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## G R E E N P A P E R

### Vital Signs: Towards Meaningful Building Performance Indicators

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Over the past several years, discussions with a number of my building science colleagues have centered on critical building performance attributes, and the need to carefully re-examine the metrics and indicators we use to inform our design thinking. This green paper could easily slide into a criticism of current energy codes and standards, how the use of the reference building as a performance baseline is inappropriate, and why energy modeling has become too onerous and expensive, often providing guidance far too long after the schematic design stage. But this would further muddy turbulent waters and render it difficult to address what many believe to be at the root of the emerging problem with building performance simulation - a failure to correlate measureable and/or observable physical attributes with key indicators that concisely reveal the critical performance characteristics of buildings. Similar to the vital signs examined by physicians to determine a patient's state of health, the idea is to develop a simple assessment framework that provides meaningful information about existing and proposed buildings to all stakeholders, not just building professionals. In preparing this green paper, I adopted an approach that was advocated by one of the greatest minds in modern science.

*Everything should be made as simple as possible, but not simpler.*

*Albert Einstein*

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#### The Big Picture

It is quite challenging to keep things simple and very easy to make them more complicated than need be. While simplification risks losing valuable information, complication often causes us to lose sight of the forest for the trees. In my view, this largely explains what has happened with building performance simulation and its inability to effectively convey key performance indicators for buildings. This green paper is an attempt to initiate a discussion about how to find a sweet spot for building performance assessment that is as *simple as possible*, while meaningfully conveying key metrics and indicators.

There is no desire to throw out the baby with the bath water. Building performance simulation has contributed significantly towards our understanding of *building-as-a-system* behavior and helped formulate appropriate design strategies for various building typologies. Instead, the idea is to seek a fairly compact and coherent set of metrics and indicators that are meaningful to everyone - designers, building owners, even the average person. This does not suggest designers are absolved from responsible decision making by simply adhering

to a specified range of key metrics and indicators. Building design is never an easy process, but it should be made more manageable and comprehensible. At present, the complexity of information provided by building performance simulation requires a great deal of synthesis before a meaningful assessment can be rendered and conveyed, often long after it is needed to inform intelligent design. Vital signs can help inform the early stages of design for high performance buildings.

#### Informative Indicators

Buildings are prosthetic devices intended to shelter humans in environments conducive to their health and well being. There may not be a one-to-one correspondence between human health indicators and building performance, but it is interesting how modern medicine has developed highly meaningful and reliable indicators of health. For the most part, heart rate, blood pressure, cholesterol, blood sugar and body mass index can inform physicians about the health status of their patients. Is it possible to develop a simple set of metrics and indicators that can provide a useful assessment of building performance?

## **The King Has No Clothes**

Low energy buildings, green buildings, smart buildings, Passivhaus, Active House, net-zero energy and carbon neutral, LEED™ and Energy Star® - so much of today's building technology is about branding.

The primacy of shelter in architecture is often overlooked and it takes natural or man-made disasters to remind us all that a very thin veneer of civilization separates us from the natural world. The current lexicon of building performance assessment is wearing this veneer even thinner and there is a need to get back to the basics of building performance, long before the time of fossil fuels, electricity, digital controls and telematics, to rediscover what really matters.

Climate change, extreme weather events, acts of war and terrorism have demonstrated the vulnerability of modern building technology. In Canada, ice storms have caused electricity grids to collapse leaving inhabitants without electricity for days during extended cold periods. People were forced to leave their homes because heating systems were inoperable and many buildings were damaged by the bursting of frozen pipes. Imagine purchasing a home for well over half a million dollars and discovering it provides no shelter when the electricity grid goes down - then the plumbing freezes to incur massive damages, disruption and inconvenience.

Primitive, low tech buildings often provide superior shelter and security than high tech architecture after the energy infrastructure collapses because they were designed for a time when people managed their own energy supply. Somehow, as civilization moved towards centralized infrastructure, the importance of passive survivability in buildings was forgotten and eventually abandoned altogether.<sup>1</sup> Like cars with electric windows, there is no manual override and everything else in the automobile depends on a supply of electricity feeding an array of actuators, sensors and controls with no way of bypassing the active systems.

There is a genuine need to reconcile low tech and high tech building features to deliver appropriate solutions in contemporary buildings. One way to begin restoring a reasonable balance between passive and active systems is to ask some tough questions about what is important and what is not in regards to environmental performance and what we value in our building assets.

## **So What Have You Got?**

At the end of the day, buildings are physical assets and they demand asset ratings that portray what you've got regardless of how you are intending to occupy, operate and maintain it. While from an actual performance perspective it's both what you've got and how you use it that counts, if you want to meaningfully compare, it's important to first establish what you've got.

Every advanced industry relies on key metrics and indicators to convey the performance of its products. Building performance assessment, including simulation, has to deliver meaningful information that is consequential. Here are some questions that need to be answered before design of new or retrofit buildings goes beyond concept.

- During prolonged energy outages, how long before the indoor temperature becomes too high or low for inhabitants?
- Over what fraction of the building's floor area can acceptable indoor air quality be maintained through natural ventilation alone?
- What fraction of the building floor area can enjoy adequate daylighting during typical periods of daytime use?
- What is the building's base metabolism independent of occupancy? (e.g., peak and annual energy demands of the unoccupied enclosure)
- How durable is the building enclosure assuming recommended maintenance? (e.g., service life of cladding and control layers, recommended inspection, cleaning, maintenance intervals, etc.)
- What is the initial and recurring embodied energy and associated carbon footprint of the passive building elements?
- How flexible/adaptable is the building? (e.g., functional obsolescence, adaptive reuse, change of occupancy, churn rates, etc.)
- How resilient is the building with respect to seismic activity, wind, flooding, energy blackouts, etc.?

These questions are becoming increasingly important and there is a need to ensure building performance assessment, including simulation, begins to address them effectively.

## The Simulation Game

The holy grail of building performance simulation (aside from universal interoperability among software) is to accurately predict the performance of a proposed building design at the early design stage, ideally across multiple indicators such as energy efficiency, indoor air quality and daylighting. The multiplicity of performance indicators is derived from an even larger number of metrics. Before proceeding, it is important to clearly define performance, metric and indicator.

From a building science perspective, the term *performance* may be defined as: *the level of service provided by a building material, component or system, in relation to a required, intended, or expected, threshold or quality.* Performance has many dimensions ranging from constituent materials to the entire building system, and across physical, social, environmental and economic parameters. In building performance simulation, a narrower bandwidth of considerations is typically examined to derive indicators of environmental performance.

It is important to distinguish between indicators and metrics. Put plainly, an indicator indicates something, whereas a metric measures something. Usually, multiple metrics are combined to produce an indicator (e.g., annual energy consumption and gross floor area are combined to yield annual site energy use intensity -  $\text{ekWh/m}^2\cdot\text{yr}$ ). Indicators are not as clear cut as their underlying metrics because there is always some debate about their suitability. Looking at site energy use intensity as an indicator of energy efficiency, it may be argued that per capita energy use, or carbon intensity, may be more appropriate indicators of energy related performance.

The building performance simulation game in North America primarily involves energy modelers seeking to demonstrate the compliance of a proposed building design with minimum levels of energy efficiency set out in codes and standards. In some cases, the building seeks to be much more energy efficient in order to attain a LEED™ rating or conform to a municipal green building standard or by-law. Energy modeling guidelines and protocols from applicable standards are normally employed in a process that models the passive and active components of a proposed building design in a particular geographic location, applying a normatively specified occupancy and operating

schedule. Energy modeling software is used to simulate the energy performance. The process involves the development of a reference energy model that meets a minimum level of energy efficiency, followed by the development of an energy model for the proposed design that demonstrates it has met or exceeded the minimum level for code compliance.

Often, to win the simulation game, desired or acceptable levels of energy efficiency are attained by trading off inefficient enclosures with efficient HVAC and lighting systems,<sup>2</sup> never fully considering the life cycle implications of such design decisions. If all of this sounds complicated, it's because it is - it takes time, is relatively costly and provides critical information long after it is required to inform enlightened design. Worst of all, the building performance simulation game has a deep inherent flaw that is overlooked in the heat of battle.

## Passive Versus Active Systems and Occupant Behaviour

Modeling and simulation seldom provide indicators that speak to the performance of passive building systems. This is because during the energy modeling process, physical attributes of the building enclosure and external phenomena in the form of weather data are mixed in with active system operations and assumed occupant behaviour. The final results are unable to separate passive and active system effects. Put simply, passive systems represent the intrinsic quality of the building asset, whereas active systems are optional and transient components that supplement passive system performance according to occupancy and building usage.<sup>3</sup>

Energy models produce results that reflect both passive and active system performance. The active system performance (HVAC, lighting, plug loads, etc.) is largely determined by occupancy of the building and the assumed occupant behavior. Passive systems, such as natural ventilation and daylighting, are not easy to integrate within energy models, hence the performance simulation results are limited to energy demands and do not distinguish between contributions by passive and active features of the proposed building design.

When performance indicators such as passive survivability are considered, it is only the performance of the passive systems that matters because it is assumed the active systems are down.<sup>4</sup> The overall effective U-value of the

enclosure, its airtightness, thermal storage capacity, daylighting and natural ventilation are the only performance indicators that need to be considered by designers interested in assessing passive performance. It may also be argued these are the only performance indicators that can be measured or tested in-situ with reasonable accuracy to assess the quality of the physical building asset. From a life cycle perspective, it is the passive systems that will endure long after active system components may have been replaced several times, and the occupancy patterns and operating schedules of the building vastly altered over time, as buildings become re-purposed or adaptively re-used.

**Passive/Active Building Systems Defined**

With the exception of the simplest of enclosures, practically all buildings consist of both passive and active systems which ideally complement each other to achieve functionality and a desired state of environmental control. Given the context of climate change and the need to reduce our carbon footprint, passive and active system roles may be defined as:

**Passive Systems Role**

To moderate the environment for the safety, health and well-being of the occupants with minimal non-renewable, embodied energy inputs over the service life of the building.

**Active Systems Role**

To supplement the passive systems to the extent that is required to achieve the desired level of environmental control and functionality, with a minimal input of non-renewable energy.

The building structure and enclosure effectively constitute the passive systems from an environmental performance perspective.<sup>5</sup> Generally, the structure contributes thermal mass whereas the enclosure, by means of its moderation of heat, air, moisture and solar energy flows, along with embedded fenestration for light and air, provides thermal comfort, daylighting and indoor air quality (natural ventilation). Together, these physical characteristics determine environmental performance in terms of the provision of shelter and moderation of the indoor environment.

*A building's passive physical attributes, not its active systems or occupancy, determine the upper boundary of its environmental performance potential.*

**Key Performance Indicators for Passive Systems Independent of Active Systems and Occupancy**

There is a need to reliably correlate basic building attributes with environmental performance potential to better inform new building designs and to assess appropriate retrofit strategies for existing buildings.<sup>6</sup> Ideally, these indicators could be obtained through some fairly simple metrics that would involve straightforward techniques suited to schematic models, rather than requiring the development of highly resolved and detailed designs.

In this green paper, several key performance indicators have been identified based on fundamental requirements of buildings: *the provision of shelter that privileges access to light and air*. There are many other indicators such as durability and resilience,<sup>7</sup> but in this green paper only those associated with moderation of the indoor environment are examined. The key indicators and their associated metrics or parameters are found in Table 1.

Indicator	Metric/Parameter
Passive Thermal Survivability	<ul style="list-style-type: none"> <li>▪ overall effective U-value</li> <li>▪ airtightness</li> <li>▪ thermal capacitance</li> </ul>
Daylighting	<ul style="list-style-type: none"> <li>▪ fenestration (WWR &amp; aperture)</li> <li>▪ solar optical properties of glazing</li> <li>▪ depth of floor plate</li> <li>▪ internal barriers to daylight penetration (building structure)</li> <li>▪ fixed and manually operable shading devices</li> </ul>
Natural Ventilation	<ul style="list-style-type: none"> <li>▪ building geometry &amp; aspect ratio</li> <li>▪ areas of operable openings</li> <li>▪ distribution of operable openings</li> <li>▪ depth and height of floor plate (distance between supply and exhaust openings)</li> <li>▪ internal resistance to airflow</li> </ul>

In order to combine metrics to arrive at indicators, a set of environmental conditions corresponding to a particular geographic location must be applied in appropriate performance assessment models.

**Table 1.** Primary passive system performance indicators and their associated metrics.

**Passive Thermal Survivability** - This performance indicator is defined as the ability of a building to maintain an acceptable indoor temperature (shelter) when all active systems have failed. This performance indicator mostly applies to the situation where the active heating system becomes inoperable for extended periods of time, but may also apply to extended periods where the active cooling system becomes inoperable. Extreme weather events and centralized energy infrastructure system crashes can expose vulnerable building inhabitants to dangerous and potentially fatal heat/cold exposure.

**Daylighting** - Before the invention of artificial lighting, daylighting enabled building inhabitants to engage in all manner of activities requiring visual acuity. Even with the advent of artificial lighting, the importance of daylighting to the well being of inhabitants has not declined. For urban dwellers that spend a majority of their time indoors, daylighting is gaining importance for health reasons. The daylighting performance indicator reflects how much natural light is available over the floor area of a building during daytime hours.

**Natural Ventilation** - Acceptable indoor air quality is determined by ventilation rates, assuming the occupied indoor environment is not emitting abnormal contaminants. Ventilation rates across operable openings induced by wind and stack pressures, that do not cause excessive discomfort, normally determine the contribution of natural ventilation to total requirements. This performance indicator is critical for estimating annual energy demands and passive thermal survivability.

*Energy modeling has become like running the building through an MRI scan while completely ignoring basic vital signs like overall effective U-value.*

Passive systems establish the armature of the building within which active systems are nested. Implicit in all *building-as-a-system* models are the site conditions, which establish the context in which passive systems perform (i.e., climate, weather, soils, groundwater, topography, etc.). The key performance indicators for passive systems may be derived from some basic metrics.

## It's Not As Simple As That

If building performance could be adequately captured with a handful of indicators based on a combination of simulated and measured metrics, a standardized design methodology would have emerged long ago.<sup>8</sup> But it's not as simple as that. Is the overall effective U-value of the enclosure consistently correlated for both skin load dominated and internal load dominated buildings,<sup>9</sup> and across all occupancies and climate zones? There is some work to be done to establish and verify appropriate overall effective U-values for enclosures and how these, in combination with thermal capacitance and airtightness, translate into enhanced levels of energy efficiency and passive survivability.

There continues to be some debate over appropriate daylighting metrics, but the physics of daylighting and how that may be simulated by computer software is very well defined. The real challenge is how to develop a useful indicator for the entire building. For example, if Daylight Autonomy is the dynamic daylighting metric selected, how should the light level thresholds be set and which areas of the building will be considered? It is reasonable to assume several standardized thresholds could be established and corresponding performance reported for all occupied zones of the building (i.e., stairwells, storage/service closets, etc., excluded from the calculations). This approach would assume none of the operable shading devices have been deployed, with the understanding occupants could do so to address glare and privacy.

Natural ventilation in a building is the result of a number of parameters including: building location, height and geometry (number of storeys, shape, size of floor plate and aspect ratio); fenestration (size and location of operable windows), openness of floor plates and porosity of enclosed rooms/spaces; and special features such as atria and solar chimneys, etc. Very few large buildings can be naturally ventilated exclusively, and even if they could be, this would preclude heat recovery from the exhaust air stream. Assuming most buildings incorporating natural ventilation features will effectively be served by hybrid ventilation systems, the question becomes what amount of the required mechanical ventilation may be displaced by natural ventilation without adversely affecting thermal comfort and energy efficiency? Similar to establishing a suitable daylighting indicator, some type of occupancy must be assumed to establish ventilation demands.

Post-occupancy evaluations are still essential to correlate predicted performance indicators with how the building behaviour is perceived by inhabitants. It is one thing to apply metrics to simulate the performance of key indicators, it is another to predict how these indicators correlate to building user satisfaction. Building science must become more focused on actual, measurable outcomes and this is the main reason to research and develop key performance indicators for buildings.

## The 90% (A+) Solution

If it is possible to develop and implement a simplified and reliable set of key performance indicators, then designers could be afforded 90% solutions for their building typologies as a basis for schematic design. The idea behind a 90% solution is to have designers borrow from high performance archetypes with exemplary performance indicators during the conceptual design process, so that the initial design iteration begins with near optimal performance, and delivers a rating of 90% as good as the best in class (state of the art). Subsequently, building performance simulation budgets can be devoted to strategically refining the design, primarily focusing on active systems and control strategies. But even if energy modeling budgets are limited, the archetypal design still represents an A+ building armature that can have its active systems enhanced and refined in future. By adopting this approach, building performance simulation would then be synchronized with design development and not have to deliver bad news to designers that their concept had missed the high performance boat after contract documents have gone out to tender.

Could things really be this simple? Of course not, but there's no sense in pretending that how building performance is modeled today necessarily encourages priority for robust passive systems DNA. In view of impending climate change scenarios and the increase in the frequency and severity of extreme weather events, passive systems performance will grow in importance. It is therefore crucial to develop indicators that reflect the durability, resilience and passive survivability of our buildings, and give these priority over other performance parameters such as energy use intensity. This empirical approach to performance assessment is situated at the intersection of sustainability and survival, and goes beyond gaming theory to actually engage emerging realities.

*Passive systems establish the armature of the building within which all active systems are nested. The relative permanence of passive elements suggests their performance should approach best in class. Only then will the ability of active systems to extend or augment performance not be compromised by an inferior armature.*

This green paper does not suggest that physical attributes are the only building performance parameters deserving meaningful assessment. The paucity of post-occupancy evaluations, life cycle environmental and economic performance, and studies about the impact of building form and density on the quality of urban design, are among the examples of areas that need to be addressed through applied research programs.

To use a medical analogy, physicians can assess the health of a patient with some rather simple indicators like blood pressure and heart rate and body temperature. Energy modelling has become like running the building through an MRI scan while completely ignoring basic vital signs. It is these vital signs or key performance indicators that are needed for buildings. This does not mean that various forms of simulation cannot be invoked, but these should be viewed as ways of predicting performance of a particular occupancy with outcomes that are predicated on the physical attributes of the building. Very much like an automobile, the user can achieve the rated fuel efficiency and service life by following recommended maintenance, but there is an upper limit to performance that is determined by the attributes of the car, never by the attributes of the driver.

The current approach to building performance simulation is unsustainable if it does not abate in complexity and shear drudgery. Like modern medicine, building science must develop a means of rapidly assessing performance meaningfully at the conceptual design stage. Otherwise, instead of practising preventive medicine during building design, the vast majority of building science practice will involve epidemiology and pathology, eventually issuing post mortem reports on buildings with irreversibly failing health. The time has come to advance beyond dismal science to focus on innovation.

## The Passive-Active Split Personality

The passive part of a building just sits there and does nothing but mediate between the exterior and interior environment. The active part of a building does everything the passive part cannot deliver, sometimes more than is needed. Buildings have a split personality and the healing of this duality was one of the great intentions of the integrated design process. It was supposed to do more than strike a healthy balance between the passive and active systems, and look at everything from economy to ecology and stuff in between and beyond - the whole enchilada. Unfortunately, being able to assess the quality and behavior of the passive systems got lost in the shuffle. This is largely due to a misfit between the metrics and indicators used to assess design at its various stages.

As every energy modeler knows, the same building can exhibit wildly different site energy use intensities depending on occupancy and use. Take a traditional elementary school, open it up to the public for evening and weekend use, and extend that into the summer when the traditional one is normally closed during vacations, and the EUI increases dramatically. But nothing has changed for any of the passive features of the building.

How does energy use intensity inform the early stages of enclosure design? How do occupancy and use influence enclosure qualities? If a particular occupancy and use is assumed, then active system efficiencies may be enhanced at the expense of the enclosure quality. Under a different scenario, another mix of measures may be suggested. Meantime, none of the passive performance characteristics that will remain part of the building, long after many active systems have been replaced, are in any way meaningfully assessed.

*How does energy use intensity inform the early stages of enclosure design?  
How do occupancy and use influence enclosure qualities?*

We have only come a short way down the path of building performance simulation, sufficiently far to see the fork in the road that lies ahead – complexity versus transparency. We do not have to aimlessly employ every tool available, sometimes the stethoscope, blood pressure gauge and weigh scale can accomplish enough to avert most health problems.

## Critical Characteristics of Key Performance Indicators

There are many key performance indicators for buildings depending on the type of building and its occupancies and uses. The ones discussed in this green paper are viewed as virtually universal to all buildings, but it remains to be seen how many other indicators may be developed going forward. Regardless of the simplicity or complexity of the metrics and phenomena underlying a key performance indicator, it should ideally embody the following critical characteristics:

1. The application of key performance indicators in professional practice should be manageable for architects and engineers. It must be far less onerous than the comprehensive energy modeling of buildings conducted at present.
2. The indicator should be capable of informing the design process for new and retrofit building projects, such that critical decisions can be made at the conceptual design stage, quickly and effectively.
3. The indicator must deal with performance that may be measured and/or modeled by some form of simulation at the design stage, and subsequently validated through post-occupancy evaluation assessments.
4. The rating assigned to the indicator must be useful to all stakeholders, not something that is arcane and comprehensible by experts only.

The latter point is important because if the electronics and computer industry can educate consumers to understand the various technical ratings for memory, processor speeds, pixel sizes, refresh rates and contrast ratios, etc., then modern building science must devise public education programs that help explain the relationship of key performance indicators to the quality of buildings.

This has been the single most significant failure of modern building science - its inability to educate the public about how buildings work and what makes for superior performance. Countless glass condo towers stand as a testament to the inability of architects and engineers to explain what makes for better buildings to the average person, allowing developers to deliver mediocrity to naive and undiscriminating consumers.<sup>10</sup>

## Example of a Rating System for Passive Performance Indicators

International consensus supporting metrics and indicators of building performance is far from becoming standardized. How we measure performance (metrics) and how those measures are correlated to provide meaningful ratings (performance indicators) will require much additional effort - it is not as straightforward as agreeing on how to rate the luminous efficacy of a light bulb.

However, the desire for shelter that provides access to light and air is universal and it is important to meaningfully rate performance across these key indicators. Figure 1 depicts an example of how passive performance indicators may be represented. It is premised on metrics founded on assumptions which are declared and may be manipulated.

In this example, the building data has not been included for the sake of brevity, but fundamental characteristics, such as building type (occupancy, use, schedules), dimensions, gross floor areas, window-to-wall ratio and enclosure component areas/compositions, would all be summarized and accompanied by floor plans, building sections and facade elevations. As well, an assumed or measured airtightness would be included. The rationale guiding requirements for building data is that the information is sufficient for anyone to independently verify the ratings for the various indicators, or to assess indicators using different models, criteria and assumptions.

The building data is accompanied by climate and weather data. In this case, key parameters are summarized, and the weather file used to conduct the various analyses has been identified.

Under the thermal rating category, two indicators are depicted in Figure 1. The first is the overall effective U-value of the enclosure which is technically a metric and indicates a value of 0.125 W/m<sup>2</sup>.K. This may be compared to the best in class for this building type (as verified by building enclosure commissioning).<sup>11</sup> The U-value corresponding to an enclosure that meets the minimum code requirements in this jurisdiction is also indicated. The passive thermal survivability indicator is premised on a design heating temperature of -18 °C and an indoor temperature threshold of 15 °C. Again, the actual design, best in class and code minimum levels of performance are rated for comparison purposes.

The daylight rating category consists of a single indicator based on the Daylight Autonomy factor referencing a 300 lux lighting level. Note that only the actual design and best in class ratings are shown since minimum daylighting levels are not required in Canadian building codes.

An indicator for natural ventilation effectiveness is based on how long and over what fraction of the total building floor area a natural ventilation rate of 1 l/s.m<sup>2</sup> can be sustained without unacceptably compromising thermal comfort.<sup>12</sup> In the absence of code requirements for natural ventilation, only the actual design and best in class are indicated.

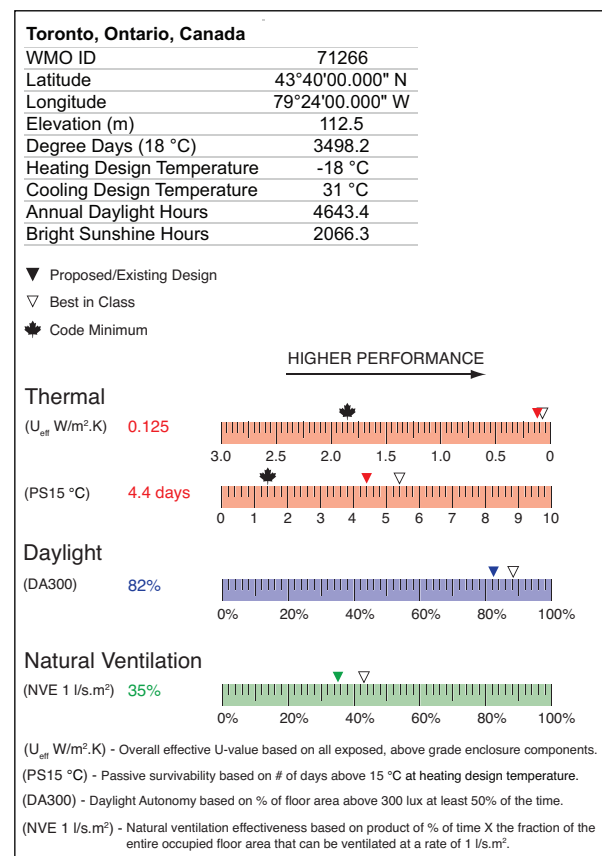


Figure 1. Example of how passive performance indicators can be used to rate a building asset.

The approach advocated in this green paper can certainly inform better design. But in the foreseeable future, a system of key performance indicators for buildings could also be standardized to serve as asset ratings for buildings. When combined with actual operating and maintenance costs, much more meaningful information could be obtained than is provided by energy modeling reports today.



## Big Questions, Big Ideas

When the idea of vital signs for buildings first started to get kicked around, there were a number of questions that naturally emerged.

One of the first questions was whether or not passive performance indicators became recipes for the design of buildings? Well one way to answer that question is to look at passive thermal survivability in cold climates. The overall effective U-value, airtightness and thermal mass needed to achieve a desired duration of comfortable habitation after the heating system becomes inoperable can be provided through virtually countless combinations and permutations of enclosure attributes. Obviously, buildings oriented and fenestrated to take advantage of passive solar gains may extend the duration of comfortable habitation, but the indicator assumes a constant outdoor temperature and overcast skies as a worst case scenario. This is what makes vital signs different than other performance indicators - they assess passive system response to less than ideal and/or critical conditions. They are not design recipes.

Another question is whether passive performance indicators for simple, archetypal building geometries and aspect ratios that deliver high performance could become the basis of design? Looking at daylighting and natural ventilation, there is no doubt that certain strategies deliver much higher performance than others. It remains to be seen how well daylit and acceptably ventilated spaces can be configured and combined to make for complete buildings. This assumes that whole building system behaviour must also be considered beyond each individual space or zone.

Perhaps we should simply develop a catalogue of high performance solutions with robust vital signs for a given climatic zone and building occupancy and forget about simulation and analysis altogether? The problem with learning design by rote is that it cannot respond well to non-standard situations where even the best of designs cannot attain very high levels of performance. Making the best of a worst case situation requires an understanding of physics and design principles beyond simple rules of thumb. On the other hand, for most typical buildings, a lot would be gained if a robust archetype formed the basis of schematic design.

How do we agree on reasonable assessment parameters? The example in this paper assumes the 2-1/2% design heating temperature and a 15 °C minimum indoor temperature threshold. Could the mean January outdoor temperature and some other indoor temperature be used? Vital signs have to be relevant and reflect reality. If the performance assessment model is transparent and accessible, then parameters can be varied to reflect the scenario of interest. Perhaps for a warehouse, it is only important that the contents do not freeze rather than the indoor environment remaining comfortable. Seniors residences and healthcare facilities may have more stringent standards.

Is it possible to develop simple models for daylighting and natural ventilation? Again, vital signs attempt to reliably indicate passive performance potential, not provide a detailed analysis of dynamic behavior. There is considerable research needed to develop simple assessment tools for daylighting and natural ventilation at the schematic design stage that are highly correlated to more sophisticated simulation models and subsequently confirmed by field measurements in built works. Key performance indicators must reliably predict outcomes in relative, if not absolute, terms.

Can durability and resilience be assessed in a straightforward manner? These types of indicators can be better assessed in existing buildings than at the design stage because the actual building becomes the observable model. There are heuristic methods for assessing durability and resilience potential at the design stage, but they will necessarily rely on quality assurance and commissioning to verify this potential has been realized in the constructed artifact. Whenever expert heuristics are needed to conduct a performance assessment, there is margin of error due to the likelihood of variation in consistency among practitioners. Modern medicine has discovered that vital signs only predict the likelihood of a particular state of health, not provide an absolute guarantee of vitality, absence of disease or longevity.

*Modern medicine has discovered that vital signs only predict the likelihood of a particular state of health, not provide an absolute guarantee of vitality, absence of disease, or longevity.*

In regards to existing buildings, vital signs can be used to inform retrofit strategies that address the intrinsic potential of the existing armature, and measures that can effectively enhance critical performance indicators.

For both new and existing buildings, vital signs are not exclusively paper exercises. The ratings assigned to a building at the design stage would be followed by actual in situ measurements of passive performance, and the rating adjusted accordingly. Implicit in the idea of vital signs are post-occupancy evaluations intended to empirically rate performance and help refine the parameters and thresholds underlying the derivation of the indicator ratings themselves. The purpose of much of the related research would be to develop the highest possible agreement between predicted and measured passive indicator ratings.

For the meantime, here's some feedback you can provide regarding this green paper, if you are so inclined:

1. In addition to being significant, should key performance indicators also be comprehensive, universal, timeless?
2. What is the best way to explain that a building with exemplary performance indicators can have wildly varying site energy use intensities depending on occupancy and use?
3. Are there any passive performance indicators that have not been identified or discussed, but that are significant and deserve to be considered?
4. How long should it take to conduct an assessment of key performance indicators for a typical new building design, and how simple should the tools be that are so deployed?
5. What degree of accuracy and precision is good enough to get on with intelligent design?<sup>13</sup>

Implicit in the idea of vital signs are post-occupancy evaluations intended to empirically rate performance and help refine the parameters and thresholds underlying the derivation of the indicator ratings themselves.

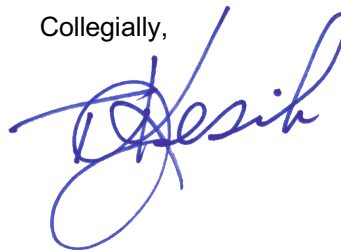
## **To All Concerned Building Scientists**

The idea behind this green paper was to circulate the notion of vital signs for buildings and start a discussion among people who have an interest and expertise in building performance assessment. Sometimes we discover early on that an idea is bigger than any one of us can ever be individually. Something almost everybody now recognizes is that building performance simulation risks becoming an unsustainable design decision support mechanism. Putting every building through detailed performance assessment using sophisticated simulation tools is no guarantee of high performance buildings. The output from simulation exercises like conventional energy modeling does not promptly signal critical indicators of passive systems performance.

In practice, sophisticated simulation tools should only be used to refine designs that have first been nearly optimized by observing vital signs. Advanced modeling techniques may also be used to identify critical parameters affecting performance and point the way to non-typical situations to deliver high performance solutions. But they are not very nimble tools at the early design stages unless they can be deployed to reveal vital signs to better guide the integrated design process. And their current trajectory will not render apparent the need for minimum levels of passive systems performance in building codes. Vital signs are the only means of enabling the average building design practitioner to cope with escalating demands by society for high performance building technology.

Readers of this paper are respectfully requested to share their views with the author, and are encouraged to circulate this green paper among colleagues in order to gain their perspectives.

Collegially,



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## Endnotes

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<sup>1</sup> Passive survivability implies a delineation of passive and active systems in buildings. For the purposes of this green paper, a system may be considered passive if it continues to provide service without external inputs of energy. Since buildings are intended for human habitation, the actions of inhabitants may be considered part of the passive systems, such that opening and closing windows or shutters, are simply enabling means of manipulating external resources, such as heat, light and air. For an insightful paper on this topic, check out: [http://proceedings.ases.org/wp-content/uploads/2014/02/SOLAR2013\\_0240\\_final-paper.pdf](http://proceedings.ases.org/wp-content/uploads/2014/02/SOLAR2013_0240_final-paper.pdf) This discussion becomes more interesting when wood burning appliances and photovoltaic panels are considered. Buoyancy vented wood burning appliances may be considered passive compared to HVAC equipment that is dependent of electricity for its operation, but they depend on an external source of energy (biomass) to operate. Photovoltaic panels actively generate electricity when the sun shines, yet they are as passive as passive solar heating. From a passive survivability perspective, there are also different aspects such as thermal autonomy, water autonomy, etc. It becomes important to qualify the survival scenario in order to identify which passive systems come into play.

<sup>2</sup> For an excellent discussion of how the modeling game is currently playing out in North America's building industry, check out High Cholesterol Buildings at: [http://urbangreencouncil.org/sites/default/files/high\\_cholesterol\\_envelopes.pdf](http://urbangreencouncil.org/sites/default/files/high_cholesterol_envelopes.pdf) There are a also number of related reports and references pertaining to the environmental performance of buildings at: <http://urbangreencouncil.org/initiatives/improving-building-envelopes> Key performance indicators for energy use in commercial buildings have been developed by the New Buildings Institute. <http://newbuildings.org/index.php?q=kpi> Unfortunately, the approach taken in a July 2011 white paper does not delineate between passive and active systems. <http://newbuildings.org/sites/default/files/SensitivityAnalysisReport.pdf>

<sup>3</sup> One of the inspirations behind the topic of this green paper came from one of my close relations. My wife's grandfather used to say that nobody makes wine - wine makes itself. Wine can only be as good the grapes picked from the vine and the best a vintner can do is approach the grape's inherent potential. The wine cannot be any better than the quality of the grape, but it can be made worse by premature harvest, improper processing and fermentation, storage under less than ideal conditions and during bottling. In this sense, the idealized design of buildings is like the grape, and how we procure, construct, commission, operate and maintain our buildings, determines if they perform to their full potential. Every building has its upper limit of performance potential that can either be realized or made worse by occupancy - it can never be any better than its constituent physical attributes. And so the idea is to discover what are those attributes and how to apply relatively straightforward metrics that reveal key performance indicators - to bite the grape and taste it, so to speak.

<sup>4</sup> Emergency backup power systems in buildings are seldom sized to operate all active systems at their full capacity. The provision of combined heat and power systems as a substitute for electrical generators is part of an increasing trend to improve resiliency, but even these systems are seldom sized to fully power all active systems.

<sup>5</sup> Interior finishes and fixed building services, such as roof drains and rainwater leaders operating under gravity, are also part of the passive systems, along with vertical means of access and egress, such as stairs. The latter example illustrates the importance placed on passive systems in health and safety codes. No one would ever imagine constructing a multi-storey building with only an elevator (active system), but no stairs (passive system).

<sup>6</sup> Levitt et al. have proposed thermal autonomy as both a metric and implicit design process that links occupant comfort to climate, building fabric, and building operation. Their thermal autonomy metric measures how much of the available ambient energy resources a building can harness as opposed to how much energy the active systems will consume. For a full discussion of this subject, download: [http://www.coolshadow.com/research/SB13VancouverProceedings\\_ThermalAutonomy.pdf](http://www.coolshadow.com/research/SB13VancouverProceedings_ThermalAutonomy.pdf)

<sup>7</sup> Resilience, like durability, is not assessed using quantitative metrics alone. There are many aspects of a building design and the features it incorporates that must be assessed using expert heuristics rather than some form of analysis or simulation. For an recent guide to building resilience, check out: [http://urbangreencouncil.org/sites/default/files/2013\\_brtf\\_summmaryreport\\_0.pdf](http://urbangreencouncil.org/sites/default/files/2013_brtf_summmaryreport_0.pdf)

<sup>8</sup> High brow architecture is diametrically opposed to any notion of standardized building designs for typical buildings. "*Why be original when you can be good,*" is considered blasphemy in many architecture design circles, and yet the most regular and ordinary of buildings have provided the highest levels of life cycle service (and often house the offices of architects who oppose archetypal design). Cars, electronics, computers and clothing are practically all mass produced and only the most eccentric and wealthy members of society insist on bespoke versions of these goods. Somehow, the idea of taking an archetypal building form that embodies high performance characteristics, and simply customizing it in minor ways to reflect personal taste and local context, is yet to be embraced by builders and developers – they tend to select inferior (cheap) design precedents. Architects look upon those members of their profession who deliver banal mass production buildings as a lower caste that has betrayed the design discipline. Yet they all use the same laptops, tablets and smartphones. The architecture populating contemporary urban development reflects this internal contradiction.

<sup>9</sup> Traditional notions of skin load dominated versus internal load dominated buildings are now on shifting grounds. Internal load dominated buildings consume most of their energy by occupant activities, appliances, equipment and processes, independent of energy transfers across the enclosure (e.g., lighting, plug loads, domestic water heating, etc.). Skin load dominated is taken to mean most of the energy consumed by the building is for space conditioning (heating and cooling) due to loads induced across the enclosure. These definitions are premised on the predominant fraction of the total building energy use ascribed to internal demands versus demands across the enclosure. However, if these terms are to be defined according to space conditioning energy only, then internal load dominated means the majority of energy consumed for heating and cooling is driven by internal gains excluding insolation. Skin load dominated means space conditioning energy is dominated by exchanges across the enclosure, including insolation. According to the first set of definitions, most new buildings, including houses, are now internal load

dominated, and will become increasingly so as the thermal efficiency and airtightness of the enclosure is improved. When the second set of definitions is applied, there are still some variations in building energy profiles. Domestic water heating and computers have tilted traditional energy end uses, especially in buildings with efficient enclosures. LED lighting will throw the next curve ball.

<sup>10</sup> For an example of a public education bulletin that explains key features of condominium buildings, check out: <https://www.daniels.utoronto.ca/sites/daniels.utoronto.ca/files/kesik-buythatcondo.pdf>

<sup>11</sup> Building enclosure commissioning and post-occupancy evaluations are not yet common practice in North America. There is no central repository where actual performance data may be reported. In this sense, the building industry is at a stage of its evolution where it does not possess critical information needed to advocate for better performing technology simply because there are no formal feedback loops. Imagine if there was no world health organization to which member nations reported the incidence of disease and causes of death. There would be no way of knowing if segments of a population were exhibiting health problems and if these were abnormally high to the point of being epidemic. Also imagine if automobile manufacturers did not track the parts and service administered to their products, and had no way of alerting car owners of defects requiring callbacks. The building industry remains a pre-industrial guild business in many respects.

<sup>12</sup> The natural ventilation rate that is selected should conform to what may be expected to provide acceptable indoor air quality in the types of occupancy the building may serve over its useful service life. Based on *ANSI/ASHRAE Standard 62.1-2013 - Ventilation for Acceptable Indoor Air Quality*, a value between 0.5 and 1.0 L/s.m<sup>2</sup> will adequately ventilate most occupancies in buildings, provided the natural ventilation effectiveness is reasonably high. It should be recognized occupancy may be exceeded under a passive survivability scenario, and discomfort may discourage providing the above-noted natural ventilation. Under such scenarios, it is likely ventilation rates would be significantly reduced to the absolute minimum levels needed for respiration. It should also be noted that solar gains are generally excluded from the passive thermal survivability calculation, yet natural ventilation rates could be generously increased during such periods of the day to flush the building air while conserving stored heat energy.

<sup>13</sup> One of the geotechnical professors at the University of Toronto used to tell his students, "Don't try to measure a horse turd with a micrometer." If we observe how buildings are actually constructed, how windows are not properly washed, and air handling filters seldom changed, it becomes obvious most buildings are only an approximation of their idealized design drawings and specifications. I often wonder if carrying even one decimal place is being overly optimistic, almost verging on naiveté. It is important to appreciate when adequate accuracy has been achieved, otherwise the perfect may become the enemy of the good. For an example of how key performance indicators can rapidly escalate in complexity and become burdensome to generate, check out: [http://www.iisbe.org/system/files/private/786final - Sustainability Indicators in Buildings, 2011 July.pdf](http://www.iisbe.org/system/files/private/786final-Sustainability Indicators in Buildings, 2011 July.pdf)