Using ASHRAE Standard 55 Adaptive Comfort Method for Practical Applications

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Abstract. The question of comfort under a natural conditioning scheme when governed by ASHRAE Standard 55, which describes the use of the adaptive comfort standard, including the elevated speed option, and compares this model to other comfort indices. The analysis requires a combined dynamic heat transfer and bulk airflow analysis method that delivers simultaneous output of expected indoor temperatures and indoor ventilation rates.

To determine if the space is compliant, the designer must demonstrate that the indoor operative temperature conditions stay within the prescribed range during occupied hours. Typically, dynamic thermal simulation software capable of modelling natural ventilation schemes is used to simulate the cooling effects of the natural ventilation airflows and the radiant impacts of the room surface temperatures.

This paper shows a Standard 55 compliance analysis and how the results are presented in an understandable manner.

Keywords. Natural Ventilation, Occupant Comfort, Ventilation
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1. Introduction

In 2021 ASHRAE published the Design Guide for Natural Ventilation 2021b) which provided information and clarification on designing and operating Natural Ventilation systems for buildings. The acceptable comfort zone is prescribed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 55, Thermal Environmental Conditions for Human Occupancy (ASHRAE 2020b). Comfort is defined as the conditions under which eighty percent or more of the building occupants will find an area thermally acceptable in still air and shade conditions.

The ASHRAE Design Guide for Natural Ventilation is meant to assist owners, architects, engineers, facilities personnel, and building design professionals to explore the feasibility of natural ventilation for their project during the early phases of design. Many in the industry can see the appeal of natural ventilation for environmental stewardship concerns, however, there appears to exist some reticence in application and confusion over the interpretation of the current standards. This may be since there is not an ASHRAE-endorsed methodology that establishes a rigorous analytical path, and the inputs and equations necessary to complete even a feasibility analysis are in disparate standards and guidance documents. This guide attempts to consolidate and organize the key information necessary to perform a feasibility analysis by excerpting content when approved by the originating authors or by reference to information in the public domain.

The progress of a design team from conception to fruition for a natural ventilation scheme is one of collaborative review of critical analysis results. Natural ventilation is reliant on a variable source of air movement and cooling capacity. Owners and tenants must be aware not only of the average expected results, but also the frequency of the extreme conditions for the current day and in a future climate-changed condition. Natural ventilation as a comfort-conditioning method will always be compared to HVAC schemes that are easier to control from a predictability perspective. Thus, the social acceptability of a natural ventilation scheme is as important to its success as its technical feasibility. This guide is intended to normalize expectations regarding the minimum steps and analyses necessary to facilitate key decision-making conversations with the stakeholders.

When natural ventilation and natural conditioning are pursued, it is important to ensure that the minimum outside air requirements are achievable under all conditions, inclusive of those hours when the back-up mechanical ventilation system is operational. This is a requirement of ASHRAE Standard 62.1 (ASHRAE 2020a) clause 6.1.3 and Section 6.4. Complying with the natural ventilation requirements does not imply any likelihood of compliance with the comfort standard. At high outdoor air temperatures, the amount of air necessary to provide a heat-absorption function is far higher than the amount of air required to meet the minimum ventilation requirements. The design team should never assume that complying with ASHRAE 62.1 (ASHRAE 2016b) will result in a comfortable space.

2. NATURAL VENTILATION STRATEGY

The I City Project is in Moscow, Russia, and lies just to the northeast of Moscow City, the new high-rise district in Moscow. The Design Brief provided by the MR Group requests a Class A office development with a total above grade area of 175,100m2 (excluding Podium Parking and Mechanical). The project is to have 2 towers: Tower 1 has a height limit of 126.9 m, and Tower 2 is to be designed to fulfil the outstanding buildable area with a desired height in the range of 236 m. The location of the two towers was generally established by an Insolation Study which positioned the tall tower at the northern end of the site and the lower tower at the site's southern half.

The two towers are naturally ventilated through the façade. The typical façade module is 2.8 meters wide and consists of a 2100 mm fixed glass panel and a 700 mm hinged window panel. The fixed glass panel is double-glazed and features high-performance and heat-reflecting properties. The narrow operable window features an exterior perforated, stainless-steel panel that provides protection from the sun, wind, and rain. This panel also contains soundproofing elements to minimize the noise from the surrounding highway and ring road. The interior side of the hinged window consists of a translucent printed screen pattern applied to heat-insulating double glazing.

The BMS controls both the natural ventilation openings and the mechanical conditioning system. Based upon outdoor conditions the BMS decides what conditioning system to operate, the mechanical system of the natural ventilation system.

The control strategy aims at enhancing individual thermal comfort of tenants in the towers. As previously mentioned, the narrow-hinged windows of the façade can be opened or closed individually to allow occupants direct control over their environment. The operation of these windows can also be controlled automatically by the central BMS to offer night-time ventilation during the hot season.

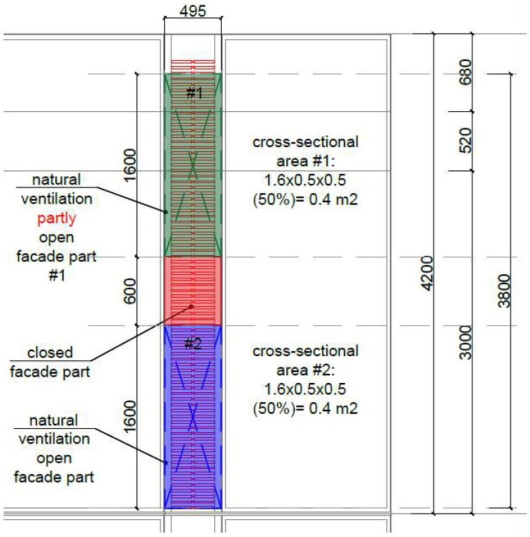

Figure 1 shows the Natural Ventilation openings integrated in the facade

The equation for estimating airflow rate, Q, through two openings of areas A_1 and A_2 on one wall as given in CIBSE Guide A (2015), where h is the total height of the single opening and $A=2A_0$. In the last step $2\sqrt{2}$ has been approximated by 3. This is the equation given in for airflow rate due to temperature difference only for a single opening. So, to simulate a single opening, we equate the single and two opening equations which gives

$h_a = 4/9 * h$

Where: h_a is the height between the two openings

i.e., A single opening may be represented by two equal size openings of half the area of the single opening with a distance between their centers of 4/9 of the total height of the single opening. To represent a single 0.7 m wide by 3.9 m high opening we have modeled a low-level opening is 0.7 m wide by 1.6m high, covered with a 50% perforated stainless-steel plate. The high-level opening is 0.7 m wide by 1.6m high, covered with a 50% perforated stainless-steel plate. The distance between the two openings is 1.73 m.

In total there are 60 openings around the perimeter of a typical floor.

The side-hinged windows can be electronically opened inward on each floor to provide individually controlled natural ventilation. When the windows are open, fresh air is drawn into the offices through the fixed perforated panels. A control panel in each office can be used to individually control lighting, ventilation, temperature, and the operability of the windows and blinds. At night, the building management system (BMS) can electronically open the hinged windows to provide night cooling and modulate temperature fluctuations within the building.

3. ASHRAE STANDARD 55 Adaptive Comfort Compliance

It is the design team's responsibility to ensure that they are using the correct based on the known and predicted conditions of the space and the representative occupants within the space.

There will be times of the year when a natural conditioning system could operate under outside air conditions that allow the space to be compliant with the simplified Graphical Method or the computer based prescriptive Analytical Method. Under warm conditions, however, most naturally conditioned spaces rely on the elevated air speed of both the Elevated Air Speed Method and the Adaptive Method, along with possibly the extended allowable comfort range under the Adaptive Method. It is important to note that the methods are means of showing compliance with comfort under a very narrowly defined set of parameters. Each path has constraints on applicability for each of the available comfort paths in ASHRAE Standard 55 (ASHRAE 2017a), primarily surrounding variables such as clo, met, and air speed.

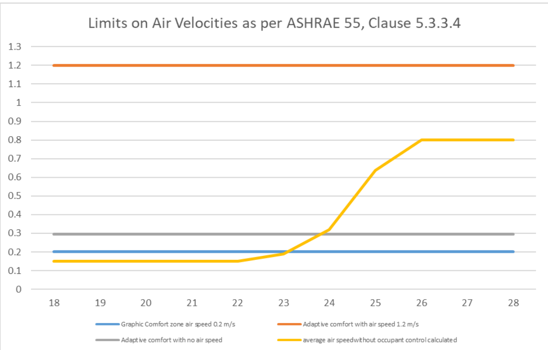

Figure 2 shows a comparison of maximum air velocities from ASHRAE Standard 55 (ASHRAE 2020)

Under the Elevated Air Speed Comfort Zone method, the following limits on air velocity apply as extracted and reordered from ASHRAE Standard 55 (2020b) clause 5.3.3.4:

- Air speed should be greater than 0.2 m/s.
- For operative temperatures (t_o) below 23.0°C.
- For operative temperatures (t_o) between 22.5°C and 25.5°C, the upper limit to average air speed (v_a) it is acceptable to approximate the curve in I-P and SI units by the following equation:
- v_a = 50.49 – 4.4047 to + 0.096425(to)2 (m/s, °C)
- For operative temperatures (t_o) above 25.5°C, the upper limit to average air speed (v_a) should be 0.8 m/s.

This upper limit for the Elevated Speed method is appropriate for most offices and commercial spaces, an air speed of 0.8 m/sec because it corresponds to the point at which loose paper, hair and other light objects may be blown about. It should be noted that when the occupants have control, there is no upper limit so long as one of the following control mechanisms is available (as excerpted from ASHRAE 2021a p.12):

a) "One means of control exists for every six occupants or fewer.

b) One means of control exists for every 84 m2 or less.

c) In multioccupant spaces where groups gather for shared activities, such as classrooms and conference rooms, at least one control shall be provided for each space, regardless of size. Multioccupant spaces that are subdivided by movable walls shall have one control for each space sub-division."

In the case of natural conditioning, the air velocity can rise to 1.2 m/s as per Table 5.4.2.4 in ASHRAE Standard 55 (ASHRAE 2020b). This table is replicated in the excerpts provided in Appendix A6.1 for ease of reference. The Adaptive Method, or Occupant Controlled Naturally Conditioned Spaces Method, also requires that occupants have control over the window openings. Although there are no regulations on control mechanism layout or rules on sharing cohort size for this path, the rules of the Elevated Air Speed Method may serve as a useful starting point, with expansion to more openings or more distribution of openings depending on the results of the dynamic thermal analysis and bulk air flow modelling exercise.

4. LIMITATIONS ON THE USE OF THE ADAPTIVE COMFORT METHOD

Appendix J of ASHRAE Standard 55 (ASHRAE 2020b) advises:

"For the purposes of ASHRAE Standard 55 Section 5.4, occupant-controlled naturally conditioned spaces are those spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of openings in the building envelope. Field experiments have shown that occupants' thermal responses in such spaces depend in part on the outdoor climate and may differ from thermal responses in buildings with centralized HVAC systems primarily because of the different thermal experiences, changes in clothing, availability of control, and shifts in occupant expectations. This optional method is intended for such spaces.

"The space in question must be equipped with operable openings to the outdoors and can be readily opened and adjusted by the occupants of the space."

5. CONSTRAINTS ON OUTDOOR AIR TEMPERATURES

Clause 5.4.1 states "The prevailing mean outdoor temperature is greater than 10°C and less than 33.5°C." This criterion establishes the allowable outdoor air temperatures that are likely to ensure acceptable indoor temperatures with occupant control over windows and openings. When temperatures expand outside this range on the low

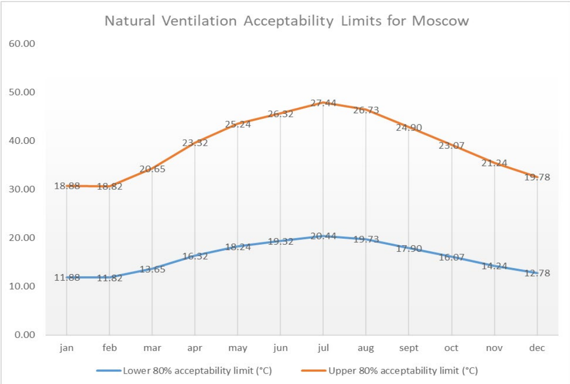

Figure 3 shows the monthly 80% upper and lower temperature limits for Natural Ventilation compliance for Moscow using the Flat Mean approach.

6. APPLYING THE ADAPTIVE COMFORT ZONE METHOD

The Standard 55 User's Manual (ASHRAE 2013) provides a worked example of the application of the Adaptive Comfort Method. This is replicated in Appendix A6.5 for ease of reference. It should be noted that this example used a Flat mean approach for the analysis proposed, which was applicable in older versions of the Standard. The new approach using a prevailing running mean is discussed in a section below.

The procedural steps followed in that example include:

1. Evaluate the applicability of the design against the requirement for operable elements and the four constraints noted above.

2. Calculate the Comfort Zone Thresholds for Compliance

3. Determine Comfort using a dynamic thermal simulation

4. Resolve Comfort Conditions if space is found to be non-compliant.

end, heating systems are likely to exceed allowable heat outputs as regulated by the applicable energy code and thus, occupants will feel overcooled. When temperatures extend outside the range on the upper end, the outdoor air temperature is essentially above the 33°C mean skin temperature of a resting human in comfortable surroundings (as per equation 85 in Chapter 9 of 2021 ASHRAE Handbook Fundamentals (ASHRAE 2021), and thus the outdoor air loses its ability to cool a body during the time when air temperature is this high. The actual outdoor air temperatures are likely to fail in compliance for indoor conditions at temperatures lower than the upper limit on prevailing mean as noted in this limitation.

7. ACCEPTABILITY LIMITS

The acceptability limits for this comfort zone method originated as a graphical representation of empirical data (noted as Figure 5.4.2 in the standard), but the information has since been resolved into the equations noted in Section 5.4.2.2:

- Upper 80% acceptability limit (°C) = 0.31 tpma(out) + 21.3

- Lower 80% acceptability limit (°C) = 0.31 tpma(out) + 14.3

As noted in the Standard 55 User's Manual (ASHRAE 2013):

"It is important to note that only the 80% acceptability limit is used when a user is to show compliance with the Adaptive Method. The 90% acceptability limits are for illustrative purposes only but can be used on a voluntary basis if a designer or building owner chooses to provide higher level of acceptability. For any jurisdictions requiring compliance with Standard 55 though, compliance is only required at the 80% acceptability limits."

8. METHOD

When the design team must demonstrate the compliance of a proposed scheme with the Standard's requirements, it is typical that a bulk airflow and dynamic thermal simulation model will be required at a minimum to understand the complexities of how a space performs under natural ventilation and natural conditioning.

Bulk airflow analytical modelling involves solving simple (linear) equations by hand (or spread sheet) to give more detail about aspects of the ventilation flow, e.g., stack pressure at a certain height or likely stratification height. This type of modelling alone will address natural ventilation flows under limited simple conditions as noted in Chapter 5 but is not sufficiently sophisticated to address natural ventilation.

9. POST-PROCESSING OF RESULTS FROM SIMULATION MODELING

Space dry bulb and operative temperatures as well as air flow through the space are calculated by a simulation program (or manually). The temperatures and air flow are calculated for each hour of the month. The results from a bulk air analysis are fed into a spreadsheet for post-processing.

The results data is sorted into workdays and hours of occupancy and then evaluated for compliance with the comfort thresholds.

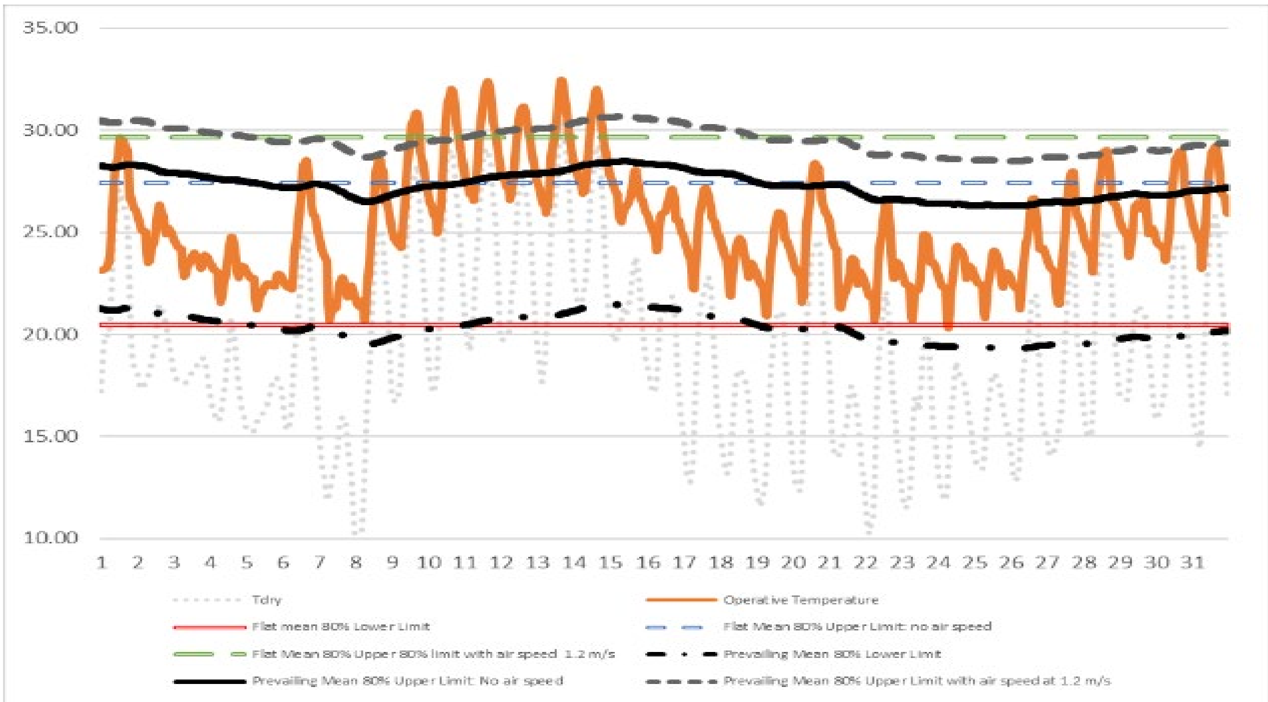

Figure 4 ASHRAE 55 Adaptive Comfort Comparison of Indoor Operative Temperature to Flat Mean and Prevailing Mean Criteria: Buoyancy driven for Moscow in the Month of July, alpha = 0.7 for prevailing mean

Adaptive Comfort Compliance Status July	
Flat mean TOO COLD	0
Flat mean No Speed GOOD	129
Flat Mean with Speed GOOD	177
Flat Mean TOO HOT	21
Prevailing Mean TOO COLD	0
Prevailing Mean No Speed GOOD	127
Prevailing Mean with Speed GOOD	177
Prevailing Mean TOO HOT	21

For the analyses performed for this paper, the assumed external dry bulb used to seed the start of the prevailing mean calculation used the first 24 hours of the outside air-dry bulb.

10. “FLAT” MEAN VERSUS PREVAILING MEAN TO SET TEMPERATURE LIMITS

Section 5.4.2.1.3 of ASHRAE Standard 55 (ASHRAE 2020b) requires that the compliance analysis use a prevailing mean daily temperature within the acceptability equations in 5.4.2.2 as noted above. According to ASHRAE Standard 55 (ASHRAE 2020b) Appendix J, this requirement “represents the broader external climatic environment to which building occupants have become physiologically, behaviourally, and psychologically adapted.”

When a design team is testing the quick feasibility of a scheme, it may be easier to obtain and calculate the Flat mean temperatures to see if the scheme is in the realm of gross compliance.

For Moscow, the Flat mean temperature is calculated to set the full month’s 80% acceptability limits as noted in the figure below.

Taking the data, the results below show the comparison between the Flat mean and Prevailing running mean methods for a month’s worth of data. As noted in the graph below, the prevailing mean fluctuates in response to the outdoor air temperatures, and it runs sometimes lower and sometimes higher than the Flat mean.

11. DEMONSTRATING COMPLIANCE WITH THE ASHRAE STANDARD 55 ADAPTIVE COMFORT METHOD

A further post-processing bins the Flat and Prevailing Mean results to show how many hours in the month meet the comfort standard, with and without elevated air speed, for the model’s current configuration of openings. The primary observation shown in the two figures below is that there is less than a 5% difference in the estimate of the hours falling into the compliance zone, whether without elevated speed or with it. The greatest percent differential is in the TOO HOT category, but as the total number of non-compliant hours is so low, this represents a total of 17 hours difference in the variability of using the Flat mean instead of the Prevailing mean.

There remain several hours in the TOO HOT category, which would fall into the definition of exceedance hours. Per the definitions in Section 3 of ASHRAE Standard 55 (ASHRAE 2020b), these are “the number of occupied hours within a defined time period in which the environmental conditions in an occupied space are outside of the comfort zone.” The designer can either perform iterations to increase opening sizes to comply with the Adaptive Comfort Method for 100% of occupied hours.

Alternatively, one could discuss with the Owner and the Authority having Jurisdiction what the acceptable number of exceedance hours can be. If one looks for parallels with mechanical comfort conditioning systems, ASHRAE Standard 90.1 (ASHRAE 2019) clauses 11.5.2.i and G3.1.2.3 require that unmet load hours not exceed 300 in terms of equipment sizing and performance within the energy model showing compliance for energy efficiency.

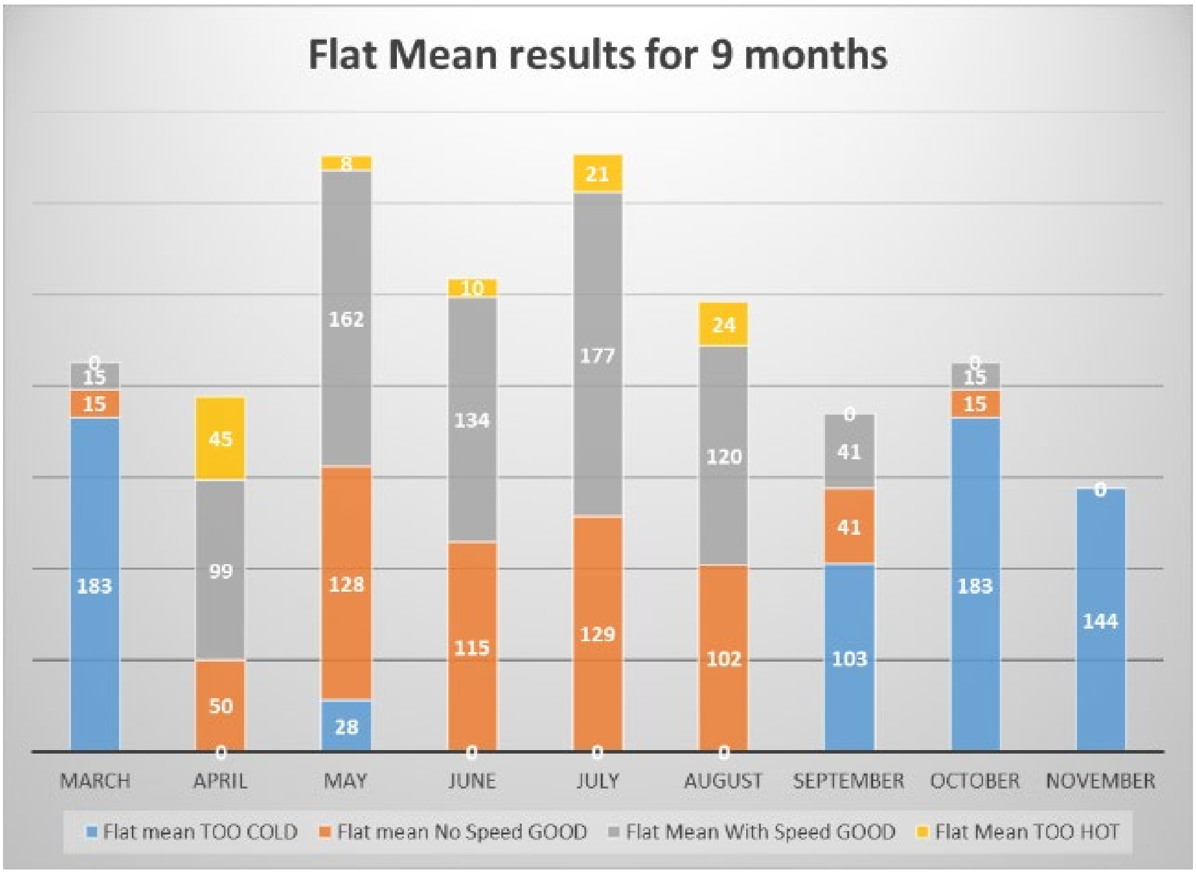

Figure 5 Shows the ASHRAE 55 Flat Mean Natural Conditioning Compliance Hours for a typical floor of the Moscow project due to Buoyancy Driven ventilation for 9 months of the year.

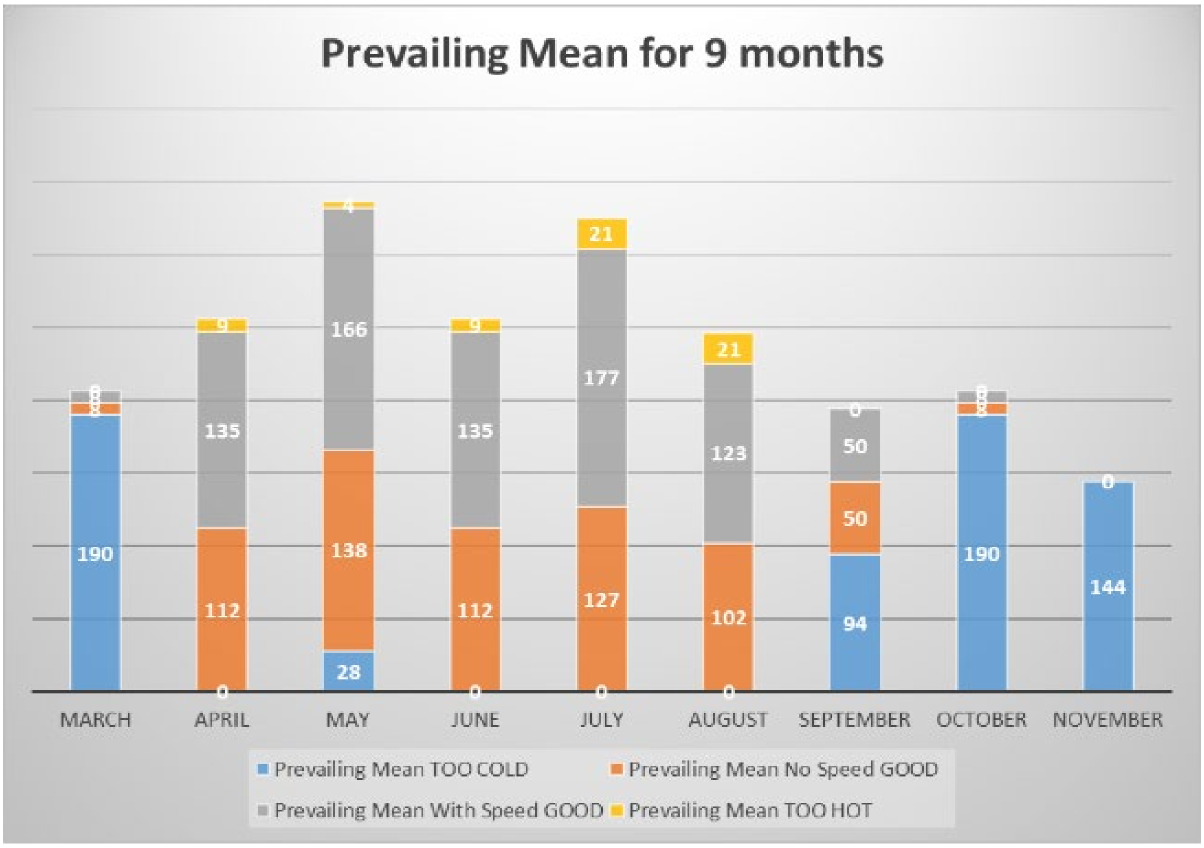

Figure 6 Shows the ASHRAE 55 Prevailing Mean Natural Conditioning Compliance Hours for a typical floor of the Moscow project due to Buoyancy Driven ventilation for 9 months of the year

From Figures 5 and 6 we can see that months March, October and November have most hours which are "too cold" and therefore Natural Ventilation should not be considered during these months as well as December, January, and February. September has more than 100 hours when it is "too cold" and we would not recommend utilizing Natural Ventilation during this month.

From Figure 5 we can see that months March, October and November have most hours which are "too cold" and therefore Natural Ventilation should not be considered during these months as well as December, January, and February. September has more than 90 hours when it is "too cold" and we would not recommend utilizing Natural Ventilation during this month.

12. Conclusions

The adaptive comfort method does provide a clear method of showing compliance for naturally ventilated spaces. However, there is some disparity when using the compliance method from ASHRAE Standard 55 (2020b) as the limits required for compliance are based upon steady state conditions. The results shown in the paper are based upon results from a dynamic simulation program. When using a post processor, the results can be simply shown as good or no good, which greatly assists the design process.

Most compliance hours during warm weather come from the assumption that spaces will have controllable ceiling fans.
This study is unique in that it simulates and reports comfort simultaneously to energy savings for each of the studied climate zones. This direct comparative reporting from simulation models can be applied at the single building level to provide credible trade-off information to help with decision making on the energy versus comfort question after many of the other risks have already been deemed manageable.
The true energy savings from utilizing natural ventilation options are integrated with dynamic simulation programs.

Acknowledgement

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Data Access

The datasets generated during or analysed during the current study are not publicly available because they are owned by the client.

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