THE TIME-BASED METRICS OF THERMAL AUTONOMY AND PASSIVE SURVIVABILITY AND THEIR CORRELATION TO ENERGY USE INTENSITY

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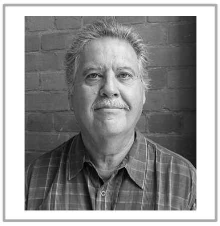

Abstract

The aim of this paper is to demonstrate an approach for analyzing robust passive measures through the time-based metrics of thermal autonomy and passive survivability. 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 to ensure architectural parameters, such as building form, orientation and fabric, are intelligently selected to improve environmental performance and resilience of buildings. Furthermore, the paper shows how time-based metrics can be correlated to enhanced energy performance, particularly comparing with enegy use intensity. Current energy-related metrics are aimed at the use of engineers more than architects in the discussion of building performance. Compared to energy metrics, such as Watts and kilowatt-hours, performance metrics based on a measure of “time" are more intuitive. The approach presented in that paper can provide a common language and fill the communication gap between architects and engineers in the discussion of building performance. In addition, architects may also maintain better control on their aesthetic and functional design values without compromising performance.

Keywords

Thermal autonomy, passive survivability, building simulation, early design stage, resilience.

1. 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 upgrades can be disruptive to the design process and costly. The central proposition of this paper is that buildings should be designed by architects with the intention of minimizing environmental impact and costs at the beginning of the design process so that the architectural design contributes to high performance during the integrated design process.

However, there is still a need for practical approaches that integrate energy simulation into the early design stage of high performance buildings in the architectural practice. Building performance assessment methods require appropriate performance metrics and indicators for specific objectives. One problem with the current approaches is that most of them request extensive input data and they provide vast quantities of output from building simulation. For design teams, it is very important and helpful (better design and time wise) to know what to expect and extract from their analysis output at the very beginning, which are 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 based on the development of an approach that could enable building simulations to be used as simpler evaluation tools to consider passive systems integration and optimization in early design phases through the use of time-based metrics of thermal autonomy and passive survivability.

2. Methodology

The aim of this paper is to demonstrate an approach for analyzing robust passive measures for improving resilience and thermal comfort of multi-unit residential buildings through the time-based metrics of thermal autonomy and passive survivability. Thermal autonomy is used as *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 and ventilation, to be intelligently arranged to improve environmental performance. Passive survivability is used as *a measure of how long inhabitants may remain in their dwellings during extreme weather events that knock out their energy supply*. It ensures buildings to be less susceptible to becoming uncomfortable or unliveable in the event of extended power outages during extreme weather periods. As part of a larger study, this paper will prove the positive correlation between thermal autonomy, passive survivability and the overall energy efficiency of passive building systems. Vancouver, British Columbia, Canada climate will be considered to demonstrate aspects of the approach through simulations after the physical characteristics of typical multi-unit residential buildings have been determined.

2.1 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 demise 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. 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 using Vancouver, Canada weather data.

<table>
<tr><td>Orientation</td><td colspan="3">South</td><td colspan="3">West</td><td colspan="3">North</td><td colspan="3">East</td></tr>
<tr><td>WWR (%)</td><td colspan="6">40</td><td colspan="6">80</td></tr>
<tr><td>Wall U-Value (W/m2.K)</td><td colspan="4">0.278</td><td colspan="4">0.210</td><td colspan="4">0.180</td></tr>
<tr><td>Glazing U-Value (W/m2.K)</td><td colspan="4">2.50</td><td colspan="4">1.70</td><td colspan="4">1.00</td></tr>
<tr><td>Glazing SHGC</td><td colspan="4">0.45</td><td colspan="4">0.35</td><td colspan="4">0.25</td></tr>
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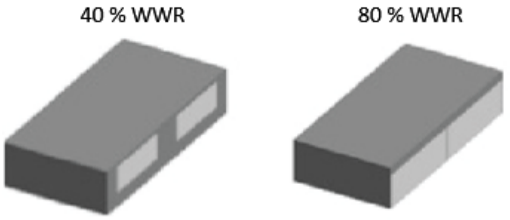

Figure 1. Units used in parametric simulations

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.) To validate the correlation of the time-based metrics with annual heating and cooling loads, simple HVAC systems are modeled using ideal loads, fuel consumption is calculated from loads using seasonal efficiencies. A COP of 1.0 for the HVAC systems was used in order to estimate demands without the influence of energy conversion efficiencies. Natural ventilation and infiltration air flow rates are calculated based on opening and crack sizes (medium), buoyancy and wind pressures.

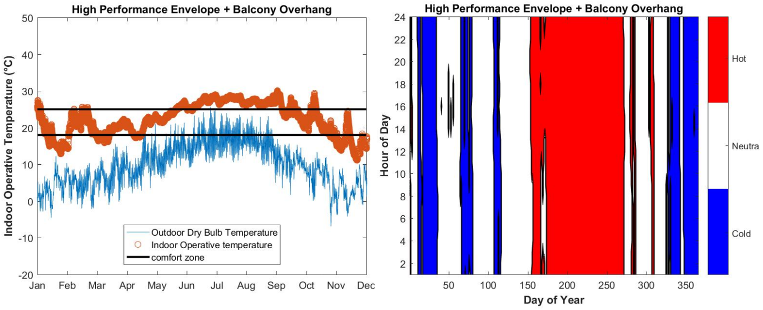

Figure 2. Demonstration of different representations for Thermal Autonomy for a single case of energy simulation. (Case 6 for a south-facing unit which has 80% WWR.)

EnergyPlus software was used to perform a large number of parametric simulations through DesignBuilder interface. For each unit configuration, based on different orientations and window-to-wall ratios, three types of simulations are conducted. In the first set of runs, passive parameters are assessed through annual space heating and cooling energy use intensity (kWh/m^2). Second, for thermal autonomy analysis, the systems for HVAC, lighting and equipment are turned off in the model. 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 as demonstrated in Figure 2. 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). Third, 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 as demonstrated in Figure 4.

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 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 briding).

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 analyze 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, horozintal 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.

2.2Analysis of Thermal Autonomy and Passive Survivability

The parametric set of simulations consist of two unit scenarios, which are having 40% or 80% window-to-wall ratio in four orientations. Each scenario starts with minimum envelope requirements as base cases, and then 10 passive measures are applied to improve the performance of units. In this paper, demonstrative results will be extracted to illustrate thermal autonomy (TA) and passive survivability (PS) concepts. Also, the thermal autonomy numbers will be compared to Energy Use Intensity (EUI) for a greater understanding and validation of these time-based metrics.

In the analysis of thermal autonomy, Figure 3 depicts a south facing unit with 80% WWR. If the unit assumes only the minimum envelope requirements, it is thermally autonomous for 20.2% time of a year, where the average envelope properties increase its performance to 22.3%. Furthermore, with the high performance envelope properties, the unit suffers from greater overheating and TA decreases to 17.8 %, 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 fixed or 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 (resulting in 46% TA overall), but in the meantime block some desirable solar gains in winter. When the balconies are exchanged for operable exterior shading device, TA reaches to 59.7%. The results show that best envelope design which has a 5% glazing open area with the combination of operable shading and natural ventilation strategies deliver the best thermal autonomy performance on an annual basis with a passive fraction of 81.5%.

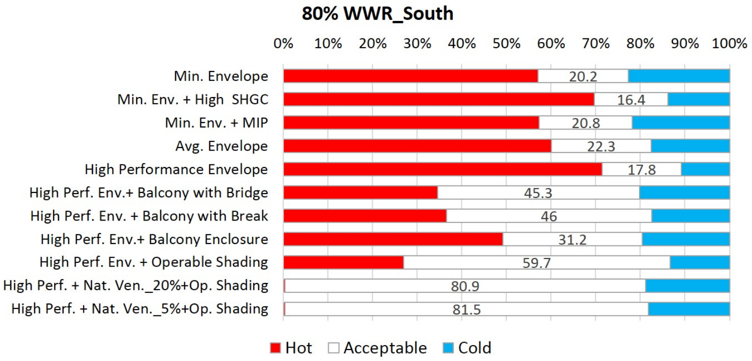

Figure 3. Comparison of TA simulation results for various passive design strategies applied to South-facing unit.

For the same unit configuration, the results in Figures 3 and 4 and Table 2 indicate that designs with high thermal autonomy also tend to have better passive survivability. Figure 4. shows the indoor operative temperature for eight days after the power failure in summer. The active occupants are able to maintain reasonably comfortable conditions by closing operable shading devices and opening windows. The envelopes with no shading strategies are the cases to suffer significantly from summertime overheating. In the winter cases, before the temperature dropped below potentially unlivable conditions, significant solar gains were admitted into the space. Only the cases with minimum envelope properties and the same envelope with movable insulation panels are exposed to extreme cold after 99 and 101 hours, respectively (Table 2).

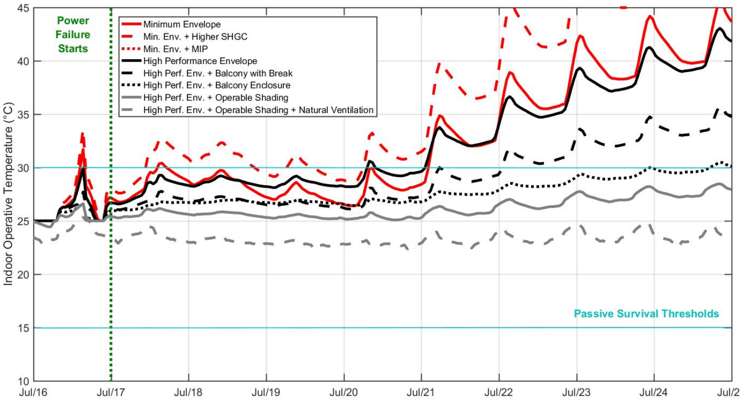

Figure 4. Comparison of PS simulation results in summer for various passive design strategies applied to South-facing unit.

Table 2. Passive Survivability for South unit with 80% WWR (Duration is marked as infinity if the temperature is not reached within 8 days of power failure)

	Min. Envelope	Min. Env. High SHGC	Min. Env. MIP	High Performance Envelope	High Perf. Balcony with Break	High Perf. Balcony Enclosure	High Perf. Operable Shading	High Perf. N.V.+Op. Shading
Winter Week (h)	99	∞	101	∞	∞	∞	∞	∞
Summer Week (h)	113	91	113	92	139	209	∞	∞

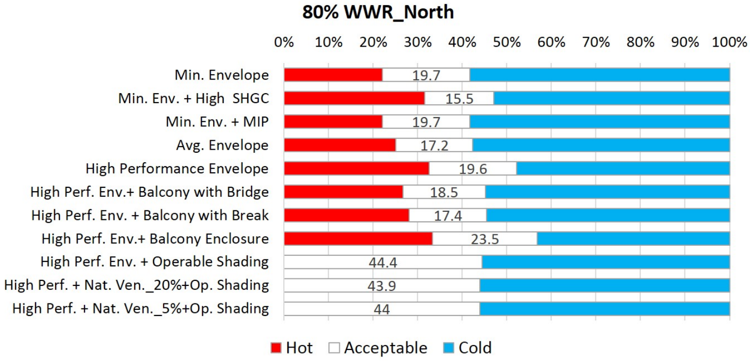

Figure 5. Comparison of TA simulation results for various passive design strategies applied to North-facing unit.

Figure 5. reveals the results of when the south unit 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. This 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. Such detailed analysis will be explored in subsequent stages of the larger study.

2.3 Correlation of Thermal Autonomy with EUI

One question of the study attempted to answer was the significance of TA as an indicator of energy performance. Figure 6 depicts a plot of the energy use intensity (EUI) of annual heating and cooling energy demands associated with thermal autonomy numbers for all the simulations conducted in this study. The data suggest that TA can be used as a significant indicator of energy demands at the early stages of design without need for more sophisticated simulation models comprising active engineering systems such as HVAC, mechanical ventilation, etc.

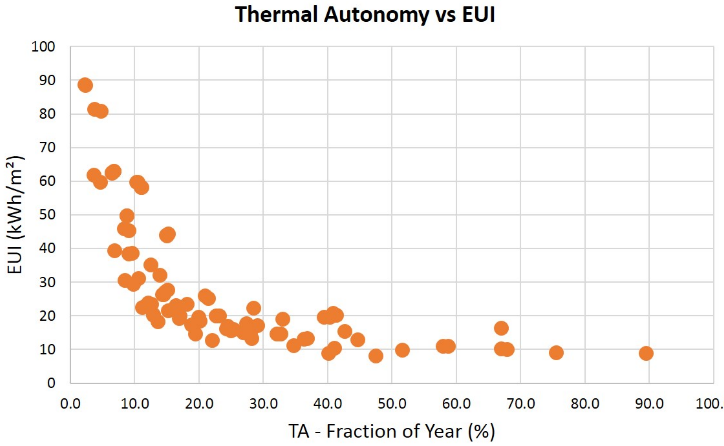

Figure 6. Relationship between EUI and TA (Fraction of year)

The graphs in Figure 7 also indicate thermal autonomy shows similar sensitivity to individual cases as energy use intensity. From one case to another, when EUI increases, TA decreases and vice versa. The conclusion for now is that thermal autonomy may be a promising metric at the early design stages which can reduce reliance on active systems.

If a strong and consistent correlation between thermal autonomy and annual energy use intensity can be established, then greatly simplified energy simulation methods can be efficiently applied at the early design stage to meet desired and/or legislated levels of energy performance in buildings. Later, more sophisticated energy modelling may be applied to refine the energy design and integrate control strategies while being confident early stage design decisions have not compromised energy efficiency targets.

Figure 7. Sensitivity of EUI and TA to design alternatives in different scenarios and orientations.

3. Results and Discussion

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 interpreating the simulation results intuitively through time-based metrics of thermal autonomy and passive survivability. It will provide guidance to architects on thinking in systems and understanding the relationships between passive parameters such as such as form, size, orientation, fenestration, materials, shading, climate factors, gains, conduction, and infiltration.

Future work includes the analysis of thermal autonomy and passive survivability for more comprehensive combinations of unit types in other climate types. The development of visualization techniques is an important aspect of the study to provide clear and quick feedback as to the seosanal patterns of thermal comfort that an architectural proposition is expected to deliver. The distribution of interior operative temperatures is aimed 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. Further, an online survey of design professionals will be developed and conducted in order to evaluate the utility and effectiveness of visualizing the time-based metrics of thermal autonomy and passive survivability to inform the design development process.

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