Visualization of Passive Performance Parameters Through Time-Based Metrics and Discussion of a Survey for Validation of the Approach

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Abstract

The aim of this paper is to present the visualization process of an approach for analysing robust passive measures through the time-based metrics of thermal autonomy and passive survivability. The objective is to provide a common language and fill the communication gap between architects and engineers through a practical visualization technique, so that architects may maintain better control over their aesthetic and functional design values without compromising performance. For this study, parametric simulations of multi-unit residential buildings are conducted in a given climatic location. The results are discussed using these two metrics through graphical feedback to ensure architectural parameters, such as building form, orientation and fabric, are intelligently selected to improve environmental performance and resilience of buildings. Further, an online survey of design professionals was developed and conducted in order to evaluate the utility and effectiveness of visualizing these time-based metrics to inform the design development process. The paper discusses the results of the survey and attempts to fulfil the comments of participants. The majority of survey participants responded that both thermal autonomy and passive survivability are useful metrics to visualize, with somewhat more preferring passive survivability.

Introduction

It is widely acknowledged that architects and building designers seldom use building performance simulation tools at the early design stage to inform their schematic building designs (Hemsath, 2013). Even though decisions at the early stages of design have the largest impact on energy and cost, current building design practices tend to leave energy reduction strategies to the end of the process when changes can be disruptive to the design process and costly. The central proposition of this paper is that in order for architects to achieve high performance buildings that minimize environmental impacts and lifecycle costs, they must meaningfully engage the integrated design process at the earliest possible stages of design.

This proposition reinforces a need for practical approaches and graphical feedback methods that integrate energy simulation into the early design stage of high performance buildings within architectural practice. Building performance assessment methods require appropriate performance metrics and indicators for specific objectives. A major problem with the current approaches is that most of them request extensive input data and they provide vast quantities of output from building performance simulation (Attia, 2013). For design teams, it is very important and helpful (better design and time wise) to identify the useful information to extract from their analysis output at the very beginning (Ulukavak, 2006) - something which is currently unknown to most architects. In view of this reality, and in recognition of the primacy of early design decisions in the environmental performance of buildings, this paper is focused on the development of practical visualization techniques. It is based on an approach that could enable building simulation tools to be used for simpler evaluation to inform passive systems integration and optimization in early design phases through the time-based metrics of thermal autonomy and passive survivability.

Methodology

The aim of this paper is to demonstrate the visualization techniques for the use of the time-based metrics of thermal autonomy and passive survivability. Thermal autonomy is *a measure of the fraction of time a building can passively maintain comfort conditions without active system energy inputs*. It ensures architectural parameters, such as orientation, form, fabric, glazing, shading, daylighting and natural ventilation are intelligently selected to improve environmental performance. Passive survivability is *a measure of how long inhabitants may comfortably remain in their dwellings during extreme weather events that interrupt their energy supply* (O'Brien, 2016). It ensures buildings are less susceptible to becoming uncomfortable or unliveable in the event of extended power outages during extreme weather periods or building system failure. As part of a larger study (Ozkan, 2016), this paper will demonstrate aspects of the approach through simulations of multi-unit residential buildings and discuss the utility and effectiveness of visualizing these time-based metrics through the results of an online survey. The Toronto, Ontario, Canada climate (ASHRAE Climate Zone 6; warm humid summers, cold winters, and moderatly sunny) will be considered after the physical characteristics of typical multi-unit residential buildings have been specified.

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Simulations

The predominant building type used for the construction of multi-unit residential buildings consists of a reinforced concrete frame where the shear walls are used to separate suites adjoining a double-loaded corridor or central core. The majority of suites have single aspect facades except for corner suites that have exterior walls on two sides, and are typically single storey. The provision of cantilevered balconies is optional and most of the buildings employ window-wall glazing systems with high window-to-wall ratios (>80%). In this study, the average size of a unit is considered as 70 m^2 (756 ft^2) with an aspect ratio of 2:1. Unit heights are assumed to be 2.5 m including thickness of a single floor slab (i.e. half thickness for ceiling and half thickness for floor attributed to internalized units). Floor area of a unit is 64.8 m^2 and gross exterior wall area is 28.5 m^2. Units are located on intermediate floors with no heat transfer across ceiling, floor or adjacent walls because the neighbouring units are assumed to be at a similar temperature and suffer from the same failures, when applicable. The parameters set out in Table 1 were applied to a floor plate depicted in Figure 1.

Table 1: Parameters and corresponding values used to perform energy simulations.

Orientation	South	West	North	East
WWR (%)	40		80	
Wall U-Value (W/m^2.K)	0.247	0.210	0.180	
Glazing U-Value (W/m^2.K)	2.50	1.70	1.00	
Glazing SHGC	0.45	0.35	0.25	

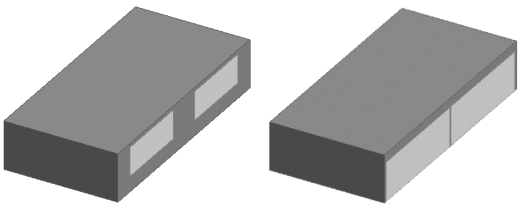

Figure 1. Units used in parametric simulations

The window-to-wall ratios (WWR) were selected such that acceptable daylighting determined the lower limit (40%) which then ranged up to practically an all glazed facade (80%). Exterior wall U-values begin with the minimum effective thermal resistance for opaque wall assemblies prescribed by applicable codes and standards and range up to an upper value after which sharply diminishing returns in energy conservation are observed. Window U-values and solar heat gain coefficients reflect technologies that are currently available, again with the least efficient window assembly being prescribed by applicable codes and standards (all U-values are effective accounting for thermal bridging.). Natural ventilation and infiltration air flow rates are calculated based on opening and crack sizes (medium), buoyancy and wind pressures.

EnergyPlus simulation engine was used to perform 176 parametric simulations through the DesignBuilder interface. For each unit configuration, based on different orientations and window-to-wall ratios, two types of simulations are conducted. In the first set of runs, the systems for HVAC, lighting and equipment are turned off in the model for thermal autonomy analysis. The number of hours above and below comfort levels of 18°C (64.4°F) and 25°C (77°F) are identified based on operative temperatures. The Thermal Autonomy metric is defined as the fraction of time over a year where a unit meets or exceeds that set of acceptability criteria through passive means only (Levitt, 2013). Second, for passive survivability analysis, all active systems are shut off during a period of extreme summer or winter weather. The time between when heating is shut off and when the indoor operative temperature reaches 15°C (59°F) from an original heating setpoint of 21°C (70°F) in winter, and the time until the indoor operative temperature reaches 30°C (86°F) from an original cooling setpoint of 25°C (77°F) in summer are defined as passive survivability metrics of multi-unit residential building units.

The most common comfort metrics (PMV and PPD) in literature derive from Ole Fanger's 1967 comfort model. In the Fanger comfort model, a statistical probability of comfort is correlated to a range of temperatures and humidity for a given air speed, metabolism, and clothing level. But, rather than being used to explore occupant comfort, these metrics are more typically used to define thermostat setpoints in conditioned buildings (Levitt, 2013). On the other hand, occupants in naturally ventilated buildings experience an expanded sense of thermal comfort when they have access to operable windows. For this reason, adaptive comfort model, based on ASHRAE Standard 55, would be considered to determine allowable indoor operative temperature thresholds for assessing only passive measures in naturally ventilated buildings. But, the allowable operative temperature limits may not be extrapolated to the mean monthly outdoor temperatures above 33.5°C (92.3°F) and below 10°C (50°F) in that model. Because the mean monthly outdoor temperature would be less than 10°C (50°F) in Toronto, this comfort model may not be used for winter months in this study. And, no more specific guidance for naturally conditioned spaces is currently available in literature. For this reason, comfort levels of 18°C (64.4°F) and 25°C (77°F) for thermal autonomy analysis are identified based on common sense in this study. Furthermore, for passive survivability analysis, a comprehensive review on the effect of low temperatures on elderly morbidity (Collins 1986) was used as the basis of the indoor operative temperature threshold as 15°C (59°F) for heating period. And, the 30°C (86°F) cooling temperature threshold is consistent with other health standards (e.g., the United Kingdom Health Service (2015) used about 30°C (86°F) as a daytime health warning trigger) (O’Brien, 2016).

It is also important to note that in this study only indoor operative temperature is aimed at providing substantial information about occupant comfort to determine how long a building can be self-sufficient in a year, and enable designers to compare design alternatives in the early stages of design. But, indoor moisture (e.g., RH) will have a significant effect on occupant comfort as well. Future studies and users of this approach may choose to take in to account the humidity criteria, or any other possible comfort criteria, but the current focus of this study is developing the approach for analysing robust passive measures through the time-based metrics of thermal autonomy and passive survivability.

The passive strategies examined for each unit configuration are:

- Base Case: Minimum envelope requirements (minimum U-value of wall (0.278 W/m^2.K) and glazing (2.5 W/m^2.K), and corresponding SHGC (0.45) for glazing).
- Case 1: Minimum U-Value requirements of envelope, and higher SHGC of glazing. (U-value of wall 0.278 W/m^2.K, U-value of glazing 2.5 W/m^2.K and 0.60 SHGC)
- Case 2: Minimum envelope requirements with movable insulation panels operated only winter nights. (Venetian blinds, which have 0.5 W/m^2.K U-value, are used with “0” airflow permeability based on night time outside low air temperature.)
- Case 3: Average envelope properties (average U-value of wall (0.210 W/m^2.K) and glazing (1.7 W/m^2.K), and corresponding SHGC (0.35) for glazing).
- Case 4: High performance envelope properties (upper U-value of wall (0.180 W/m^2.K) and glazing (1 W/m^2.K), and corresponding SHGC (0.25) for glazing).
- Case 5: High performance envelope properties and provision of 2m deep balcony overhang with bridge (balcony as a fixed shading device with thermal bridging).

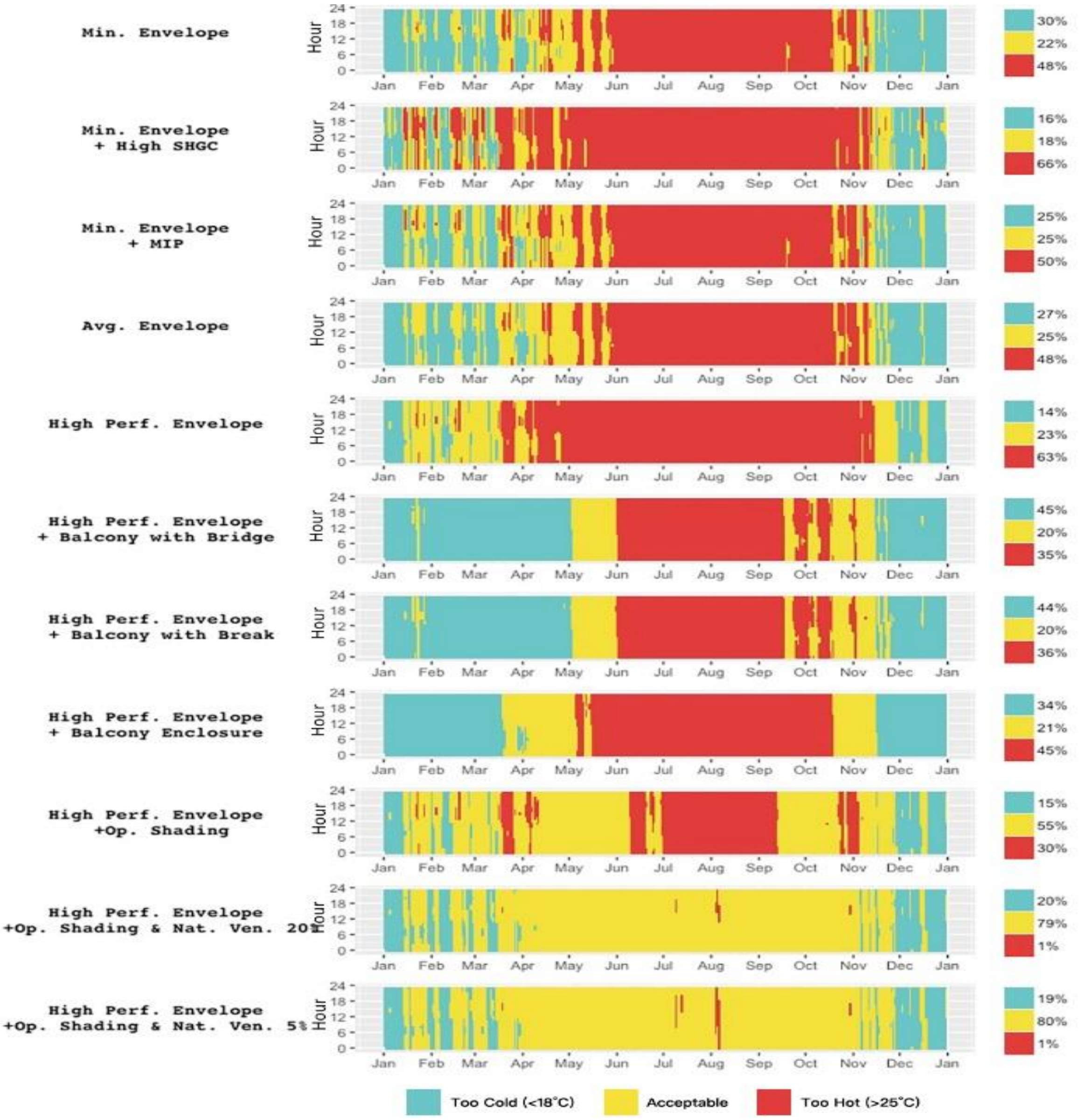

Figure 2. TA in a south facing unit with 80% WWR

- Case 6: High performance envelope properties and provision of 2m deep balcony overhang with break (balcony as a fixed shading device).
- Case 7: High performance envelope properties and provision of 2m deep enclosed balcony (to analyse buffer zone effect).
- Case 8: High performance envelope properties and operable shading operated based on outdoor air temperature and solar on window (vertical blinds with high reflectivity slats in West, horizontal blinds in other orientations).
- Case 9: High performance envelope properties, operable shading and providing natural ventilation from 20% glazing area opening.
- Case 10: High performance envelope properties, operable shading and providing natural ventilation from 5% glazing area opening.

Visualization of Thermal Autonomy and Passive Survivability

Analysis

The parametric set of simulations consist of two unit scenarios, which have 40% or 80% window-to-wall ratio in four orientations. Each scenario starts with minimum envelope requirements as base cases, and then the 10 passive measures are applied to improve the performance of units. In this paper, demonstrative results will be extracted to illustrate visualizing thermal autonomy (TA) and passive survivability (PS) concepts.

In the analysis of thermal autonomy, Figure 2 depicts a south facing unit with 80% WWR. If the unit assumes only the minimum envelope requirements, it is thermally autonomous for 22.3% time of a year, where the average envelope properties increase its performance to 25%. Furthermore, with the high performance envelope properties, the unit suffers from greater overheating and TA decreases to 23.1 %, because the better-insulated envelope trap more heat, but it provides a considerably longer comfortable period when combined with effective passive design strategies such as operable shading and natural ventilation. A conflict was identified between balconies versus no balconies when examining cold weather and hot weather thermal autonomy. Balconies that provide shading enhance hot weather thermal autonomy significantly (decreasing from 63.3% to 36.1% hot weather TA), but in the meantime block desirable solar gains considerably in winter (increasing from 13.5% to 43.6% cold weather TA) resulting in 20.4% TA overall. With an optimized size of balcony or fixed shading louvers, better thermal autonomy can be achieved. When the balconies are exchanged for operable exterior shading device, TA reaches to 55.3%. The results show that the best envelope design which has a 5% glazing open area with the combination of operable shading and natural ventilation strategies (Case 10) deliver the best thermal autonomy performance on an annual basis with a passive fraction of 79.7%.

For the same unit configuration, a south facing unit with 80% WWR, the results in Figure 3 shows the indoor operative temperature for eight days after the power failure in summer, and indicate that designs with high thermal autonomy also tend to have better passive survivability. The occupants are able to maintain reasonably comfortable conditions by activating operated shading devices (based on best-possible manual operation

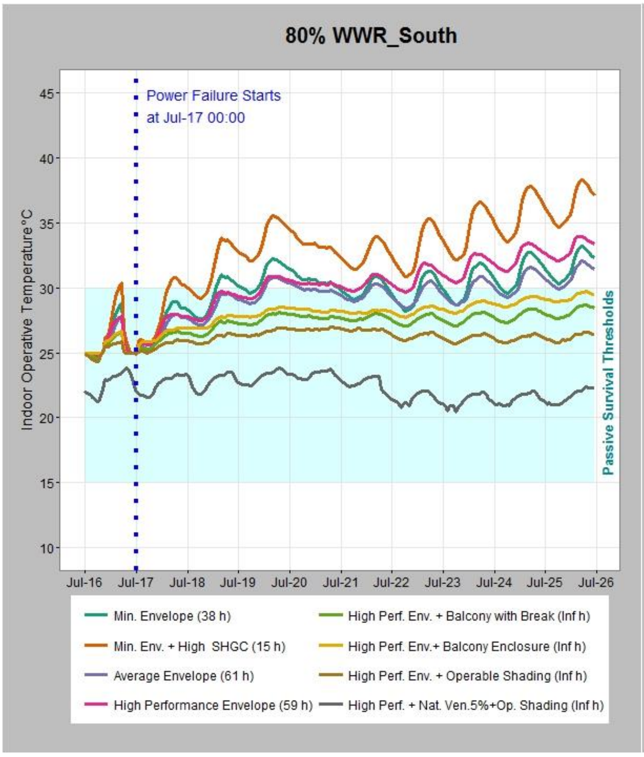

Figure 3. Passive survivability in Summer

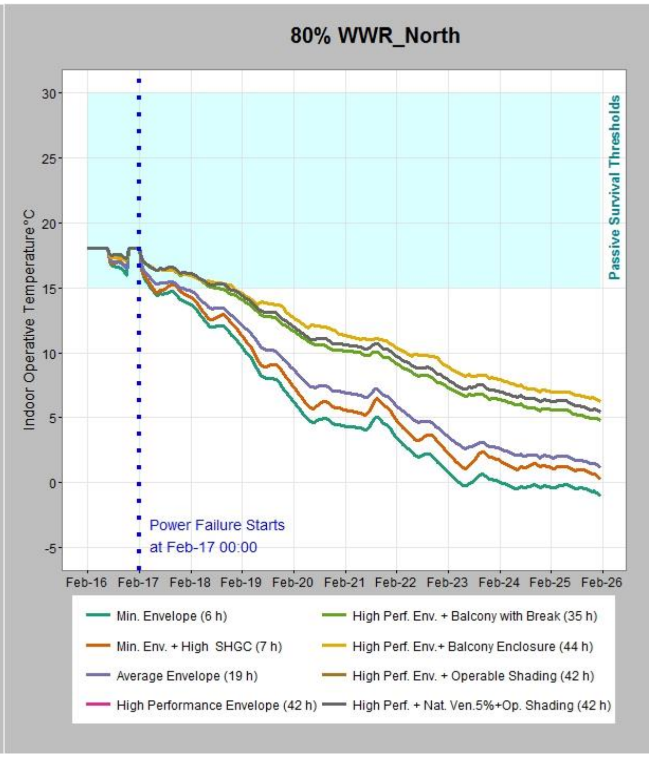

Figure 4. Passive survivability in Winter

by occupants) and opening windows. The envelopes with no shading strategies are the cases to suffer significantly from summertime overheating.

Figure 5 reveals the results of when the south facing unit with 80% WWR is re-oriented to face north. Cold weather thermal autonomy for non-south-facing units is more challenging and an approach combining a shading device with thermal protection, such as enclosed balconies or exterior insulated shutters, may prove more effective. The high-performance envelope combined with an enclosed balcony has the longest comfortable period during winter in this case. In summer period, balcony enclosure causes more overheating. In the winter, passive survivability of that north unit (Figure 4) indicates the temperature drops below potentially unliveable conditions within hours for the cases with minimum envelope properties, whereas for the high performance envelope cases it takes around two days to reach that passive survival threshold.

Such detailed analysis will be explored in subsequent stages of the larger study. Overall, the analysis suggests that for skin load dominated buildings such as MURBs in cold climates, different passive strategies are needed corresponding to the solar orientations of the facades.

Design of Visualization

The graphs are plotted in ggplot2, which is a plotting system for R based on the grammar of graphics. In design of the graphs affordance theory is followed in which visualization design can be evaluated and compared (Gibson, 1977). Based on this theory, good visualization should be clearer, easier, and faster for the user to identify target information/patterns. To improve affordance in this study, compact design is applied to minimize the cost of visual searches, for faster pattern seeking (e.g. yearlong data in one bar). Further, pre-attentive processing is taken advantage of with line continuity that captures the attention of the user almost immediately (Treisman,

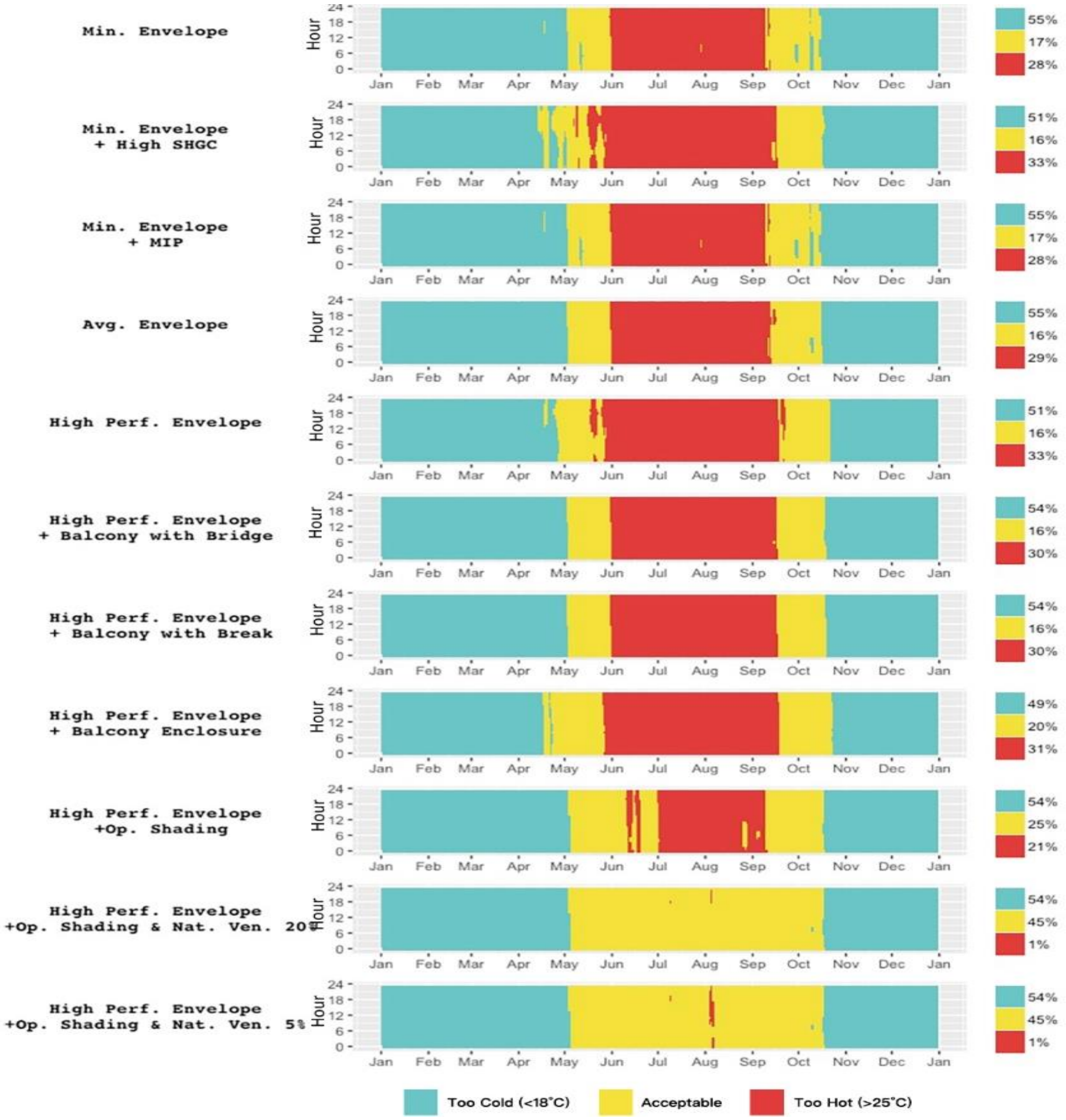

Figure 5. TA in a north facing unit with 80% WWR

1985). The human eye is believed to have evolved to subconsciously capture movements and discontinued lines (Ware, 2013). Also, colours at very different wavelength are expected to be perceived very differently due to cone sensitivity variations (Healey, Booth, & Enns, 1996). This can lead to better processing time (e.g. warmness of the colour to sense of temperature). Additionally, the focus in PS graphs provides distinct spatial texture on the figure so that passive survival thresholds can be easily identified (Ware, 2013).

This research claims that TA graphs indicate how a building design might perform independently from mechanical systems and they give an idea of when or if mechanical systems can be turned off. TA graphs show daily and seasonal patterns and predict occupant comfort. Further, they are effective in visualizing building-level passive design strategies and have temporal resolution that is sufficient to understand the building's energy performance. Overall, they are useful for facilitating passive systems design decision making because they are intuitive. Likewise, PS graphs are aimed at indicating how a building design might perform independently from mechanical systems. They predict occupant comfort and they are effective in visualizing building-level passive design strategies. PS graphs have temporal resolution that is sufficient to understand the indoor comfort conditions during extended power system failures. They are also useful for improving resilient design decisions because they display information at a human scale with a familiar metric: temperature.

The Survey

A 35-question online survey was conducted, using Google Forms, to assess the effectiveness of visualizing the time-based metrics of Thermal Autonomy and Passive Survivability in building performance simulations. In total, 65 valid responses were collected from architects, engineers and educators from a population of approximately 500 individuals contacted by email.

In this paper, first, the survey questions are briefly described. Then, the results of the survey are discussed with the aim of answering the following questions:

1. What are the participants' attitudes about using building BPS tools and visualizing data?
2. What are the participants' knowledge of common energy performance metrics in current practice?
3. Do the participants' feel that proposed thermal autonomy graphs are suitable for interpreting output of simulations appropriately?
4. Do the participants' feel that proposed passive survivability graphs are suitable for interpreting output of simulations appropriately?
5. What is the participants' opinion about the use of current and proposed metrics and their suggestions for future work related to time-based metrics?

Finally, the results of the survey and resulting analysis are discussed to inform designers, researchers, software developers, and building standards developers about the effectiveness of time-based metrics on improving the building energy metrics that inform building design, particularly at the early stages of design.

The Survey Questions

Many of the questions were multiple-choice (i.e., select one or multiple, five-point Likert-type scale of *agree* to *disagree*, short answer, long answer). However, participants were allowed to add further information where they wished to share further insights. The survey questions were separated into five categories:

1. Background information: Participants are requested to tell about their profession, country, experience with building energy related work, the frequency of building energy performance related work in their practice, and tools and methods they used for visualizing building performance data.
2. Knowledge of common energy metrics: The graph in Figure 6 was provided to demonstrate a common use of energy metrics in current practice. Participants were asked how familiar they are with the metrics and units presented in the graph and how useful they find them for making decisions about mechanical systems

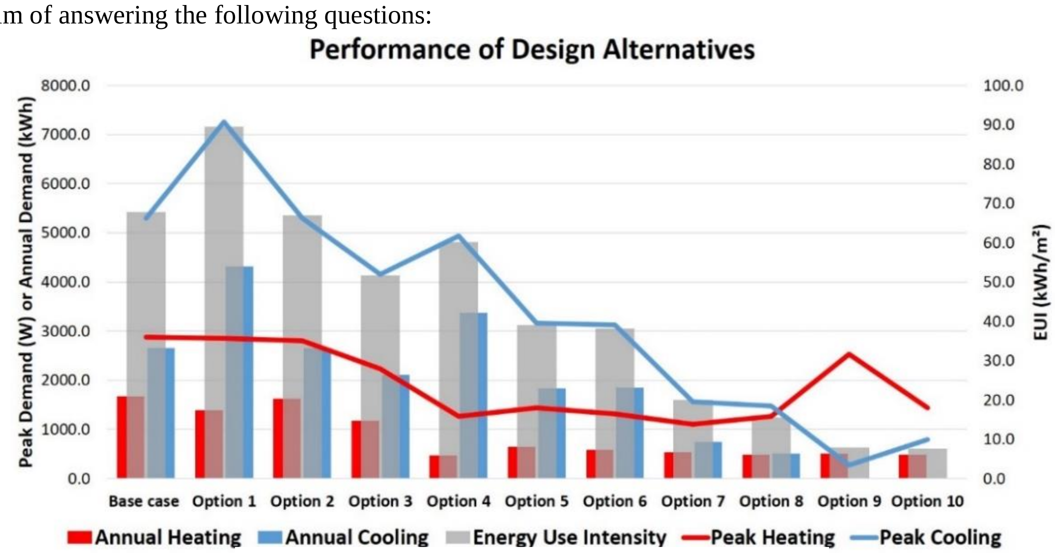

Figure 6. A common use of energy metrics

and passive design decisions related to the building envelope.

3. Interpreting proposed thermal autonomy graphs: A short explanation of thermal autonomy concept and an example visualization of TA is provided and the participant's understanding of the graph is tested with related questions. Then, their opinion is asked about the facts claimed in this paper using five-point Likert-type scale of *agree* to *disagree.*
4. Interpreting proposed passive survivability graphs: A short explanation of the passive survivability concept and an example visualization of PS was provided and the participant's understanding of the graph was tested with related questions. Then, their opinion about the facts claimed in this paper was asked using five-point Likert-type scale of *agree* to *disagree.*
5. General Questions: After the participants had an opportunity to compare conventional energy performance metrics [peak energy demand (kW), annual energy consumption (kWh) and energy use intensity (kWh/m².year)] and time based metrics like Thermal Autonomy and Passive Survivability, they were asked which metrics they find the most useful and what suggestions they have for future work related to time-based metrics.

Results and Discussion

The majority of the 65 participants were architects (40%) and engineers (40%), followed by 9% technicians. 11% participants identified themselves as belonging to other professions, such as educator, contractor, consultant, planner and sustainability specialist. Participants were asked about their years of experience in a building performance related profession. The majority of participants (75%) had more than 5 years of experience. The vast majority of participants work in Canada (94%), with the rest working in the United States and Panama. 50% of the participants encounter building energy performance related work every day, while 20% encounter it a few times a week. When asked how they visualize building performance simulation data, participants mostly stated that they use graphs or charts created in spreadsheets for visualizing building performance data mostly, while features in building simulation tools, graphs or charts created in programming tools and manual methods to overlay data on 2D and 3D drawings are the other frequently-used methods.

With regards to how familiar the participants are with the most common metrics and units in current practice (Figure 6), most of them are extremely familiar (35%) or very familiar (26%) and these are the participants who find those metrics and units useful for making decisions about mechanical system. These participants mostly tended to give the same response for passive design decisions. But 12% of the participants, who find these metrics and units very useful or somewhat useful for making decisions about mechanical systems, think they are less or not very useful for making decisions about passive design decisions. The majority of participants agree (43%) or strongly agree (14 %) that these metrics are aimed at engineers more than architects, while 30% of

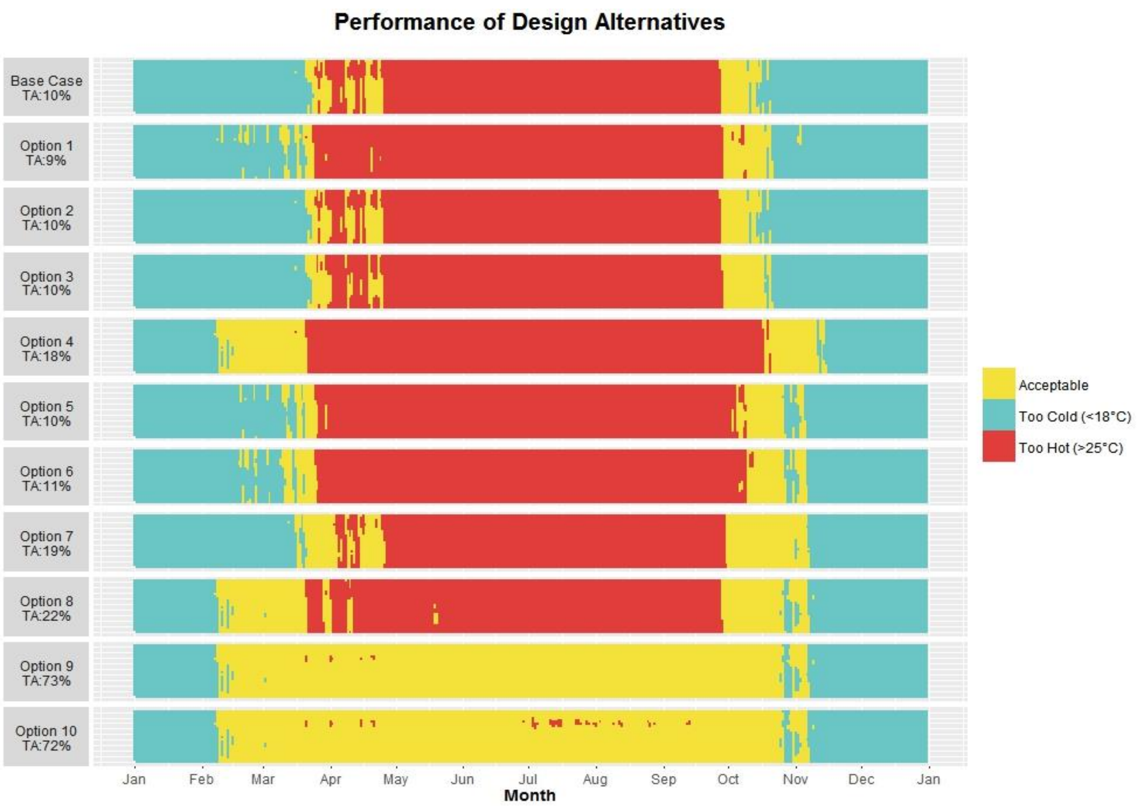

Figure 7. Former Visualization of Thermal Autonomy

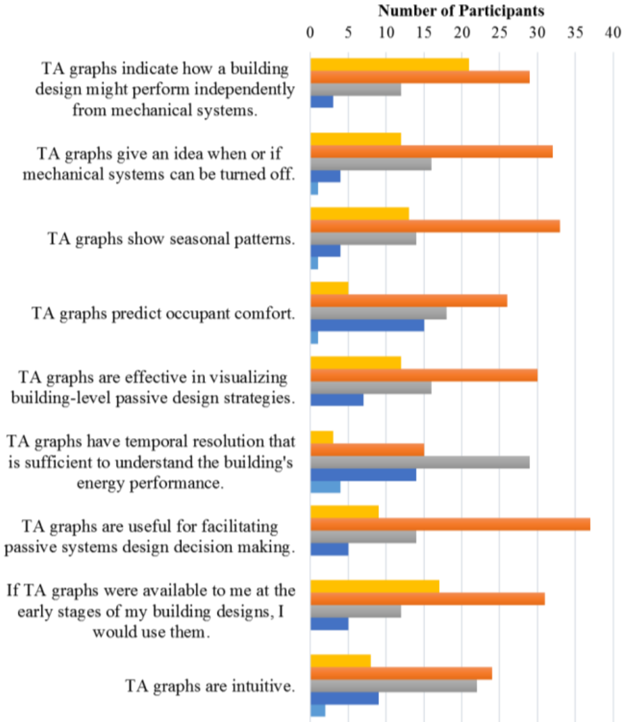

Figure 8. Statements regarding the use of TA graphs for facilitating decision making during early design stage.

participants are neutral about this statement. Understandably, the architects who have more than 20 years of experience in that field, mostly disagree with the statement while the rest of the architects mainly agree, or neutral at least. Interestingly, there is only one engineer participant who disagrees, while 70% of engineers agree these metrics are aimed at engineers more than architects.

In the next category, 90% of participants responded correctly to the question of which design option causes the most overheating in the demonstrative thermal autonomy graph (Figure 7) and 8% of participant stated they did not understand the graph.

Examining the questions of to what extent participants agree or disagree with the statements regarding the use of TA graphs for facilitating decision making during the early design stage (Figure 8), the vast majority (77%) of participants agree or strongly agree that the graphs indicate how a building design might perform independently from mechanical systems, while 68% of participants also agree or strongly agree that they give an idea when or if mechanical systems can be turned off.

Similarly, the majority (71%) of participants agree that the graphs show seasonal patterns and are useful for facilitating passive system design decision making. On the other hand, 48% of participants agree or strongly agree that the graphs predict occupant comfort, and 49% of participants agree the graphs are intuitive, while 25% and 17% of participants, respectively, disagree or strongly disagree with that statement. Much fewer participants (28%) agree or strongly agree that TA have temporal resolution that is sufficient to understand the building's energy performance while 28% of participants disagree or strongly disagree with that statement, and rest of them are neutral. This reveals the need for more comprehensive study to correlate thermal autonomy to enhanced energy performance. Overall, the vast majority (74%) of participants responded that if TA graphs were available to

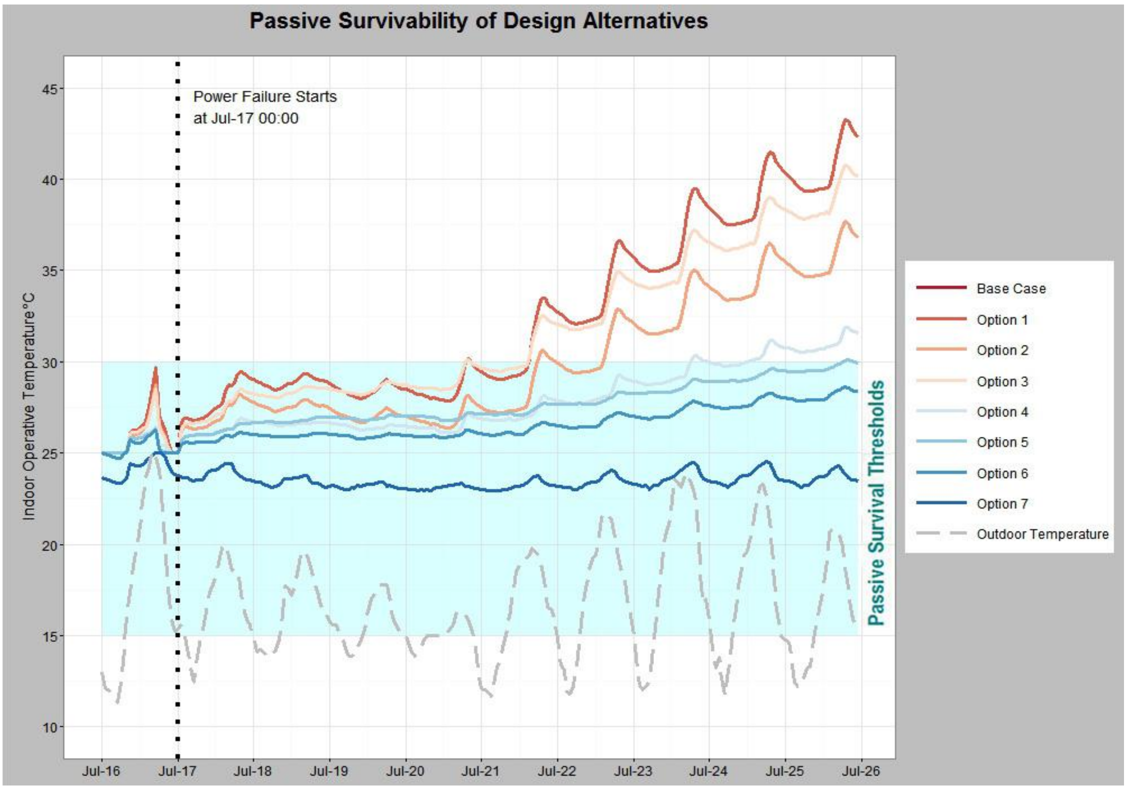

Figure 9. FormerVisualization of Passive Survivability

them at the early stages of their building designs, they would use them.

The most common comments and suggestions to improve TA graphs include adding a label for the Y- axis (time of day), larger text and fonts, providing better resolution of day/night data, and adding % of hours for each of the three categories (too hot, too cold, and acceptable) because they think decisions require numbers to confirm. There are participants who think incorporating indoor relative humidity into this concept is fundamental. Their comments suggest that indoor moisture (e.g., RH) will have a big effect on occupant comfort and most passive (ventilation) systems will not provide the same level of control that mechanical systems would.

In the PS category of questions, 86% of participants responded correctly to the question of which passive strategy provides the longest period of tolerable interior temperatures after a power failure in the PS graph (Figure 9) and 8% of participant stated they didn't understand the graph. When we look at the questions of to what extent participants agree or disagree with the statements regarding the use of PS graphs for facilitating decision making during the early design stage (Figure 10), the vast majority (83%) of participants agree or strongly agree that the graphs indicate how a building design might perform independently from mechanical systems, while 77% of participants also agree or strongly agree that they are useful for improving resilient design decision. Similarly, the majority (71%) of participants agree the graphs are effective in visualizing building-level design strategies. On the other hand, 57% of participants are agree or strongly agree that the graphs predict occupant comfort, and 63% of participants agree the graphs are intuitive, while 15% and 9% of participants, respectively, are disagree or strongly disagree with that statement. Unlike the responds to TA graph, the cast majority (69%) of participant agree or strongly agree that PS have temporal

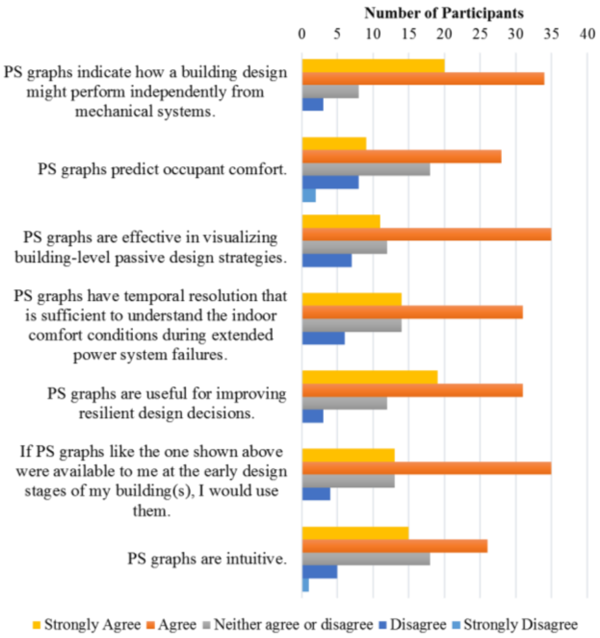

Figure 10. Statements regarding the use of PS graphs for facilitating early decision making

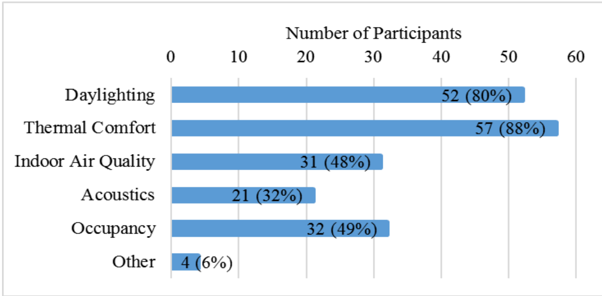

Figure 11. Other performance parameters for possible future studies

resolution that is sufficient to understand the indoor comfort conditions during extended power system failures. Overall, the vast majority (74%) of participants responded that if PS graphs were available to them at the early stages of their building designs, they would use them. The most common comments and suggestions to improve PS graphs include having larger text and more distinct colors, and adding number of hours in the passive survival zone for each category. There are participants who think that depending on climate, humidity and fresh air are important considerations as well.

In the last category of questions, the majority (65%) of participants responded both conventional metrics (kW, kWh and kWh/m^2.year) and Thermal Autonomy and Passive Survivability are useful for the design of passive systems while 14% of participants think TA and PS are most useful metrics and 11% of participants indicate they don't know enough about energy performance modelling to decide. Most of the participants are interested in having the visualization of time-based metrics for thermal comfort (88%) and daylighting (80%) in further studies (Figure 11).

The results of the survey strongly suggest that time-based metrics of thermal autonomy and passive survivability are useful and desirable to building design professionals at the early stages of design. Additional parameters dominated by passive measures include daylighting and thermal comfort. One observation is that at the early design stage, building performance simulation should focus on these visualization techniques and their associated metrics instead of the conventional measures for energy use intensity and compliance with code targets. By focusing on passive measures and time-based performance metrics, the design team can better focus on architectural contribution to building performance.

Conclusion

It is well-known that architects' early design decisions impose a major impact on a building's energy performance. With the approach discussed in this paper, architects and designers will be able to use simulation tools in a very simple, fast and reliable way by interpreting the simulation results intuitively through time-based metrics of thermal autonomy and passive survivability. It will provide guidance to architects on understanding the relationships between passive parameters such as form, size, orientation, fenestration, materials, shading, climate factors, gains, conduction, and infiltration. The practical visualization techniques will provide clear and quick feedback as to the seasonal patterns of thermal comfort that an architectural proposition is expected to deliver. The temporal distribution of interior operative temperatures is aimed at providing substantial information about how long a building can be self-sufficient in a year, and enable designers to compare design alternatives in the early stages of design.

Subsequent stages of our ongoing study will include the analysis of thermal autonomy and passive survivability for more comprehensive combinations of unit types in other climate zones. They will also explore how time-based metrics can be correlated to enhanced energy performance, particularly comparing with energy use intensity, and prove the significance of TA as an indicator of energy performance at the early stages of design without need for more sophisticated simulation models comprising active engineering systems such as HVAC, lighting controls, etc.

This comprehensive study is also expected to raise questions for possible future research. The first question may be how to create benchmarks to consistently apply time-based metrics in the early design stage. A second is how to define comfort thresholds that are appropriate for the analysis of only passive measures in naturally ventilated buildings. Third, is to determine how to create a commonly accepted weather data file that can be used to consistently evaluate extreme cases for PS analysis. Finally, it is important to investigate how individual suite analyses can be amalgamated to visualize passive performance on a whole-building level.

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Important Note

The term “passive survivability” is sometimes referred to as “thermal resilience” to distinguish it from non-thermal aspects of passive survivability, like rainwater harvesting or renewable energy generation.

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