings specify an relative humidity range between 40 and 60%, some experts (e.g., Joseph Lstiburek [2002] and Health Canada) recommend 25-30% as a lower limit for relative humidity in cold and very cold climates. They also argue that maintaining relative humidities in the range of 25 to 60% between winter and summer eliminates the risk of humidity-related damage to wood floors and wood furniture.

In many countries located in cold climates, buildings are not humidified, typically resulting in low relative humidity inside buildings. In buildings without air humidification or appropriate measures applied to the building envelope, human activities (e.g., breathing, cooking, showering without proper ventilation) allow the indoor air moisture to condense on cold surfaces like windows or inside walls and slabs, which often causes mold problems. Simply increasing relative humidity inside the building will intensify this problem if special measures are not taken. Such measures include reduction of air leakage through the building envelope, installation of a continuous internal vapor barrier, reduction of thermal bridges between building envelope elements, and installation of continuous external insulation.

This presentation is a proposed input into Guidelines to be developed under the ongoing International Energy Agency Energy in Buildings and Communities Program Annex 93 “Energy Resilience of the Buildings in Remote Cold Regions” and is intended to initiate a discussion among subject matter experts during the “Healthy Buildings 2025 - Europe” conference.

REFERENCES

ASHRAE. 2023. ANSI/ASHRAE Standard 55. *Thermal Environmental Conditions for Human Occupancy*. Atlanta, GA: ASHRAE.

ASHRAE. 2022. ANSI/ASHRAE Standard 62.1-2022. Ventilation and Acceptable Indoor Air Quality. Atlanta, GA: ASHRAE.

Axelarris, Lyle, Aaron Cooke, Craig Fredeen, Robbin Garber-Slaght, Emmett Leffel, Lorne Ricketts, William Rose, John P. Zarling, and Alexander Zhivov. 2021. *Building Envelope Characteristics in Cold Climates*. ASHRAE Annual Conference, June 28-30, 2021.

D. Law J., S. Watkins, W.S. Alexander, J. Law. 2010. *In-Flight Carbon Dioxide Exposures and Related Symptoms: Associations, Susceptibility and Operational Implications*. NASA Tech. Rep. (2010), pp. 1-21,

Georgescu, Matei Razvan, Amina Meslem, Ilinca Nastase, Florin Bode, J.T. James, V.E. Meyers, W. Sipes, R.R. Scully, and C.M. Matty. "Personalized Ventilation Solutions for Reducing CO_2 Levels in the Crew Quarters of the International Space Station." 2021. *Building and Environment*. Vol. 204, 15 October 2021.

Loncar, M. 1997. *Air Sampling Onboard the Submarine Gotland* [in Swedish]. The Swedish Defence Research Agency. Report No. FOA-R—97-00403-720—SE.

Wargocki, P., D.P. Wyon, J. Sundell, et al. 2000. "The Effects of Outdoor Air Supply Rate in an Office on Perceived Air Quality, Sick Building Syndrome (SBS) Symptoms and Productivity." *Indoor Air.* 10:222-236

Zhivov, Alexander. 2021. *Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates*. Atlanta, GA: ASHRAE.

John T. James, Ariel Macatangay. 2009. Carbon Dioxide – Our Common "Enemy". NASA/Johnson Space Center Houston, Texas 77062. SAMAP Submarine Air Monitoring Air Purification Conference. San Diego, CA. ASHRAE. 2017. ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy.

Atlanta, GA: ASHRAE.

ASHRAE 62.1 (2007) Ventilation for acceptable indoor air quality, Atlanta, GA, American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Sterling, E.M., A. Arundel, and T.D. Sterling. 1985. Criteria for human exposure to humidity in occupied buildings. ASHRAE Transactions 91(1B):611-622.

ASHRAE. 2016. Handbook—HVAC Systems and Equipment. Chapter 22 – Humidifiers.

Joseph Lstiburek. 2002. RR-0203: Relative Humidity. Building Science.com Corporation https://buildingscience.com/documents/reports/rr-0203-relative-humidity/view.

Health Canada. RELATIVE HUMIDITY INDOORS: FACTSHEET. https://safe.menlosecurity.com/doc/docview/viewer/docNFB392F3D824A6ce65942f7f55ede12e9805bdd6e8487f8732b6ecf49afc88fe72e8fd124ad2e

Gabriella Guarnieri, Bianca Olivieri, Gianenrico Senna and Andrea Vianello. 2023. Relative Humidity and Its Impact on the Immune System and Infections. International Journal of Molecular Sciences. 2023, 24(11), 9456; https://doi.org/10.3390/ijms24119456.