Exploration of a new forward-looking site-specific reference house approach for building energy performance modeling

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EXECUTIVE SUMMARY

Buildings currently account for 40% of energy use in most countries, putting them among the largest end-use sectors. Moreover, by reducing overall energy demand, improving energy efficiency in buildings can significantly reduce carbon dioxide (CO_2) emissions from the building sector [1]. In the Province of British Columbia, buildings currently account for approximately 22% of the energy consumed, and 12% of the greenhouse gas emissions released into the atmosphere [2]. While other factors affect energy use in buildings, including operation, maintenance, and the level of services provided, if a building does not start with energy-efficient infrastructure such as those required by an energy code, it will never achieve its full energy efficiency potential [5].

Hui and Cheung (1998) reported that building energy codes can help raise concern and awareness of building energy conservation in society and overcome the market barriers to energy-efficient design in buildings [6]. However, there has been growing sentiment that energy codes in their current form are getting too complex, change too often, limit design flexibility, don't achieve their desired outcomes, have reached a point of diminishing returns, and do not consider the building as an integrated system [5].

In addition to the environmental impacts of the energy performance of buildings, their financial valuation can also act as a catalyst to change consumer and investor behavior toward energy efficiency; having in mind that energy efficiency won't make much difference in financial valuation of buildings by 2032 when codes get to net-zero targets [7]. The point is that for the real estate industry, the value of a greener, more energy-efficient asset is easier to ascertain with an understanding of an evaluative reference [3]. However, defining a baseline building becomes a complex design problem, with many acceptable solutions [5].

Since the baseline building is designed based on energy codes, it would be reasonable to examine the different format of codes in regulating energy efficiency including (Table 1):

- Prescriptive Approach
- Prescriptive Packages
- Capacity Constrained Approach
- Predictive Performance Approach/Performance-Based Approach
- Outcome-Based Approach
- An Independent, Fixed Baseline Approach

Code Approach	Examples	Compliance Basis		Baseline Dimensions					
				Design		Time		Test	
		Reference Model Baseline Used	Energy Bills Used	Dependent	Independent	Current	Stable	Equivalent	Differential
Prescriptive Options:									
Prescriptive (with System Tradeoffs)	90.1; IECC; T24[a]	No	No	NA[e]	NA	NA	NA	NA	NA
Prescriptive Packages	Res. Envelope T24[a]	No	No	NA	NA	NA	NA	NA	NA
Predictive Performance Options:									
Equivalent to Current Dependent Baseline	90.1 Chapter 11	Yes	No	x		x		x	
Differential to Current Dependent Baseline	2012 IECC Performance	Yes	No	x		x			x
Equivalent to Current Independent Baseline	T24-2013[a]	Yes	No		x	x		x	
Differential to Current Independent Baseline	90.1 Appendix. G; LEED; 189.1[b]	Yes	No		x	x			x
Differential to Stable Independent Baseline	90.1 Addendum bm[c]	Yes	No		x		x		x
Equivalent to Energy Use Index (EUI) Target	Canadian Energy Code Green Globes; Seattle	Yes	No		x	x		x	
Outcome Performance Options:									
Outcome Based Code; EUI Target	Seattle; Sweden	No	Yes	NA	NA	NA	NA	NA	NA
Outcome Based Code; Differential to Stable Independent Baseline Prediction[d]	No current example	Yes	Yes		x		x		x

(a) T24 = California Title 24 (CEC 2013).
(b) A differential predictive performance approach has recently been approved for inclusion in ASHRAE Standard 189.1-2014.
(c) Addendum bm to Appendix G of Standard 90.1 (Rosenberg and Eley 2013).
(d) Outcome with predictive model could have other baselines with similar characteristics as predictive performance options.
(e) NA is not applicable.

Table 1: Characteristics of code formats and approaches [5]

Among them, a differential predictive approach with a stable and independent baseline allows a reliable comparison to a known baseline, normalizes the performance target to each specific building, enhances the ability to track improvement over time, requires that low-efficiency prescriptive choices be offset with more efficient choices, rewards designers for optimization, paves the way for automated performance modeling, and markedly improves predictive accuracy [5].

This report aims to evaluate a the potential of using a new forward-looking reference house approach that is based on a future desired performance level, instead of past minimum standards. The report will also explore other performance metrics that could be examined to better promote resiliency, and will explore approaches where site-specific design constraints could be considered in evaluating the reference building.

The path through defining the new reference house approach can include (Figure 1):

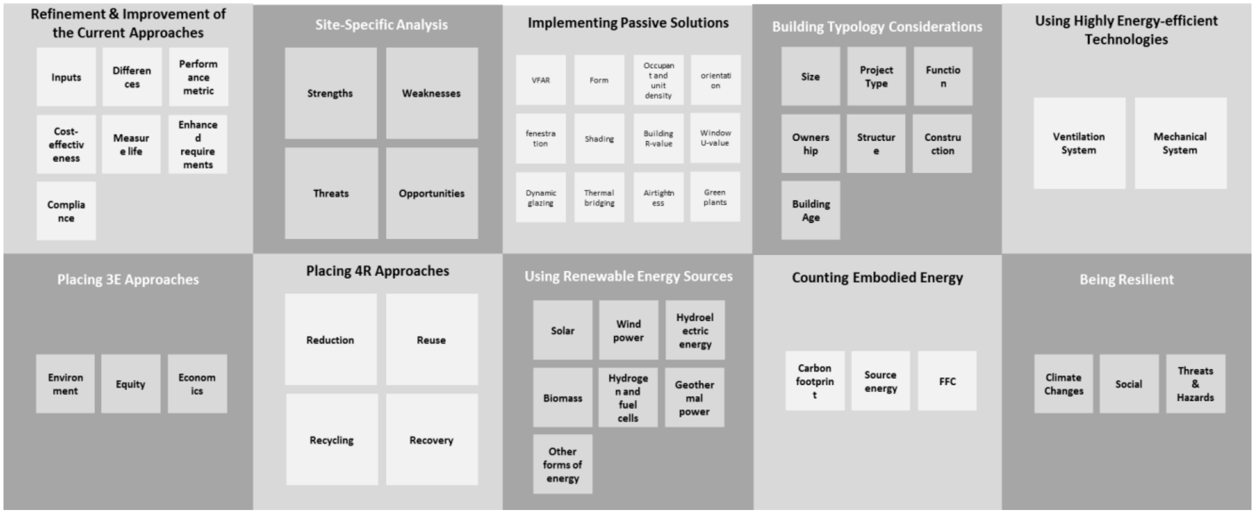


Figure 1: The new reference house performance matrix

- **Refinement and Improvement of the Current Approaches Through:**
  - Defining the set of inputs that would be used in the baseline building modeling
  - Determining essential differences between the baseline and the proposed buildings inputs in the modeling process
  - Considering an appropriate performance metric
  - Defining cost-effectiveness borders
  - Counting impact of measure life on performance trade-offs
  - Enhancing mandatory requirements
  - Specifying ways of Compliance
  - Considering building alterations
  - Eliminating gas process equipment

- **Site Analysis**
  - Strengths
  - Weaknesses
  - Opportunities
  - Threats

- **Building Typology Considerations**
  - Size
  - Project Type
  - Function
  - Ownership
  - Structure
  - Construction
  - Building Age

- **Using Highly Energy-Efficient Technologies**

- Ventilation Systems
- Mechanical Systems

- **Implementing Passive Solutions**
  - Lowering VFAR (vertical surface area to floor area ratio)
  - Simplifying Form
  - Considering Occupant and Unit Density
  - Optimizing Orientation
  - Optimizing Fenestration
  - Advancing Shading Strategies
  - Increasing Building R-Values
  - Decreasing Window U-Values
  - Using Dynamic Glazing
  - Reducing Thermal Bridging
  - Increasing Airtightness
  - Using green plants on and around buildings

- **Placing 3E Approaches**
  - Environment
  - Equity
  - Economics

- **Placing 4R Approaches**
  - Reduction
  - Reuse
  - Recycling
  - Recovery

- **Using Renewable Energy Sources**
  - Solar
  - Wind Power
  - Hydroelectric energy
  - Biomass
  - Hydrogen and fuel cells
  - Geothermal power
  - Other forms of energy

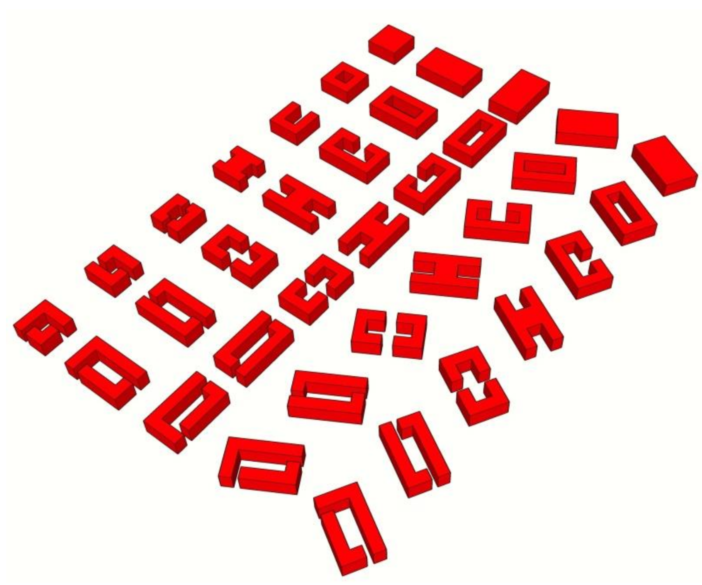


Figure 2: The influence of the building forms on social interactions.

- **Counting Embodied Energy Rather Than Site Energy**
  - Determining buildings' "carbon footprint"
  - Measuring source energy rather than site energy
  - Pondering full fuel cycle as an alternative to source energy where possible

- **Being Resilient (Figure 2)**
    - Being resilient to climate changes
    - Being socially resilient
    - Being resilient to unexpected events, threats, and hazards

Consequently, a new forward-looking site-specific net-zero (Figure 3) reference house approach is a top-down approach being modeled to a net-zero standard with results being presented in a % more consumption than the reference building. Such a reference is stable enough to not be affected by ever-changing prescriptive paths. It is to effectively establish a framework to design a fixed scale.

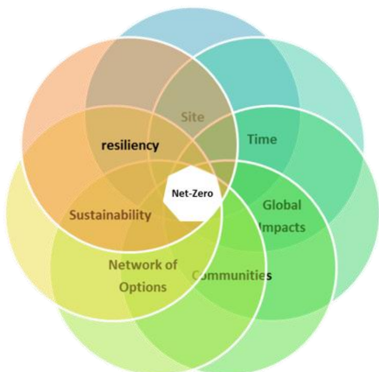


Figure 3: Criteria defining the borders of the net-zero concept

Following potentials and challenges can be mentioned for the new reference house approach.

Potentially, the new reference house approach:

- is a comprehensive, flexible, and high-compliant approach all contribute to lower energy use of buildings.
- is technically feasible, economically justified and environmentally beneficial.
- ensures low performing design options are eliminated or balanced with high performing options.
- considers the building as a system, accounting for building system and climate interactions.
- expands its scope to cover post-occupancy energy use.
- expands its scope to include those loads within a building that are not currently regulated such as cooking equipment, plug loads, industrial processes, computing equipment, etc.
- mentions on-site renewable energy as a possibility to enable a path to net-zero energy buildings.
- counts embodied energy during the life-cycle of a building as one of the possibilities to fully cover the actual energy use
- provides a context for enhanced mandatory requirements
- is stable enough to not be affected by ever-changing prescriptive paths.
- can result in flexible design approaches giving a trade-off opportunity to designers
- eliminates the influence of different simulation programs on predicting building energy use
- balances occupant's effect on building energy performance by placing passive solutions
- considers greenhouse gas emissions as the primary metric
- counts on trade-offs between expensive high-tech solutions and passive solutions

- integrates mitigation and adaptation

However, the new approach faces the following challenges:

- It would take more time to be modeled and implemented
- It would need the contribution of professionals in different fields
- It would require either further research or deeper insight in contexts that have not been covered in the previous approaches or not examined profoundly

As a result, the future vision is based on code development being led by a specific approach to predictive energy, ecological, economic, and social performance combined with building-specific prescriptive packages that are designed to be both cost-effective and energy-efficient and to achieve a desired level of performance. To make the proposed vision more clear, it would be beneficial to re-mention the most important challenges in regulating energy efficiency led by current code formats alongside remarking the main potentials of the code future vision in defining a forward-looking reference building.

Having the aforementioned considerations and constraints of the proposed reference house approach in mind alongside all the pros and cons of the current code visions (Table 1), we can conclude that:

Significant problems of the current code formats in regulating energy efficiency can include (Table 2):

- Variation in energy use
- Diminishing returns
- Limited credit for good design choices
- Difficult to track progress
- Performance path rules can’t keep pace with prescriptive changes
- Expected savings may not be realized
- Unregulated loads ignored
- Too many performance approach options
- Modeler influence on building energy modeling

On the other hand, potentials of the future vision of codes in defining a new forward-looking reference building can be (Table 2):

- Considering greenhouse gas emissions as one of the metrics
- Counting on trade-offs between expensive high-tech solutions and passive solutions
- Integrating mitigation and adaptation
- Including on-site renewable energy

	ASPECT	THE NEW APPROACH	THE CURRENT APPROACHES
COMPARING	Building Typology	Uses more detailed classification	What determined as a classification for reference buildings is inefficient. For example, ASHRAE standard’s classification is mostly function-based and Energy Step Code’s is generally size-based.

	Envelop	In addition to thermal properties, it takes into account different orientations' special requirements such as WWR and shadings, as well as site-specific considerations such as view, proximities, and special features.	Takes into account thermal properties and some of the orientation-based features
	Internal Loads	Counts regulated and unregulated loads	Mostly focus on regulated loads
	Ventilation	Mainly focuses on using natural ventilation, and using HRV with an economizer when needed.	Mainly focuses on mechanical ventilation with an integrated economizer. Energy Step Code mention the possibility of natural ventilation by window-design options as well as using HRV systems
	Highly Energy-Efficient Technologies	Uses Highly Energy-Efficient Technologies.	Uses Highly Energy-Efficient Technologies.
	HVAC Systems	Uses high performance, the most energy-efficient, carbon-neutral and independent systems.	Dependent on the proposed building
			Independent of the proposed building
	Reference House Typology	A top-down stable and independent baseline.	A dependent and time-variable baseline
			No baseline
			A bottom-up stable and independent baseline
	Sustainability Approaches	Ponders 3E and 4R dimensions.	Takes into account the energy sub-dimension of the ecology dimension.
	Option Combinations	Uses the least energy-consuming combinations of options.	Uses the most cost-effective combinations of options.
	Material	Considers the full life cycle for durability, adaptability, and flexibility.	Uses standard materials.
	Environmental Analysis	Considers the impact of all phases of production, operation, maintenance, deconstruction and re-use on energy, water, and land use, global warming and ozone depletion potential, toxic emissions (to air, land, and water), and the impact on human health.	Counts the impact of operational energy.
	Vision	Predictive energy, ecological, economic, and social performance combined with building-specific prescriptive packages that are designed to be both cost-effective and energy-efficient, and to achieve a desired level of performance.	Prescriptive
			Capacity constraint
			Predictive energy performance
			Outcome-based
CONTRASTING	ASPECT	THE NEW APPROACH	THE CURRENT APPROACHES
	Performance Target	Source Energy and FFC Energy Use Index	Energy Cost Index
			Site Energy Use Index
	Geometry	Considers trade-offs between social resilience and energy efficiency.	Solely cares about energy efficiency
	Lighting	Gives prominence to passive solutions such as daylighting.	Mostly focuses on electrical lighting
	Schedules of Operation	Sets an optimized, fixed schedule based on weather data.	Generally, adjusts the reference house schedules to the proposed building.
	Resilience	Ponders social resilience as well as	Ignores resilience

		resilience to climate changes and unexpected events, threats, and hazards.	
	Site-Specific Features	The given constraints of a building site would be modeled similarly in both the reference and proposed design (e.g. lot size, orientation, topography, solar access, shading from adjacent structures, etc.)	Ignores site-specific features
	Passive Approaches	Mainly concentrates on passive solutions to achieve net-zero targets.	Ignores the passive solutions in defining energy-efficient approaches.
	Embodied Energy	Considers buildings and components lifecycle, source energy, and FFC energy while counting the energy consumption and GHG emission.	Counts site energy for energy consumption and GHG emission calculations.
	Renewable Energy Sources	Uses renewable energy sources to achieve net-zero targets.	Does not address renewable energy sources.

Table 2: Comparing and contrasting current and proposed vision

PROJECT OUTLINE

1 INTRODUCTION

Buildings currently are among the largest end-use sectors. The International Energy Agency (IEA) has identified the building sector as one of the most cost-effective sectors for reducing energy consumption, with estimated possible energy savings of 1 509 million tonnes of oil equivalent (Mtoe) by 2050. Moreover, by reducing overall energy demand, improving energy efficiency in buildings can significantly reduce carbon dioxide (CO2) emissions from the building sector, translating to possible mitigation of 12.6 gigatonnes (Gt) of CO2 emissions by 2050 [1]. In the Province of British Columbia, buildings currently account for approximately 22% of the energy consumed, and 12% of the greenhouse gas emissions released into the atmosphere [2]. As mentioned, since buildings use large amounts of energy with significant short-term economic and long-term environmental costs, building energy efficiency, therefore, is a valuable comparative indicator [3].

Building performance is determined by multiple factors, including building function and design, occupant behavior, equipment degradation and failure, and climate aging of building materials [4]. While other factors affect energy use in buildings, including operation, maintenance, and the level of services provided, if a building does not start with an energy-efficient infrastructure as required by an energy code, it will never achieve its full energy efficiency potential. Initial construction is the best time to significantly influence building energy efficiency; otherwise, there is a lost opportunity, as it is rarely as cost-effective to retrofit a building later [5].

Hui and Cheung (1998) reported that building energy codes can help raise concern and awareness of building energy conservation in society and overcome the market barriers to energy-efficient design in buildings. They can also encourage the development of energy-efficient building products and form a basis for assessing building energy performance and developing energy efficiency policy [6]. Energy codes are intended to minimize energy use in buildings, resulting in cost savings for building owners and occupants, decreased power demands, and reduced environmental impacts. However, based on the U.S. Department of Energy report, there has been growing sentiment that energy codes in their current form are getting too complex, change too often, limit design flexibility, don't achieve their desired outcomes, have reached a point of diminishing returns, and do not consider the building as an integrated system. Besides, the ever-upgrading trend in component efficiency, as one of the current approaches to achieve energy efficiency, will not result in net-zero approach by 2030, which has been a stated goal of many stakeholders in the buildings industry. On the other hand, adding requirements for on-site renewable energy can be a necessity to achieve the net-zero goal, in addition to a more system-based, passive, site-specific, and resilience-oriented approach to energy efficiency [5].

In addition to the environmental impacts of the energy performance of buildings, their financial valuation can also act as a catalyst to change consumer and investor behavior toward energy efficiency; having in mind that energy efficiency won't make much difference in the financial valuation of buildings by 2032, when codes get to net-zero targets [7]. The point is that for the real estate industry, the value of a greener, more energy-efficient asset is easier to ascertain with an understanding of an evaluative reference [3]. However, defining a baseline building becomes a complex design problem, with many acceptable solutions [5].

A baseline building is a model similar to the proposed building with different parameters that are set by the energy codes and performance rules. The baseline has characteristics in three dimensions: ***design*** parameters, ***time*** reference, and ***test*** criteria. ***Design*** indicates if the baseline design parameters are dependent on the proposed building design or follow an independent rule set. A dependent design parameter in the baseline tracks the design decisions in the proposed building but its efficiency is adjusted to meet prescriptive code values. An independent baseline with parameters determined by the building program rather than the design solutions may differ proposed building models. Therefore, the energy impacts of those differences are captured in the comparison. ***Time*** indicates if the baseline parameters are updated to match the current code or based on a stable reference code, typically a historical or earlier version of the same code. A stable baseline allows easier tracking of code improvements, changes less often and allows for easier development of automated software. ***Test*** indicates if the proposed building must be equivalent to (no more energy use or cost than) the baseline or differential, meaning it must beat the baseline by an established percentage.

1.1 DIFFERENT APPROACHES TO REGULATE ENERGY EFFICIENCY IN BUILDING CODES

Since the baseline building is designed based on energy codes, it would be reasonable to examine the different format of codes in regulating energy efficiency. Consequently, six different approaches can be defined including prescriptive, prescriptive package, capacity constraint, predictive performance, outcome-based, and finally fixed baseline approach.

- **Prescriptive Approach**

Compliance through the prescriptive path is achieved by designing each building component to meet a minimum efficiency level required in energy codes [8].On the one hand, it is simple to use and follow [6]. On the other hand, it is restrictive in nature as it does not credit good building design [8], tend to limit development of new technologies and techniques, is not able to consider the interactions between the building systems and measures that would optimize the combined performance, and it is a barrier to innovation [5,6]. Besides, it has reached the point of diminishing return as incrementally increasing component efficiency is unlikely to be cost-effective and will not achieve the net-zero energy targets [5, 8].

According to the U.S. Department of Energy, two reasons could be mentioned for prescriptive approach constraints. First, this format of code in its current form is getting too complex, change too often, limit design flexibility, and don’t achieve their desired outcomes. Strictly speaking, a prescriptive code requires a particular defined component quality, such as insulation R-value in a wall of a particular framing type. And second, prescriptive criteria are usually set at the limit of cost-effectiveness using assumptions that must apply to a wide range of buildings. Calculations use national average energy rates, equipment costs, and other economic assumptions as well as standard operational assumptions and selected climate locations. This results in criteria that are generally cost-effective on a national scale but may not necessarily be for any individual building. This reality necessitates a relatively conservative approach to setting prescriptive requirements.

The current focus on prescriptive codes has limitations including significant variation in actual energy performance depending on which prescriptive options are chosen, a lack of flexibility for designers and developers, the inability to handle optimization that is specific to building type and use, the inability to account for project-specific energy costs and the lack of follow-through or accountability after a certificate of occupancy is granted [5].

- **Prescriptive Packages**

A prescriptive package approach provides more flexibility as compared with the rigid prescriptive requirements [6] by putting together packages of items that are intended to reach a desired minimum level of performance. An example might be a higher efficiency heating system in conjunction with either larger window areas or cathedral ceilings with less insulation. Rather than individual prescriptive requirements for individual components, packages of linked requirements that meet a pre-determined target performance level could be developed [5]. Even though the system/component performance is a partial-performance path and it combines the consideration of several parameters and provides "trade-off" among them in the compliance process [6], it is a kind of temporary solution to meet the codes minimum requirements and provide minimum energy performance level. An important issue affects the development of prescriptive packages including products covered by federal efficiency regulations such as some boilers, furnaces, service water heaters, air conditioners, motors, transformers, and refrigeration equipment [5].

This approach sounds to be more flexible but could be more complicated while considering 8,944 possible combinations of the 9 prescriptive options for the sample analysis performed for one building type in one climate zone which were within 97% to 100% energy cost of the primary package; all reaching a desired minimum level of performance. Also, it is not well-defined to be the most energy-efficient one.

- **Capacity Constrained Approach**

Capacity constraint refers to a code or standard that expresses its requirements as a limit on one or more service capacities (e.g., maximum capacity of the electric service panel (kilowatts) or natural gas service (therms/hour)). The capacity limit can be applied to equipment, like total heating or cooling capacity. Unlike a performance-based code, however, a capacity constraint-based code imposes very real limits on the actual building because it acts as a governor so that when the building is occupied, the capability to use energy is limited. To some degree this is the opposite of a performance approach or outcome-based approach (see below) in that instead of being based on the amount of energy use over time with no specific limit on peak use, it addresses a limit on-peak use - that occurs a few hours per year- without a specific limit on the timeframe over which that use occurs. Of importance to compliance verification, a limit on-peak use or capacity can be easily addressed before occupancy, while a limit on use over time can only really be assessed in a post-occupancy situation. [5]

- **Predictive Performance Approach**

Performance approach is the practice of thinking and working in terms of ends rather than means. It is concerned with what a building or building product is required to do, and not with prescribing how it is to be constructed. Trend towards the performance approach arises from the accelerating rate of change of building technologies, the availability of improved space-planning and design techniques and the higher expectations of the conditions to be provided by buildings. The performance-based approach in building energy code is important for promoting innovation and new techniques in energy-efficient building design and minimizing the limitations of prescriptive criteria. Moreover, it provides a clear definition of the levels of health, safety, and other societal issues that a particular country has chosen to establish as a minimum for its society [6]. This approach refers to code compliance formats that are based on predicted building performance using energy simulation.

A whole building predictive performance path allows some items to be less efficient in exchange for other items being more efficient than the prescriptive approach. It also provides additional flexibility as it allows the designer to use a variety of materials and approaches that may not meet prescriptive requirements. The typical goal of a performance approach is equivalent or better annual performance based on an hourly building energy simulation. In predictive performance approaches, a model of the proposed building is compared to either a hard target (such as energy use or energy cost index (ECI)) or a reference baseline (Figure 4). A target can be set by building type and climate or be adjusted based on building occupancy and requirements. Predictive performance allows for a compliant design solution that is more flexible than prescriptive solutions and can be optimized for a particular building's climate, operations, system interactions, and utility rate structure[1] [5].

The performance-based approach often requires a higher level of skills from the designers or users and could be more complicated in the implementation and validation. One major challenge here is to balance flexibility against complexity in the code and this requires careful consideration of the compliance process and the proficiency of the local building industry. As well, verification is an important component of the performance-based approach because it will be necessary to demonstrate that a particular building solution will meet given performance criteria [6]. Nevertheless, it is quite difficult to set a fair and appropriate energy use target and even more difficult to produce a consistent prediction of energy use for a particular building [5].

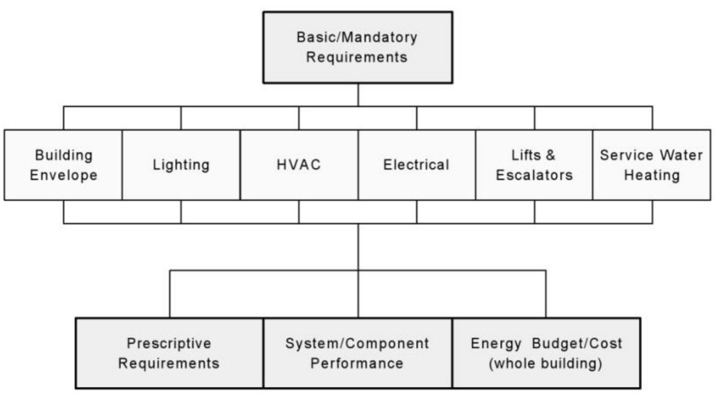


Figure 4: Major elements and compliance options for building energy codes [6]

- **Outcome-Based Approach**

Outcome-based is not a building design and construction approach, but more a method of compliance verification. It is based on verification of actual monitored energy consumption for a specified period after occupancy. Implicit in this approach is the assumption that the code is expressed in terms that can be verified by billing data (or other metered data), something not possible with a prescriptive code. An outcome-based approach could exist alone with a target developed based on building type and climate zone or layered on top of a performance-based approach with a customized performance developed via building simulation.

Unlike any of the other proposed approaches, an outcome-based approach readily embraces existing building energy use and allows such an approach to be readily applied to all buildings, not just new buildings. The outcome-based approach would require substantial new enforcement paradigms and infrastructures. The necessity of post-occupancy evaluations, uncertainties related to occupants and their habits, issues of building energy data confidentiality, and the potential requirement for corrective post-occupancy reconstructions makes this option difficult to envision in the near term for private sector buildings.

The outcome-based approach provides the ultimate in confirmed energy performance. The actual energy use of the building is compared to the desired target. No Hardly can anyone deny the fact that benchmarking actual building energy use is a vital part of any energy management program and could become an extension of building energy codes. U.S. Department of Energy studies have shown that buildings don't always achieve the results predicted by simulation, and measurement is necessary to take corrective action and demonstrate movement toward an energy goal. A major benefit of an outcome-based approach is that it considers all energy used by a building. Controlling the energy use of unregulated loads cannot simply be ignored. However, is an outcome-based approach a valid replacement for a building design and construction energy code? Some issues stand in the way such as timing, scope, appropriate targets, and impact of the energy service level. There would be more issues considering the repercussion of an unmet outcome especially when the approach is solely based on outcomes and not gives prominence to the performance-based approach as a pre-requirement.

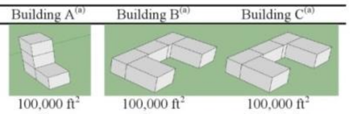
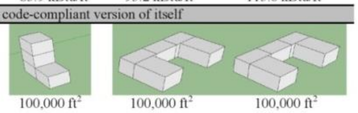
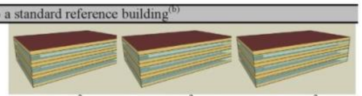
Therefore, while an outcome-based approach would be a valuable expansion of energy efficiency regulation for all buildings, it cannot be a replacement for a design and construction energy code. Instead, an outcome-based approach can be coupled with a design and construction code, focused on the efficiency of the building infrastructure to ensure building energy use is minimized during the building life cycle [5].

- **An Independent, Fixed Approach**

The fixed baseline approach is being piloted by LEED as an alternative to the 2010 PRM for Energy and Atmosphere Credit 1, Optimize Energy Performance. The fixed baseline approach has multiple advantages. It provides a solution where a single model can be used for both code compliance and beyond code assessment. With a baseline, whose performance requirements don't change every three years users can focus on the development of technical expertise, software tools and verification systems instead of re-familiarizing themselves with a new set of rules for defining the baseline buildings. It also streamlines the code development process where each new version of the standard can focus on refining existing ruleset and establishment of market viable improvement targets, rather than trying to align itself with the improved set of prescriptive requirements of the new standard. In other words, to indicate the future performance levels in terms of a percentage better than reference, we need that percentage to stay the same over time. Also, allows one energy model or workflow to be used for multiple purposes: code compliance, LEED points, utility incentive programs, etc. Most importantly, a stable reference is also what is needed when doing a Step Code looking out to the future [2, 8, and 9].

With an independent baseline, the essential factors and items would be set, and differences in the proposed building would result in a credit or penalty. The dependent baseline doesn't credit energy-efficient design including use of thermal mass to flatten heating and cooling loads, optimized orientation, "right-sizing" of HVAC equipment, natural ventilation, and passive cooling (Table 3).

However, the challenge with a stable baseline is in creating the appropriate differential target. The differential target can be established by comparing current prescriptive requirements to the stable baseline, but the range of prescriptive choices means the level of efficiency defined by the available prescriptive options varies considerably. Choices need to be made regarding which prescriptive options define the desired level of performance [5].

	Building A[(a)]	Building B[(a)]	Building C[(a)]
Rated building			
Total floor area	100,000 ft^2	100,000 ft^2	100,000 ft^2
Heating fuel	Gas	Gas	Electricity
Heating equipment	Boiler (80% efficiency)	Boiler (80% efficiency)	Electric resistance heat (100% efficiency)
Modeled site energy use	32.9 kBtu/ft^2	36.5 kBtu/ft^2	34.0 kBtu/ft^2
Modeled source energy use	83.9 kBtu/ft^2	93.2 kBtu/ft^2	113.6 kBtu/ft^2
Method 1: Compare to a code-compliant version of itself			
Baseline building			
Total floor area	100,000 ft^2	100,000 ft^2	100,000 ft^2
Heating fuel	Gas	Gas	Electricity
Heating equipment	Boiler (80% efficiency)	Boiler (80% efficiency)	Electric resistance heat (100% efficiency)
Modeled site energy use	32.9 kBtu/ft^2	36.5 kBtu/ft^2	34.0 kBtu/ft^2
Modeled source energy use	83.9 kBtu/ft^2	93.2 kBtu/ft^2	113.6 kBtu/ft^2
Ratio of rated building and baseline building based on site EUI	1	1	1
Ratio of rated building and baseline building based on source EUI	1	1	1
Method 2: Compare to a standard reference building[(b)]			
Baseline building			
Total floor area	(53,628 ft^2)	(53,628 ft^2)	(53,628 ft^2)
Heating fuel	gas	gas	gas
Heating equipment	Furnace (78% efficiency)	Furnace (78% efficiency)	Furnace (78% efficiency)
Modeled site energy use	50.4 kBtu/ft^2	50.4 kBtu/ft^2	50.4 kBtu/ft^2
Modeled source energy use	174.6 kBtu/ft^2	174.6 kBtu/ft^2	174.6 kBtu/ft^2
Ratio of rated building and baseline building based on site EUI	0.65	0.72	0.67
Ratio of rated building and baseline building based on source EUI	0.48	0.53	0.65

(a) Assuming buildings A, B, and C are office buildings built to ASHRAE Standard 90.1-2007 in Baltimore.
(b) DOE reference building: medium office, new construction, compliant with ASHRAE Standard 90.1-2004 in Baltimore. Source: DOE EERE 2012c.

Table 3: An example of ratio calculations to compare the dependent and independent baseline [4]

There could be two opposite approaches in defining the fixed baseline concept: top-down and bottom-up. In the bottom-up approach, Standard 90.1[2]- 2016 fixes the baseline at 2004 efficiency levels, allowing each new code to specify a performance cost index target improvement over the previous version. In other words, with each future update to Standard 90.1, the stringency of the baseline will remain unchanged but the level of improvement relative to this baseline will be increased [8, 9]. There were two main reasons for settling in 2004 as the performance baseline. First, after 2004 the prescriptive requirements in Standard 90.1 started becoming too complex to develop clear rules that result in consistent modeling of the baseline. Second, the efficiency levels for lighting power and envelope components would make reasonable enhanced mandatory minimum requirements that can be used in conjunction with a performance or tradeoff path.

On the other hand, in the proposed top-down approach, the reference building could be modeled to a net-zero ready standard, and the results would be presented in a % more consumption than the reference building. Considering the highest performance in a forward-looking reference house approach first, provides a context for enhanced mandatory requirements, second, defines a straight forward path towards energy efficiency, and finally, broadens the current perspective to not be limited to the site energy consumption but consider GHG emission, source energy, full-fuel cycle, building life-cycle, etc.

1.2 DEFINING A NEW REFERENCE HOUSE APPROACH

As a part of the energy codes compliance process, any reference building should be based on a code format analysis in regulating energy efficiency. Consequently, a new reference house approach can be defined based on one of the aforementioned code formats, and a differential predictive performance method with a stable and independent baseline sounds to be the most practical one for the following reasons (Table 4):

- Predictive performance with energy use index (EUI) targets falls short since it is difficult to match individual building use to broad EUI targets.
- Outcome-based approach, while an essential approach that can be applied to all buildings as after-occupancy code compliance, is not a substitute for design and construction energy codes that focus on compliance at occupancy.
- As a bridge, prescriptive packages (such as EnergyStar, the Ontario Building Code, etc.) can provide a transition from the current component prescriptive approach to a performance only approach, while providing flexibility and improved energy equivalency.
- At some point in the future, tools that demonstrate predictive performance compliance may become so simple that there will no longer be a need for any prescriptive path.

		Compliance Basis		Baseline Dimensions					
				Design		Time		Test	
Code Approach	Examples	Reference Model Baseline Used	Energy Bills Used	Dependent	Independent	Current	Stable	Equivalent	Differential
Prescriptive Options:									
Prescriptive (with System Tradeoffs)	90.1; IECC; T24[a]	No	No	NA[e]	NA	NA	NA	NA	NA
Prescriptive Packages	Res. Envelope T24[a]	No	No	NA	NA	NA	NA	NA	NA
Predictive Performance Options:									
Equivalent to Current Dependent Baseline	90.1 Chapter 11	Yes	No	x		x		x	
Differential to Current Dependent Baseline	2012 IECC Performance	Yes	No	x		x			x
Equivalent to Current Independent Baseline	T24-2013[a]	Yes	No		x	x		x	
Differential to Current Independent Baseline	90.1 Appendix. G; LEED; 189.1[b]	Yes	No		x	x			x
Differential to Stable Independent Baseline	90.1 Addendum bm[c]	Yes	No		x		x		x
Equivalent to Energy Use Index (EUI) Target	Canadian Energy Code Green Globes; Seattle	Yes	No		x	x		x	
Outcome Performance Options:									
Outcome Based Code; EUI Target	Seattle; Sweden	No	Yes	NA	NA	NA	NA	NA	NA
Outcome Based Code; Differential to Stable Independent Baseline Prediction[d]	No current example	Yes	Yes		x		x		x

(a) T24 = California Title 24 (CEC 2013).
(b) A differential predictive performance approach has recently been approved for inclusion in ASHRAE Standard 189.1-2014.
(c) Addendum bm to Appendix G of Standard 90.1 (Rosenberg and Eley 2013).
(d) Outcome with predictive model could have other baselines with similar characteristics as predictive performance options.
(e) NA is not applicable.

Table 4: Characteristics of code formats and approaches [5]

Moreover, summarizing the various approaches considered here, Table 5 demonstrates that the differential predictive performance approach with a stable and independent baseline has the most beneficial qualities for a building design and construction code providing the best accuracy and potential for a highly automated approach that could eventually be applied to most buildings.

A differential predictive approach with a stable and independent baseline allows a reliable comparison to a known baseline, normalizes the performance target to each specific building, enhances the ability to track improvement over time, requires that low-efficiency prescriptive choices be offset with more efficient choices, rewards designers for optimization, paves the way for automated performance modeling, and markedly improves predictive accuracy [5].

- For a design and construction code, a differential predictive performance method with a stable and independent baseline

Code Approach	Examples	Strengths of Approach: Ensures energy efficient design and construction	Accounts for bldg. specific operation & service requirements	Promotes optimized design	Promotes energy equivalency	Simplicity; compliance & enforcement	Design Flexibility	Compliance enforced during occupancy for persistent savings
Prescriptive Options:								
Prescriptive (with System Tradeoffs)	90.1; IECC; T24	No	No	No	No	Yes	Some	No
Prescriptive Packages	Res. Envelope T24	Yes	No	Yes	Yes	Yes	More	No
Predictive Performance Options:								
Equivalent to Current Dependent Baseline	90.1 Chapter 11	No	Yes	No	No	No	Yes	No
Differential to Current Dependent Baseline	2012 IECC Performance	No	Yes	No	No	No	Yes	No
Equivalent to Current Independent Baseline	CA Title 24-2013	Yes	Yes	Yes	Yes	No	Yes	No
Differential to Current Independent Baseline	90.1 Appendix. G; LEED; 189.1	Yes	Yes	Yes	Yes	No	Yes	No
Differential to Stable Independent Baseline	90.1 Addendum bm	Yes	Yes	Yes	Yes	Yes[c]	Yes	No
Equivalent to EUI Target	Canada Energy Code	No	Might	Yes	Yes[b]	No	Yes	No
Outcome Performance Options:								
Outcome Based Code; EUI Target	Seattle; Sweden	No	No	No	Yes[b]	Yes	Yes	Yes
Outcome Based Code; Differential to Stable Independent Baseline Prediction[a]	No current example	No	Yes	Yes	Yes	Yes	Yes	Yes

(a) Outcome with predictive model could have other baselines with similar strengths as the predictive performance options.
(b) EUI targets make it difficult to fairly account for differences in building services and operation.
(c) Independent modeled performance with a stable baseline is more likely to encourage automated and integrated compliance software with detailed checklists.

Table 5: Strengths of the potential code options [5]

Continuing past reference house approaches into the future, may not achieve net-zero, resilience-oriented targets. Hence, future progress will need to include on-site renewable energy and occur at an integrated system level that considers the specific building interactions of systems, utility rate structures, and operational parameters that are not easily regulated with current prescriptive approaches. As an evaluative reference, the new forward-looking reference house approach would allow for a compliant design solution that is more flexible than prescriptive solutions and can be optimized for a particular building's climate, operations, system interactions, and utility rate structure. It would serve as a clear roadmap to 2032 when all new construction must be built to a net-zero-energy-ready level of performance. Its staggered approach gives the industry the time it needs to upgrade skills, adopt new techniques, and identify new products and suppliers [2].

This report aims to develop a framework for energy codes by anticipating all the design scenarios where intensity metric will not work, and where a traditional reference house would be less than adequate (e.g. in considering climate resilience, site constraints, societal design objectives, etc.), by mentioning all the validated design considerations (for resilience or community/societal needs) and constraints (site limitations) that should be incorporated into developing the new reference house approach.

2 NEW FORWARD-LOOKING SITE-SPECIFIC NET-ZERO REFERENCE HOUSE APPROACH

A new forward-looking site-specific net-zero reference house approach is a top-down approach being modeled to a net-zero ready standard with results being presented in a % more consumption than the reference building. Determining the highest performance in this approach provides a context for enhanced mandatory requirements, for a straight forward path towards energy efficiency, and for considering beyond code compliance. Such a reference is stable enough to not be affected by ever-changing prescriptive paths. Instead, it would create net-zero targets upon which updated versions of energy codes establish new paths to gradually achieve the target. In other words, it is to effectively establish a framework in to design a fixed scale.

2.1 WHAT NET-ZERO MEANS IN THE REFERENCE HOUSE APPROACH

In any given building, several factors influence energy use such as physical infrastructure, building systems, occupancy, operations, etc. [4]. Being related to the notion of energy, "net-zero" could be simply defined as an approach with zero energy consumption at first glance. Doubtless, it is not a comprehensive definition for the "net-zero" concept regarding tones of influential factors that not only are interconnected but also constitute a complicated network. Consequently, the "net-zero" notion contains both the definition and the path due to its relation to the complex network of factors which means that there are multiple ways to achieve the net-zero target but not all of them considered as perfect.

Based on a discussion with Remi Charron[3]and Wilma Leung,[4] net-zero energy ready terminology for building codes is not clearly defined. Instead, the term high performance buildings might be more relevant, as it can be more flexible to respond to the ever-changing situations while considering communities rather than individuals, networks of factors rather than isolated ones, global environmental effects instead of local impacts, site specifics rather than city feature, and finally, time constraints, sustainability, and resilience (Figure 5).

Figure 5: Criteria defining the borders of the net-zero concept

2.2 PATH THROUGH DEFINING THE NEW REFERENCE HOUSE APPROACH

Figure 6 summarizes all the possible design considerations and constraints that should be incorporated into developing the new reference house approach.

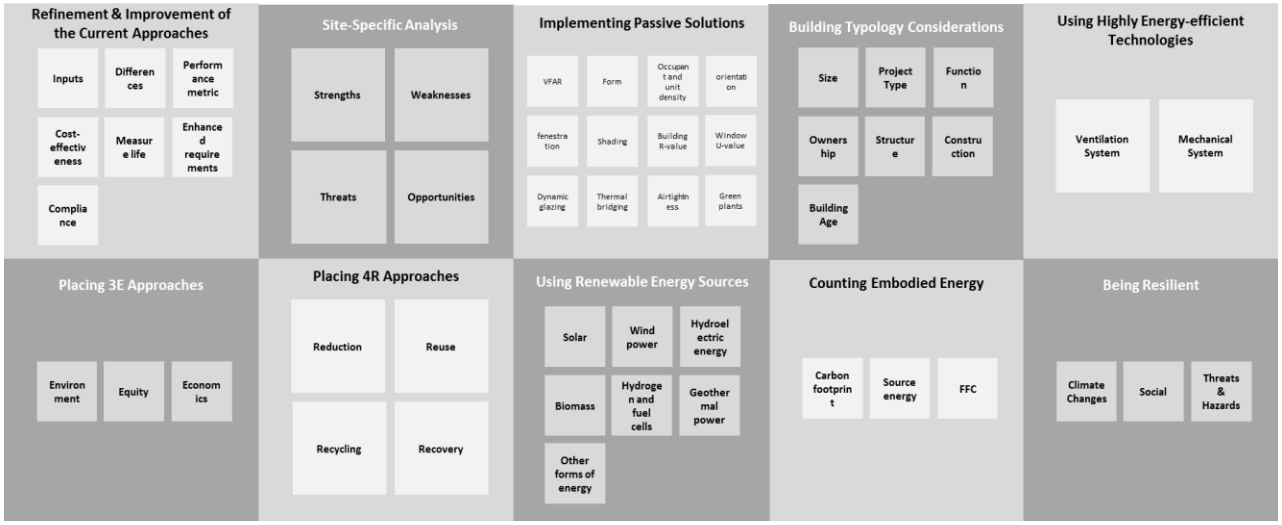


Figure 6: The new reference house performance matrix

2.2.1 REFINEMENT AND IMPROVEMENT OF THE CURRENT APPROACHES

Principally, while countless possible combinations of energy conservation measures can be used to reduce building energy consumption, taking into account the strategies and principles outlined below will yield significant results (Table 6) [2].

✓ **Strategies for Achieving TEDI (Thermal Energy Demand Intensity) Targets**

1. Minimize heat loss
2. Consider occupant and unit density
3. Optimize fenestration
4. Increase building R-values
5. Reduce thermal bridging
6. Increase airtightness
7. Recover heat during ventilation

✓ **Strategies for Achieving TEUI (Total Energy Use Intensity) Targets**

1. Consider occupant and unit density
2. Optimize fenestration
3. Increase airtightness
4. Recover heat during ventilation
5. Separate heating and cooling from ventilation

- ✓ **Strategies for Increasing Airtightness**
    1. Designing buildings with a more compact massing to reduce the number of corners
    2. Limiting building-envelope penetrations
    3. Paying careful attention to detailing at interfaces
    4. Ensuring strict adherence to construction practices

BC ENERGY STEP CODE			
Primary Objective Reducing the impact of the built environment through the use of thoughtful design techniques that minimize building energy consumption.	**Performance Metrics** The BC Energy Step Code requires buildings to achieve specific levels of performance in three key metrics:	**Key Strategies** Design strategies for achieving Step Code required performance targets in each of the three metrics.	
	Thermal Energy Demand Intensity (TEDI)	Minimizing Heat Losses Through Simplified Massing	Reducing Thermal Bridging
	Total Energy Use Intensity (TEUI)	Minimizing Heat Losses Through Orientation	Increasing Airtightness
	Airtightness	Considering Unit Density	Using Compartmentalization
		Optimizing Fenestration	Using Heat Recovery In Ventilation
		Increasing Building R-Values	Separate Heating And Cooling From Ventilation

VANCOUVER'S ZERO EMISSIONS BUILDING PLAN (ZEBP)	In addition to limits on heat loss and energy use, the City of Vancouver sets limits on greenhouse gases (GHG) to further target reductions in emissions.	
Primary Objective	**Performance Metric**	**Key Strategy**
Minimizing GHG emissions	Greenhouse Gas Intensity (GHGI)	Select Low-Carbon Mechanical Systems (See Supplement S, pg 45.)

Table 6: Significant strategies and principles to reduce building energy consumption [2]

As a secondary consideration, the following actions would serve the proposed approach in its primary stages of development.

- ## DEFINING THE SET OF INPUTS THAT WOULD BE USED IN THE BASELINE BUILDING MODELING [9]

According to the ASHRAE standard 90.1-2016, a set of inputs define the current baseline building. It seems that the current reference house approach simply shapes the model by defining the physical features of essential components without pondering their impact on passive strategies, 3Es (Environment, Equity, and Economics), 4Rs (Reduction, Reuse, Recycling, and Recovery), and embodied energy that is incorporated in the building lifecycle. What would form the forward-looking reference house contains all dimensions from environmental to economic and social, alongside the optimized version of ASHRAE inputs including:

- **Schedule**[5]
- **Geometry**[6]
- **Opening Shade**[7]
- **Construction Assembly**[8]
- **Fenestration Construction**[9]
- **Material**[10]
- **Slab Construction**[11]

- **Exterior Surface Properties**[12]
- **Occupant Heat Rate**[13]
- **Furniture and Contents**[14]

- **DETERMINING ESSENTIAL DIFFERENCES BETWEEN THE BASELINE AND THE PROPOSED BUILDINGS INPUTS IN THE MODELING PROCESS [9]**

Based on the Reference Manual, some inputs would be different between the baseline and the proposed buildings. The point is that in the current reference house approach, the bottom-up procedure results in defining high-level inputs in the proposed building which is contrary to the top-down procedure of the new approach that considers all inputs in their most optimized version. Essential differences are in:

- **Envelope**

    - Opaque Envelope[15]
    - Fenestration[16]

- **Natural Ventilation**

    As defined in Standard 90.1-2016, the corresponding thermal zone in the baseline building is not modeled with automatically controlled natural ventilation. In the baseline building, the fans are required to run constantly during occupied periods and cycle with loads during unoccupied periods, the same as the proposed building. On the contrary, what defines the ventilation system of the new baseline approach can be automatically controlled natural ventilation which relies on passive electric sources. Such a system would decrease the energy demand for fans operation and thus, is more energy-efficient than the current approach.[17]

- **Interior Lighting**

    Surprisingly, there is no daylighting control applicability for the current baseline building. Daylighting contribution to the interior lighting is obvious enough to consider it as an essential factor in modeling the new reference house. Taking into account factors such as daylighting availability, the geometry of the space, size and configuration of daylighting aperture, the reflectance of the surface, and the light transmission of the glazing, the new baseline building can be modeled more energy-sufficient than what it is now.

- **Exterior Lighting**

- **Process Loads**

- **HVAC**

    The HVAC system in the baseline building depends on the primary building activity, the number of floors, conditioned floor area and climate zone. Even though for many of the building descriptors there is a one-to-one relationship between the proposed design and the baseline building, for HVAC systems, this one-to-one relationship generally does not hold. There may be the different number of HVAC systems serving the proposed design compared to the baseline building, and equipment such as cooling towers, circulation pumps, etc. may be present in the baseline but not proposed design. According to the HVAC System Map and HVAC System Descriptions provided in Table 3 and Table 4 of the ASHRAE standard 90.1-2016 respectively, all types of baseline building in warm climates, except hospitals are limited to select HVAC systems having an electric-based heating type. It can create a great opportunity for proposed buildings using solar systems or other passive solutions to provide an electric source for the system operation, of course by considering some positive points in rating schemes. However, what can be proposed in the new forward-looking approach for the HVAC system of the baseline building can be a net-zero ready system which relies on solar systems or other energy-efficient solutions to provide electricity for the system operation.[18]

- **Service Hot Water**

- **CONSIDERING AN APPROPRIATE PERFORMANCE METRIC**

An important decision is what metric to use for building performance. There are several options including site energy use, source energy use, energy cost, and greenhouse gas emissions. Energy cost tends to be the preferred metric within ASHRAE, as its use avoids long-standing debates over the proper calculation of source energy. However, source energy is more closely tied to emission and greenhouse gas reductions and can be therefore favored in the new reference house approach alongside pondering full-fuel cycle in the calculation of actual energy consumption where possible and maybe as an extra assessment. Besides, regarding performance options such as resilience, embodied energy, thermal comfort, and passive solutions that need specific evaluation metrics, there can be determined multiple performance metrics in the proposed reference house [5, 9].

- **DEFINING COST-EFFECTIVENESS BORDERS**

On one hand, as long as there are reasonable paths through the cost-effective code, the code as a whole can be deemed cost-effective. On the other hand, many in the building and energy policy sectors subscribe to the goal of net-zero building energy use; however, baring a significant drop in the price of renewable energy generation or some unforeseen improvement in building system technology, it is unlikely that a broad range of net-zero buildings can be constructed and still meet current cost-effectiveness criteria. A major reason for this is that the current approaches to cost-effectiveness have not considered environmental externalities or non-energy benefits such as green market value. It may not be possible to achieve significant further reductions in energy codes-eventually reaching net-zero-if these factors are not brought into the cost-effectiveness equation [5, 9]. In other words, we need to broaden the borders of cost-effectiveness while going towards net-zero energy or net-zero carbon, meaning that cost-effectiveness should be discussed not only in a building-related scale but also in a local and regional scale. The point is that both notions of net-zero energy and net-zero carbon are tightly relevant and complementary to each other; the more the energy consumption, the more the GHG emission.

- **COUNTING IMPACT OF MEASURE LIFE ON PERFORMANCE TRADE-OFFS**

A valid concern that has been expressed about trade-offs is that a shorter-life high-efficiency item could be traded for a reduction in efficiency of a long-life item. An example is a condensing furnace or advanced lighting controls traded for lesser wall insulation. Allowing trade-offs has benefits for design, and as long as trade-offs are subject to enhanced mandatory standards, the benefit is likely to outweigh disadvantages.

- **ENHANCING MANDATORY REQUIREMENTS**

Enhanced mandatory requirements are desirable for performance trade-offs or outcome-based codes, because, while tradeoffs make sense based on energy equivalency, allowing any trade-off can have unintended consequences. An example of an enhanced mandatory requirement might be requiring that insulation levels not be traded off below a defined level for the performance path.

- **SPECIFYING WAYS OF COMPLIANCE**

Updates to the energy code need to consider the impact on compliance. Better solutions could include approved software that automates the process of creating a baseline building by focusing on a stable differential and independent baseline.

- **CONSIDERING BUILDING ALTERATIONS**

While the current approaches work well for new construction, it is a different story for minor alterations and retrofits. Replacement of worn-out equipment, energy-related changes associated with cosmetic improvements, lighting upgrades, and other renovation or alteration work will require that some prescriptive component requirements remain in the code. Prescriptive requirements for alterations and renovations can be separately addressed in a section of the code that clarifies what is required for these situations that are different from new construction.

- **ELIMINATING GAS PROCESS EQUIPMENT**

Since one of the objectives of the new approach is to decrease the GHG emission, there can be penalties for gas equipment [5, 9].

2.2.2 SITE-SPECIFIC ANALYSIS

Every single site serving as a building setpoint has its specific features that can be classified as strengths, weaknesses, opportunities, and threats; (e.g. lot size, orientation, topography, solar access, shading from adjacent structures, etc.). The SWOT analysis can distinguish a site as a unique component that would have its impact on buildings' energy consumption, and thus, can be counted as one of the proposed approach's parameters.

The first and the most important part of the SWOT analysis is evaluating the climate zone that a specific site located in. The challenge is the accuracy of using a representative city for each climate zone. However, Figure 7 shows that, within each climate zone, the difference between the highest and lowest modeled source energy use varies from 30 to 190 kWh/m2 (10 to 60 kBtu/ft2) when the weather location changes. To evaluate the building characteristics fairly, specific weather locations should be used [4].

Other site constraints can include existing street grids, adjacent landmarks, etc. that affect building design scenarios and thus, influence building energy performance. For example, while orientation is often highly constrained by existing street grids and other considerations, the building can be designed in such a way that its podium aligns with the grid, and the tower is oriented to align towards the south.

The flexible proposed reference house approach, therefore, would input constraints on a reference house as to not unfairly penalize a building.

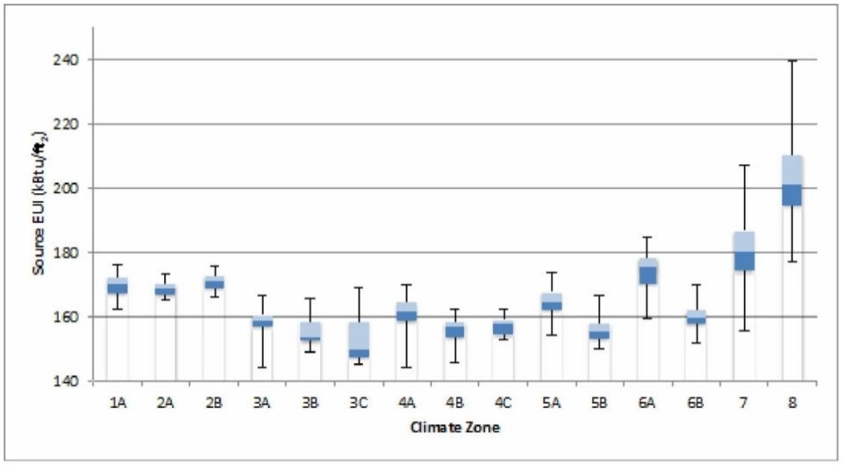


Figure 7: Modeled overall building energy use using TMY3 weather files (DOE Commercial Reference Building, Medium Office, New Construction, compliant with ASHRAE Standard 90.1-2004) [4].

A specific site SWOT analysis can be on different scales from building-surrounding scale to local, regional, and global scale. For example, a site adjacency to a bunch of high-rises can consider as a building-surrounding-scale threat in that they would block daylighting and influence lighting and heating loads significantly. On the other hand, seismic events are regional-scale threats that affect not only any given site but also whole sites throughout the region with their effects on building structures and their related embodied energy. Consequently, taking into account the site analysis in designing a new reference house approach is essential due to such analysis' wide impact on energy consumption and GHG emission.

2.2.3 BUILDING TYPOLOGY CONSIDERATIONS

To ensure a fair comparison, the proposed reference needs to be categorized based on different parameters such as size, use, realm, and construction date (Figure 8), primarily because the assumed standard operating conditions differ among building types. In other words, the building type classifications determine the standard operating conditions, including occupant density, receptacle power, and operating schedule [4].

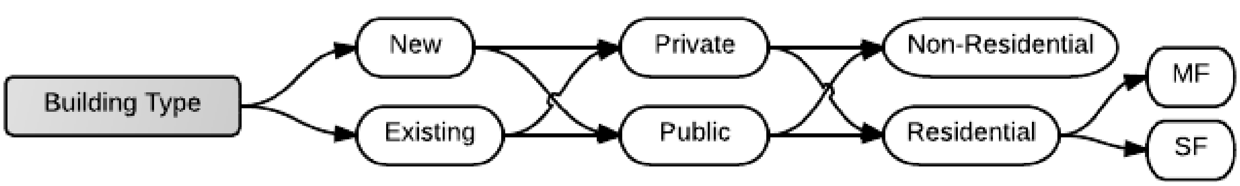


Figure 8. Building Type Options ("MF" is Multifamily; SF is single-family) [3]

- **SIZE**

Classifying buildings regarding the size can include sub-categories because there are factors that directly or indirectly influence the size of the building such as area, number of floors, height, and number of units (Figure 9). Considering such divisions would result in a more specified reference house in terms of energy performance.

1. Number of units: Single-Family/Multifamily [3]
2. Occupancy: Low-Occupancy/Mid-Occupancy/High-Occupancy [9]
3. Floor plate: Small/Medium/Large [2]
4. Number of Floors: Low-Rise/Mid-Rise (three to six stories)/High-Rise (six stories or higher) [2]

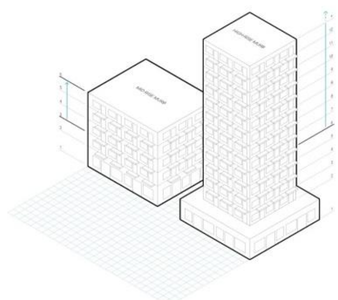


Figure 9: The size of the building [2]

- **PROJECT TYPE**

Depending on the project type, the assumed standard operating conditions can differ dramatically. While the current approaches work well for new construction, it is a different story for minor alterations and retrofits. The type of project could be anyone or combination of the following [9]:

1- New building
2- Additions to an existing building
3- Alterations of an existing building
4- Unmodified existing building

- **FUNCTION**

  1- Residential
  2- Non-Residential
    a. Commercial
    b. Institutional
    c. Industrial
    d. Mixed-Used

This classification reduces building use types to two options, non-residential and residential. While there are many more sub-types, this singular distinction is sufficient to understand the majority of ratings used in international assessment systems without overly-complicating the analysis [3]. However, future researches are needed to provide new and updated data regarding default values (such as the number of occupants, equipment power density, lighting power density, hot water load, ventilation rate, and schedules) dedicated to each function resulting in a more precise classification. For example, commercial buildings are diverse in their function, working patterns, and equipment. This influences both energy consumption and the certification process. On the other hand, multi-dwelling buildings need careful consideration: the position of the individual unit (different floors with differing orientation and exposure) influences the unit's energy performance. Furthermore, energy performance will vary depending on whether the individual units or the building as a whole are taken into account [1].

- **OWNERSHIP**

  1- Owned
  2- Rental

Energy performance of a building would vary based on its ownership; in other words, occupants' energy consumption will depend on whether the energy supply is paid directly by the individual or the building syndicate as a whole [1].

- **STRUCTURE**

  1- Concrete
  2- Steel
  3- Wood
  4- Composite (future visions)

Taking into consideration the embodied energy of different types of building structures illustrates their huge differences regarding energy efficiency. As a case in point, wooden structures are one of the most energy-efficient ones in Canada using a local construction material that lessens or removes the need for transportation and consequently reduces GHG emission. Diverse structure types are designed for particular purposes so, counting their related embodied energy and consider it as a crucial factor in the decision-making process would lead to a net-zero reference house approach.

- **CONSTRUCTION**

  1- on-site
  2- prefabricated
  3- mixed-approach

Again, embodied energy can have a key role in the decisionmaking process. There will be a significant difference between applying on-site construction and using prefabricated components (Figure 10) while pondering material wastes, environmental pollutions (noise, trashes, etc.), and unregulated energy waste on one hand, and costs, transportation options, and sustainability aspects on the other hand.

Figure 10: Prefabricated construction [12]

- **BUILDING VINTAGE**

  1- New Construction
  2- Post-1980
  3- Pre-1980

For the most part, new constructions are easy to manage in terms of energy performance, comparing to existing buildings. What makes the existing buildings' compliance with the energy codes hard or even impossible is that they are not designed to be energy efficient. While other factors affect energy use in buildings, including operation, maintenance, and the level of services provided, if a building does not start with an energy-efficient infrastructure as required by an energy code, it will never achieve its full energy efficiency potential. Initial construction is the best time to significantly influence building energy efficiency; otherwise, there is a lost opportunity, as it is rarely as cost-effective to retrofit a building later [3, 5].

2.2.4 USING HIGHLY ENERGY-EFFICIENT TECHNOLOGIES

- **VENTILATION SYSTEMS [2]**

Typical centralized ventilation systems without heat recovery can lead to significant heat losses through the building envelope and can increase the stack effect, while centralized systems that use heat recovery achieve higher levels of energy efficiency (Figure 11). On the other hand, Compartmentalized Ventilation helps to control the overall flow of air in a building, reducing overall energy demand and improving the health and comfort of unit occupants. With Heat Recovery Ventilation (HRVs, figure 12), designers can limit centralized, conditioned ventilation to corridors and common areas only, reducing the energy that is often wasted through redundant heating. They can be considered as a heat source for service water heating, space heating, and/or process heating, improving a building's overall TEDI and TEUI.

- ✓ Using electricity-based systems reduce greenhouse gas emissions
- ✓ Decentralized ventilation systems that make use of heat recovery are the most efficient
- ✓ Vertical Flat Panel HRV is the least costly HRV systems
- ✓ Horizontal Flat Panel HRV is more expensive but achieve higher levels of performance

- ✓ Cellular HRV is more costly but the highest available performance
- ✓ Direct ducting can be routed into each room within a dwelling unit
- ✓ A minimum of 60% HRV efficiency can be considered for designs targeting Steps 2 and 3, while those aiming for Step 4 can seek minimum efficiencies of 80%.
- ✓ Larger cores tend to achieve higher efficiencies
- ✓ Energy Recovery Ventilation (ERV) Systems can be considered in high humidity environments
- ✓ Short-circuiting,[19] circuitous routing,[20] improper sizing, and excessively long duct runs are not appropriate.

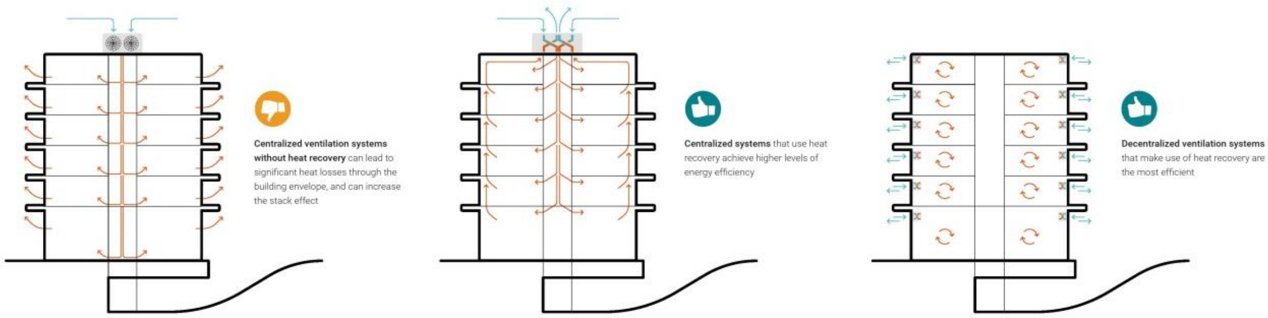


Figure 11: Ventilation systems [2]

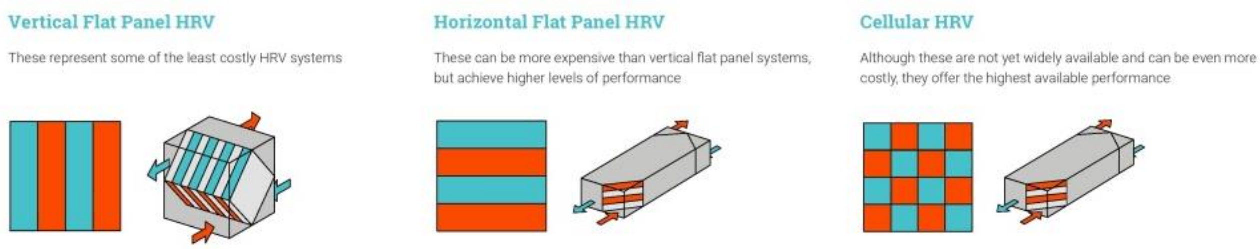


Figure 12: Three forms of high-efficiency HRV technology [2]

- ## MECHANICAL SYSTEMS [2, 9]

The selection of mechanical strategies is of central importance to the achievement of GHGI (Greenhouse Gas Intensity) performance targets. Of all mechanical space-conditioning systems, heat pumps generally do the most effective job of lowering TEUI scores. Options include geo-exchange, air-source, and variant refrigerant flow (VRF) systems. Systems that connect to district energy systems also tend to incorporate some type of heat pump. However, before selecting mechanical systems, designers can take a passive-first approach to reduce energy demand as much as possible.

Heat pump technologies are desirable in that they can also provide cooling in summer months and can efficiently provide heat to buildings in cooler months. The most efficient available mechanical systems are including (Figure 13):

- **Hydronic[21] Delivery Using Natural Gas[22]**
- **Hydronic Delivery Using Electricity[23]**
- **Electric Baseboards[24]**
- **Forced Air[25]**

- **Ground-Source Heat Pump**[26]
- **Water Heating Auxiliaries**[27]

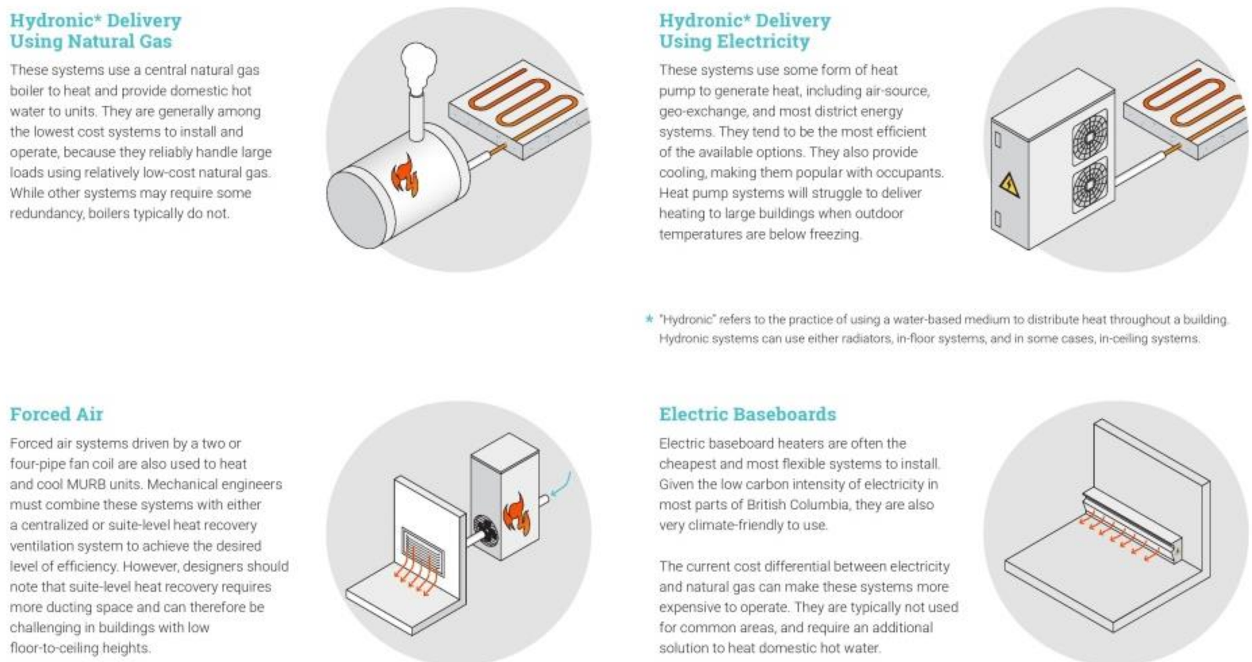


Figure 13: Four major types of mechanical systems [2]

- ✓ Using heat-recovery strategies to improve system efficiency
- ✓ Selecting Low-Carbon Mechanical Systems to achieve Zero Emissions Building Plan
- ✓ Separate heating and cooling from ventilation which allows for continuous ventilation, regardless of whether a suite requires heating (Figure 14)

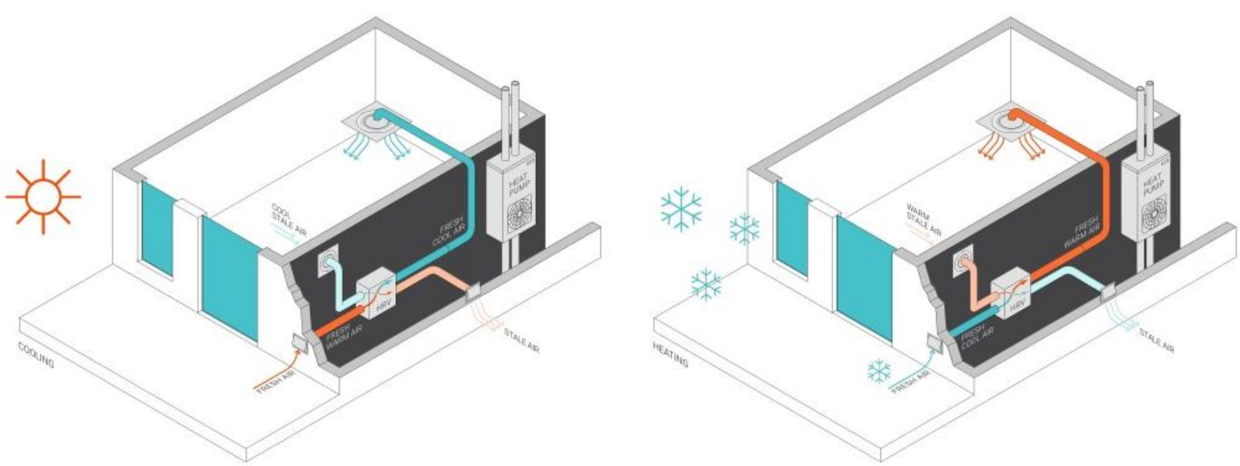


Figure 14: Separate heating and cooling from ventilation [2]

2.2.5 IMPLEMENTING PASSIVE SOLUTIONS

In response to the question of why passive solutions are essential in defining the new reference house approach, it is fair to say that first; a prescriptive approach isolates a system from the evaluated building. For example, a building with a low thermal mass due to its envelope characteristics may force its HVAC system to handle more extreme operating conditions and use more energy than another building with the same HVAC system but more thermal mass. Passive solutions, on the other hand, consider all building components as a system. Second, in many cases, savings related to the implementation of the passive solutions do not present any net, the long-term economic cost to the owner, as the savings outweigh the costs of the investments. A key challenge, however, is that consumers tend to focus on short-term costs rather than long-term value, and do not seize opportunities to improve efficiency that might require a pay-back time that exceeds what they would perceive as a good return on their investment [1]. Furthermore, the benefits of taking a passive approach are satisfying enough to give it prominence. They include [2, 4]:

- Improving Health and Comfort
- Reducing Costs
- Achieving Better Performance with Today's Technologies
- Reducing Greenhouse Gas Emissions

Taking the "passive solutions" as one of the parameters of the main matrix (Figure 7), parameters to include in its related sub-matrix can be as followings.

- **LOWERING VFAR** [2]

Massing can also be thought of in terms of a building's vertical surface area to floor area ratio (VFAR). A lower VFAR decreases overall heat loss potential because vertical surfaces (walls) tend to have lower R-values than horizontal ones (floors and roofs). Higher VFAR values are often a function of the building's floor plate size, as well as the level of articulation, or the complexity of its overall form.

- ✓ Towers with smaller, narrower floor plates (600m^2 or less) tend to lose more heat through the building envelope.
- ✓ As cities often emphasize smaller floor plates to help maximize daylight to the street, building designers will need to strive for a balance between municipal requirements and a building's energy performance

- **SIMPLIFYING FORM [2]**

A building's massing can influence the achievement of Thermal Energy Demand Intensity (TEDI) performance targets: the more complex a building shape, the greater the number of opportunities for heat loss through the envelope. A building with several complex junctions and corners will lose far more heat through the envelope than a building that has been designed as a simple, solid form, such as a cube or rectangle. Compact buildings also reduce the total number of exterior walls — where heat is lost — as well as the number of ledges and other horizontal surfaces where accumulations of moisture can degrade the building envelope (Figure 15, 16). However, considering the impact of the forms on social interactions, some forms seem to be more public-inclusive than others. Since social aspects of building performance are essential in defining the forward-looking reference house approach, some trade-offs between public-inclusivity and energy-efficiency can be pondered.

- ✓ minimizing the number of junctions, indents, and intersections in the building envelope to minimize heat loss
- ✓ considering the impact of the forms on social interactions

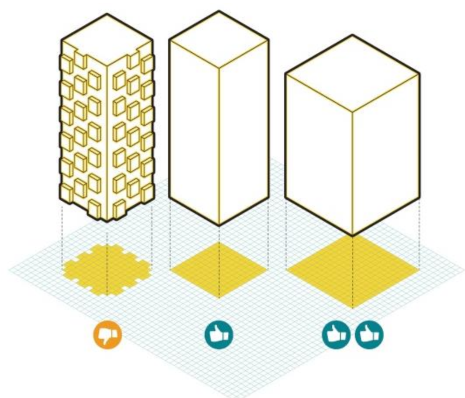


Figure 15: The influence of the VFAR and the form of the high-rise buildings on energy performance [2]

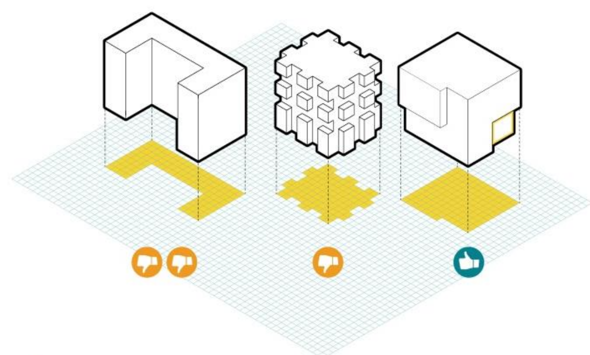


Figure 16: The influence of the mid-rise buildings' form on energy performance [2]

- **CONSIDERING OCCUPANT AND UNIT DENSITY [2]**

Occupant and unit density significantly influence a proposed building's TEDI and TEUI performance (Figure 17). Higher occupant density (those related to multi-unit buildings and not to single-family houses) can make it easier to achieve a TEDI target while pushing a TEUI objective farther out of reach. This is because a building's occupants drive plug loads, as more people switch on more appliances, and turn on hot-water faucets. As such, the higher a building's occupancy, the more difficult it may be to achieve a specified TEUI. Designers can nevertheless look for opportunities to reduce hot-water demand when planning high-occupancy buildings. On the flip side, the higher a given building's occupancy, the greater the potential for passive internal heat gains. Those appliances and all that hot water, and even the warmth generated by human bodies, all help passively heat buildings. As such, in cooler months, higher occupancy can also reduce a building's heating requirements. The proposed approach can therefore carefully consider expected occupant and unit densities when calculating TEDI and TEUI.

✓ Considering the trade-offs between TEDI targets and TEUI targets early in the design process since higher occupant and unit densities make TEDI targets easier to achieve, but make TEUI targets more difficult.

Figure 17: The impact of the unit density on a building energy performance [2]

- **OPTIMIZING ORIENTATION [2, 9]**

Professionals who orient their buildings to maximize the solar-gain potential from the south can reduce heating demands by as much as 30 to 40% (Figure 18). While this strategy does not minimize heat losses per se, it does take advantage of passive heat gains that can provide a benefit when reaching for a TEDI target. To maximize the potential for solar gains, designers can orient a proposed building's longest facade as close to due south as possible. Ideally, the south-facing facade can be within 30 degrees of due south in Canada. While many sites are constrained by existing adjacent buildings and street grids, opportunities may exist to orient upper floors to the south. At the same time, designers taking advantage of solar gain must be careful to avoid overheating in the summer months, by specifying the use of thermally-broken external shading. Per section 3.4.1 of the Reference Manual, the baseline building is not required to be simulated for all four orientations, if the orientation of the proposed design is dictated by site considerations. Nevertheless, for the new reference house, taking into account the best orientation regarding the constraints of a specific site is crucial.

✓ Maximizing solar gains by optimizing orientation to reduce heating requirements in the wintertime, helping to achieve TEDI performance targets.

- ✓ The orientation can allow the longest facade of the building to align with due south as much as possible while ensuring precautions are taken to address the potential for overheating.
- ✓ There may be constraints such as the lot or adjacent landmarks that could limit the main orientation. In such conditions, buildings can be designed in such a way that its podium aligns with the grid, and the tower is oriented to align towards the south
- ✓ Taking advantage of natural light to reduce lighting loads and reach Total Energy Use Intensity (TEUI) targets
- ✓ The best orientation in a given location can be evaluated based on the latitude and longitude.

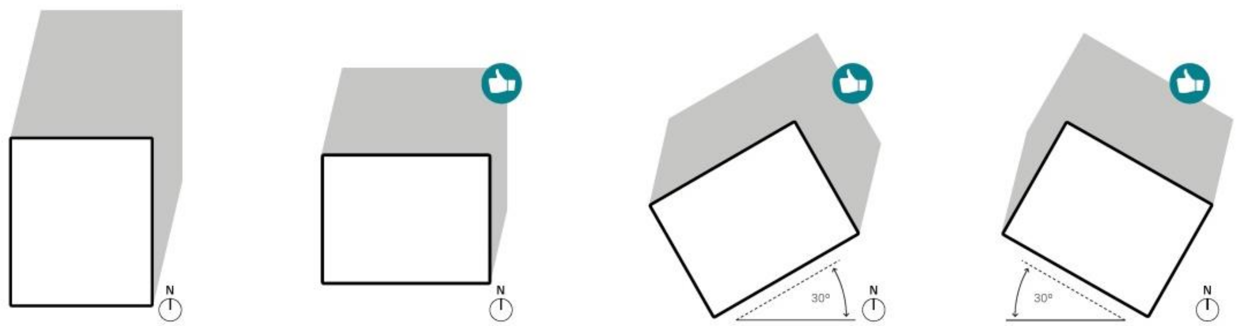


Figure 18: Optimizing orientation [2]

- **OPTIMIZING FENESTRATION [2]**

Fenestration includes windows, doors that have more than 50% glazed area, and skylights that have a tilt of less than 60° from horizontal and contains the number, size, and placement of windows on a building's facades. Size and placement are key factors when considering passive heat gains and daylighting. When compared with opaque walls, windows offer low thermal resistance. As such, a lower window-to-wall ratio (WWR) reduces heat gain and loss through the envelope by increasing the area of the insulated wall (Figure 19). Designers can also consider the direction the building's windows will face, as well as site-specific considerations, such as shading from nearby buildings. Buildings with a high WWR on the southern elevation will maximize their solar gains in the cooler winter months when the sun is lower in the sky. As north-facing windows have the lowest potential for solar gains, WWR on north facades can be more modest if possible. Abundant glazing on the south and west facades will support solar heat gains during the winter months.

However, in some cases where the optimal WWR may not be possible (such as where a building located on the north slope of a mountain or shaded by adjacent taller buildings), the reference house should consider other limitations to achieve the net-zero targets.[1]

- ✓ Optimizing size and placement of windows
- ✓ Maximizing incoming solar gains in the winter, and minimize solar gains in the summer
- ✓ Careful placement of windows can also improve cross-ventilation, support daylighting, and reduce the need for artificial lighting, all lowering total energy demand
- ✓ Increasing sill heights, and ensuring that operable windows are on multiple facades or walls wherever possible
- ✓ Moving corridors and elevators to the north side of a building can also help to minimize areas that require glazing and daylight access

[1] . Please refer to the section 2.3 (An Example) for more clarification.

- ✓ Aiming for an overall WWR of 40% for vertical fenestration and a 3% of gross roof area for horizontal fenestration (skylight)
- ✓ Defining WWR restriction regarding specific orientation

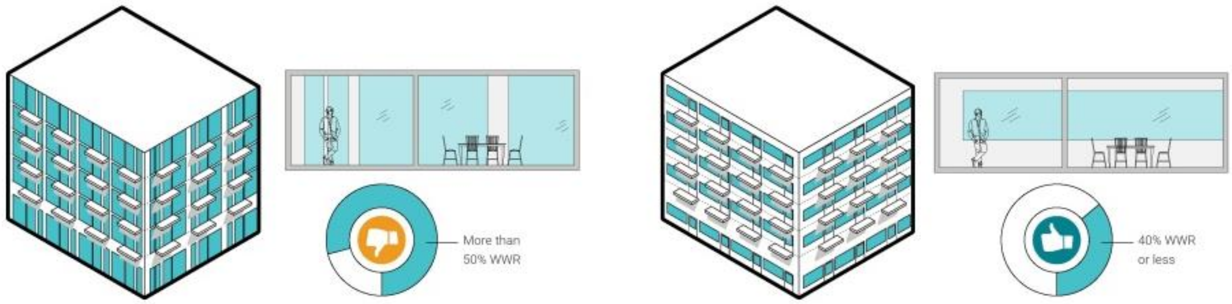


Figure 19: Fenestration requirements [2]

- **ADVANCING SHADING STRATEGIES [2]**

Shading devices are among factors to consider when defining the new reference house due to their ability in affecting the energy performance passively. Shading devices can be used to block unwanted solar gains and keep indoor temperatures comfortable in the summer months. These will become even more important as the climate warms, and the number of days of extremely high temperatures rises. Solar shading devices such as louvers, overhangs, eaves, and balconies can be used to improve occupant comfort, as well as programmable motorized shades placed on the exterior of a building. On lower floors, deciduous trees can provide shade in summer months. In some cases, horizontal shading devices as "light shelves" may also be used to direct light deeper into building interiors, reducing the need for artificial illumination (Figure 20). Unlike the current baseline building, advanced shading strategies can be considered in modeling the new reference house.

- **External Shading Devices**

These are devices or building features that are documented in the construction documents and shade the glazing from the exterior face of the wall. Orientation-specific types are as follows:

- **North-Facing**
  Shading devices aren't necessary on north-facing facades, but the WWR can be reduced to decrease heat losses through the envelope.

- **East-Facing**
  Shading on the east facade has minimal impact on TEUI but can improve occupant's thermal comfort. Thus, vertical fins can be used to block incoming summer sun on eastern elevations.

- **West-Facing**
  Vertical shading is necessary on western facades to prevent unwanted solar gains in summer.

- **South-Facing**
  Shading devices (horizontal) can be placed along a building's southern elevation to block incoming solar radiation in the summer while welcoming solar gains from lower winter sunlight.

- **Internal Shading Devices**

These are curtains, blinds, louvers, or other devices that are applied on the room side of the glazing material. Glazing systems that use blinds between the glazing layers are also considered internal shading devices. Manual fenestration shading devices are modeled the same as proposed building in the current baseline so that there is no credit. The internal shading devices have a direct relationship with users' behavior in the buildings. For instance, leaving the blinds closed when there is enough daylight would increase energy use due to the need for artificial lights. Thus, they could have a great impact on energy efficiency and ignoring them in the new reference house approach can affect the net-zero targets. One option can be modeling automatically controlled internal shades following a fixed schedule.

- ✓ Considering existing adjacent buildings and trees as a temporary shading strategy (Adjacent trees and buildings are subject to change!)
- ✓ Use thermally broken external shading devices on south and west facades to reduce risk of summer overheating.
- ✓ Programmable motorized shades can be placed on the outside of a building eastern and western facade to shade interiors when necessary.

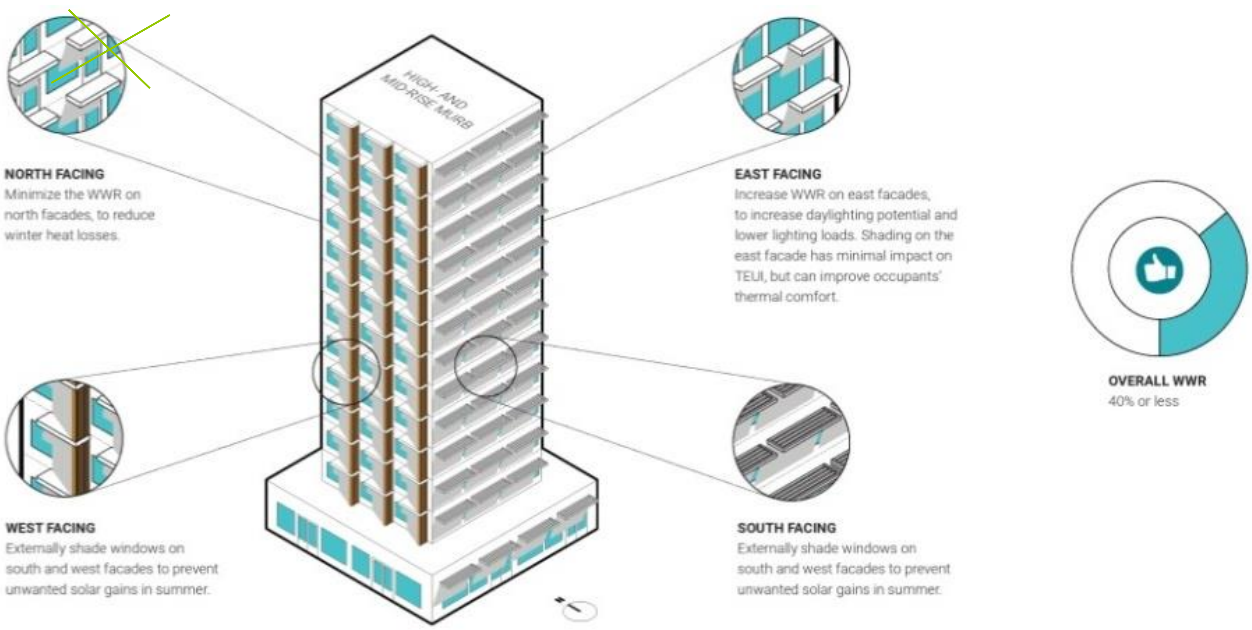


Figure 20: Shading and fenestration requirements [2]

- **INCREASING BUILDING R-VALUES [2, 9]**

R-values indicate an envelope's thermal resistance, or its ability to prevent heat from moving from one side to the other. The higher the R-value, the better the envelope is in terms of its insulating effectiveness (Figure 21). Selecting building-envelope components with higher R-values can result in a higher thermal performance of a building and can help reach TEDI targets. Higher R-values also help to improve occupant comfort by keeping building interiors warmer in the winter and cooler in the summer.

Building R-values, as one of the parameters of the performance matrix (Figure 6), are not stand-alone and have interrelations with other parameters such as climate zone, building type, embodied energy, embodied carbon, etc. For instance, different climate zones require varied R-values and wall systems that are scalable with respect to their insulation allowing greater flexibility in balancing glazing and wall performance throughout the design process are beneficial. Besides, if we take embodied energy constraints into account, material assemblies with the capability of being reused, recycled, and recovered that have local roots should be chosen. Hence, the new reference house approach can carefully select envelope systems for their effective R-values rather than individual material's nominal R-values in response to the other parameters systematic effects.

Systems that can influence R-values include:

- **Roof Systems**

The three classifications of roofs defined in Standard 90.1-2016 are including:

  - Insulation entirely above deck
  - Metal building
  - Attic and other

Among them, the current baseline building roof type is of the type "insulation entirely above deck." However, more types can be evaluated relating to their energy efficiency while defining the new reference house approach. The R-value requirements for roofs can depend on the type and the insulation requirement can be determined by climate zone and the new baseline standard.

- **Exterior Wall Systems**

Depending on different categories of above-grade wall assemblies, minimum insulation requirements for walls would vary. The wall type categories are as follows:

  - Mass walls
  - Metal building walls
  - Steel framed walls
  - Wood-framed and other

The current baseline building wall type is steel-framed where the insulation is installed within the cavity of the steel stud framing. However, more types can be evaluated relating to their energy efficiency while defining the new reference house approach. The R-value requirements for walls can depend on the type and the insulation requirement can be determined by climate zone and new baseline standards. Also, the following design metrics are worthy of mention according to the BC Energy Step Code guidelines.

  - **For High-Rises:**

    - Selecting wall and roof systems with an optimized R-value based on the performance matrix (BC Energy Step Code sets a minimum effective R-10 value for wall systems and a minimum effective R-20 value for roof systems)
    - Designing high-performance window and wall systems
    - Using wall systems that exhibit the most favorable characteristics for achieving better building performance including:

        - Concrete assemblies with a continuous layer of exterior insulation around the entire envelope
        - Concrete sandwich panels
        - Steel-stud with a continuous layer of exterior insulation around the entire envelope

- **For Mid-Rises:**

    - Selecting wall and roof systems with an optimized R-value based on the performance matrix (BC Energy Step Code sets a minimum effective R-20 value for wall and roof systems)
    - Using Wood-frame construction since it typically achieves higher thermal performance than concrete wall systems
    - Considering four major wall approaches including:
        - Wood-stud with split insulation
        - Deep wood-stud assemblies
        - Steel-stud with a continuous layer of exterior insulation around the entire envelope
        - Concrete assemblies with exterior insulation which is more durable and has a better thermal performance

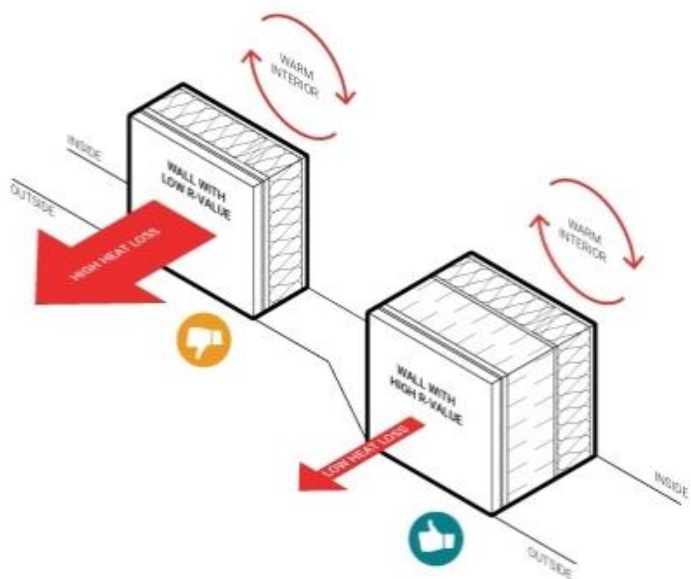


Figure 21: Scalable wall systems [2]

- **Exterior Floor systems**

Specifying two classes for floors in contact with ground including heated and unheated, the floor type categories defined in Standard 90.1-2016 for high-rises are as follows:

- Mass
- Steel-Joist
- Wood-Framed and Other

Among them, the exterior floor type for the baseline building is steel joist. However, more types can be evaluated relating to their energy efficiency concerning different building typologies (e.g. high-rises, mid-rises, residential, commercial, office, etc.) while defining the new reference house approach. The R-value requirements for floors can depend on the type and the insulation requirement can be determined by climate zone and the new baseline standard. Again, considering the systematic interrelations of the performance matrix parameters in mind, the proposed reference house approach, therefore, would input constraints on a reference house as to not unfairly penalize a building.

- **DECREASING WINDOW U-VALUES [2, 9]**

Professionals typically evaluate window performance in terms of U-value, a measure of how well a given window allows heat to pass through. U-values are the inverse of R-values. As such, the lower the U-value, the better a window's performance.

- ✓ Aligning windows with Insulation (Figure 22)
- ✓ Reducing framing elements by having fewer, larger windows
- ✓ Utilizing low-conductivity framing materials such as vinyl and fiberglass
- ✓ Improving window performance:
    - **For high-rises:**
        - Using an appropriate window type with an optimized U-value(BC Energy Step Code uses double-pane windows with a maximum U-value of usi-2.5 and triple-pane windows with a maximum u-value of usi-1.6)
    - **For mid-rises:**
        - Using an appropriate window type with an optimized U-value(BC Energy Step Code uses double-pane windows with a maximum U-value of usi-2.5 and triple-pane windows with a maximum u-value of usi-2.0)

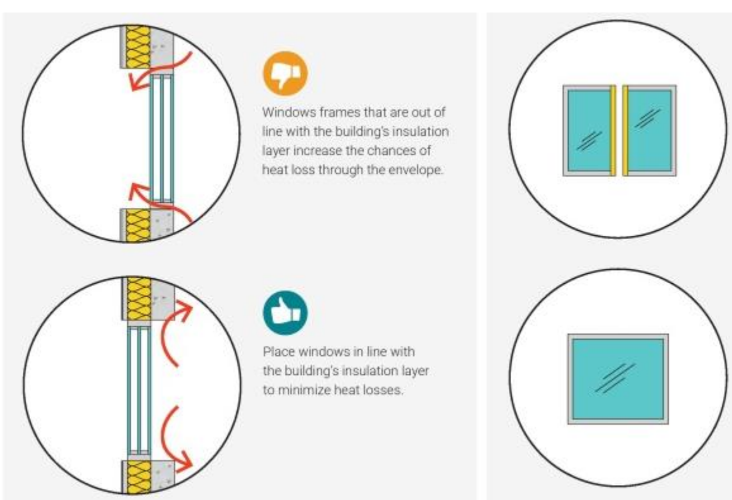


Figure 22: Aligning windows with Insulation [2]

- **USING DYNAMIC GLAZING [9]**

Dynamic glazing can vary the SHGC (solar heat gain coefficient) and VT (visible transmittance) of the glazing in response to a signal from an energy management system, direct sunlight on the glazing, or other inputs. Unlike the current approach, dynamic glazing can be modeled for the new baseline design and controlled in such a way that maximizes energy efficiency.

- **REDUCING THERMAL BRIDGING [2]**

A thermal bridge refers to an area in a building's envelope that interrupts the building's continuous insulation layer, causing heat to escape the interior of the building to the outside (Figure 23). Designers can mitigate thermal bridging by choosing a compact building design that reduces articulations and junctions. They can also design continuous insulation around floor edges, and position window frames in line with building insulation. Doing so will minimize heat loss through the frame-to-wall connection.

- ✓ Breaking thermal bridges with insulating materials (Figure 24)
- ✓ Considering compact massing
- ✓ Designing continuous insulation
- ✓ Using thermally-broken balconies

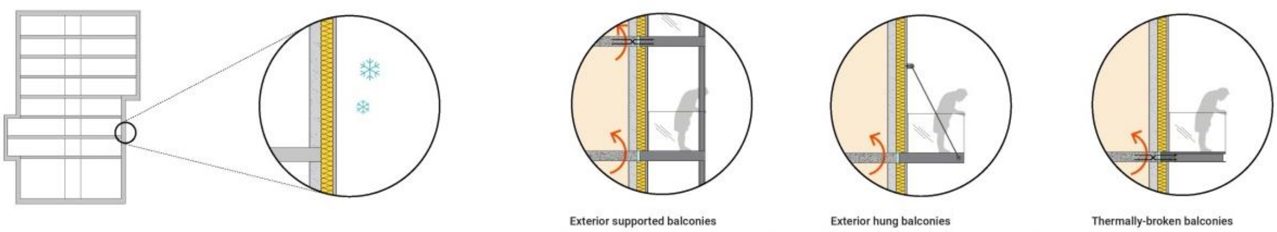


Figure 23: Mounted balconies [2]

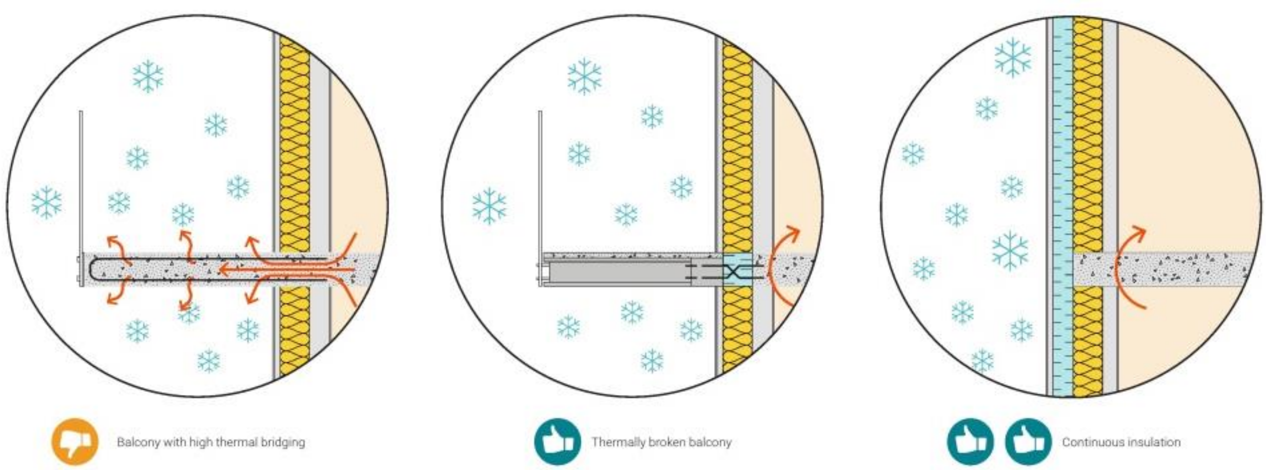


Figure 24: Breaking thermal bridges with insulating materials [2]

- **INCREASING AIRTIGHTNESS [2]**

Buildings designed for a compact shape, form, and size not only improve thermal performance but can improve airtightness as well. Complex forms with more corners have a greater overall potential for air leakage through the building envelope. A compartmentalization[28] strategy might also be considered to improve a proposed project's airtightness (Figure 25).

- ✓ Compact Building Massing
- ✓ Designing a High-Quality Building Envelope
- ✓ Detailing the Installation of a Continuous Air Barrier
- ✓ Setting a Target to a Design Infiltration Rate of Approximately 0.00001 $m^3/s\ m^2$
- ✓ Considering Compartmentalization Approach (sealing off building uses and units from one another)
- ✓ Limiting building-envelope penetrations
- ✓ Paying careful attention to detailing at interfaces
- ✓ Separating building uses (e.g. parking, retail, residential) from one another

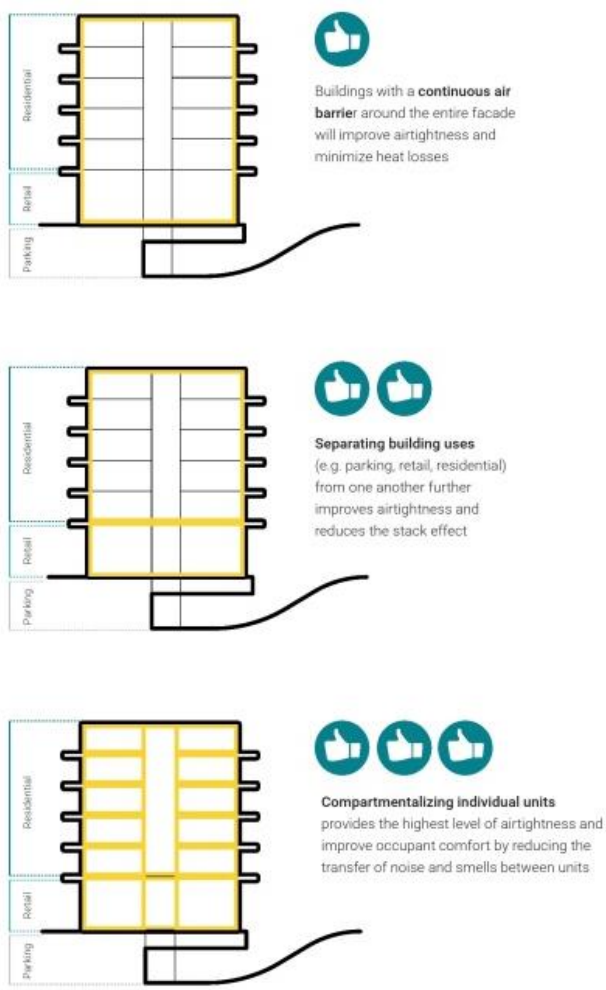


Figure 25: Design strategies for improving airtightness [2]

- **USING GREEN PLANTS ON AND AROUND BUILDINGS [12]**

Research into the effects of green plants on and around buildings shows their effect on the reduction of solar heat gain and the increase of internal comfort levels in the summer. Plants have a considerable evaporative cooling capacity that is capable of completely balancing or significantly reducing the heating from solar radiation. A site design that is resilient to extreme weather needs to have significant current and future provision for new areas of green plants, including green roofs, to reduce the effects of overheating from solar radiation, and thus mitigate the heat island effect. An ultimate provision for site mitigation would be to achieve 1 m^2 of green surface for each m^2 of hard surface.

- ✓ Plants have a considerable evaporative cooling capacity.
- ✓ They mitigate the heat island effect.

2.2.6 PLACING 3E APPROACHES

The new reference house approach tends to cover a wide variety of sustainability aspects rather than focusing just on an energy-related one. As a comprehensive approach, the new reference house can consider economy and society alongside environment as contexts to interact with, influence on, and take effect from. It is impossible to define a new forward-looking reference without having a broader perspective since for example, there is significant overlap between projects that aim to bring neighbors together and projects that aim to reduce environmental impact through sharing resources and tools within a local community [13].

- **ENVIRONMENT**

The environmental pillar is the most talked-about aspect of sustainability. It refers to the conservation of natural resources and the reduction of impacts on ecosystems. The environmental pillar concerns itself with protecting natural habitats, developing eco-friendly products, conserving resources, ensuring air and water quality, reducing pollutants, and reducing waste.

Greater recognition of ecological resilience would be required within the planning practice in order to achieve long term resilience of urban systems. It is also applicable for buildings as one of the subsystems of urban systems. From a sustainable design standpoint, this includes appropriate site selection, reducing energy usage, the use of locally-sourced, recycled, and sustainable building materials, and stormwater management techniques, to name a few. Sustainable design can incorporate a whole-systems approach. In order to minimize a project's impact on our environment, one must take into account the building envelope, electrical and mechanical systems, site characteristics, local environment, and material selections.

- **EQUITY**

Equity refers to social equity. As a region-level notion, this is a qualitative approach to test the future performance of current sustainability interventions to achieve social resilience to future uncertainties. This pillar protects the health of communities and educates and empowers residents to participate in the process, encouraging them to take action to improve their health and the surrounding environment. The new reference house approach can pave the way towards equity through defining the form and function-related constraints to impact the social aspect of sustainability. Having public places in forms of open spaces, some buildings can provide opportunities for social interactions that would be a start point towards equity [12, 13, and 14].

- **ECONOMICS**

The economic pillar relates to cost. One barrier to energy efficiency investments is the difficulty of obtaining reliable information on building system efficiencies and the related challenge of finding cost-effective ways to improve energy efficiency. Research shows a need to communicate energy and cost savings to owners, investors, financiers, and others to overcome market barriers and motivate capital investment in building energy efficiency. The point is that what should be communicated is not short-term savings in that net-zero targets may not be cost-effective in their implementation phase. Instead, long-term savings can be declared as proof of the new approach cost-effectiveness [4]. High-performance buildings help owners and occupants save money by lowering the amount of energy needed to provide a comfortable indoor temperature. They do so through improved insulation levels, passive strategies, more efficient mechanical systems, etc. [2].

Thus, economic feasibility is required if the new reference approach is to remain viable in the long term. For example, solutions that are cost neutral (that won't cost more to implement such as passive solutions or buildings with thicker, higher-quality envelopes tending to last longer and so, lessen the need for costly repairs and upgrades over time) are most likely to succeed [14]. Although the proposed approach would not be the most economical, pondering the economic parameter's trade-offs with other parameters in the performance matrix would result in more viable net-zero targets. Although not part of the actual spelling of the word, these three E's spell a sustainable reference house. When considered together, they represent a balanced approach to a greener way of life. [1, 14]

2.2.7 PLACING 4R APPROACHES

In defining the new reference house approach, it is crucial to not only evaluate the energy efficiency of building strategies but also consider the future potentials of these strategies to be beyond energy-efficiency compliance to achieve substantive net-zero targets. The new reference house approach can implement 4Rs through defining constraints on choosing materials, construction types, energy sources, and considering resilience parameters. However, since the 4Rs are a new concept in defining the reference house, determining comparing metrics needs further researches. One possibility can be calculating the embodied energy of chosen components or any other parameters that 4Rs can be applied on, and comparing it to their lifecycle (ratio of embodies energy to the component life cycle).

- **REDUCTION**

Wherever possible, reduction (waste, energy use, etc.) is the preferable option.

- **REUSE**

Every effort can be made to reuse every part of building components if practicable rather than simply reproduce them. Certainly, taking reusing approach would be more energy-efficient than the reproducing one.

- **RECYCLING**

Recycling is the third option in the energy and resources management hierarchy. Although recycling does help to conserve resources and reduce wastes, it is important to remember that there are economic and environmental costs associated with recycling including the required energy for the process and its related GHG emission. For this reason, recycling can only be considered for building parts which cannot be reduced or reused.

- **RECOVERY**

Finally, it may be possible to recover materials or energy from building components which cannot be reduced, reused or recycled [15].

2.2.8 USING RENEWABLE ENERGY SOURCES

Using renewable energy in defining the new reference house approach is remarkable in response to the goal of zero carbon emission [12]. Consequently, as renewable energy sources become cost-effective, they can be incorporated into the standard design package from which performance targets are derived [5]. There are many forms of renewable energy.[29] Most of these renewable energies depend in one way or another on sunlight. Wind and hydroelectric power are the direct results of differential heating of the Earth's surface which leads to air moving about (wind) and precipitation forming as the air is lifted. Solar energy is the direct conversion of sunlight using panels or collectors. Biomass energy is stored sunlight contained in plants. Other renewable energies that do not depend on sunlight are geothermal energy, which is a result of radioactive decay in the crust combined with the original heat of accreting the Earth, and tidal energy, which is a conversion of gravitational energy. Unfortunately, these are currently insufficient to fully power our modern society but can be considered as one of the main resources for energy in the future. Every one of these power sources (except for hydroelectric) has low environmental costs and combined have the potential to be important in avoiding a monumental crisis when the fossil fuel crunch hits. These energy sources are often non-centralized, leading to greater consumer control and involvement. Although all of BC's electricity is hydro, we need to include other renewables in defining resilience targets of the new reference house approach however in some cases.[2]

2.2.9 COUNTING EMBODIED ENERGY RATHER THAN SITE ENERGY

Embodied energy is the energy consumed by all of the processes associated with the construction and operation of a building, from the mining and processing of natural resources to produce, transport and delivery [17]. In defining the new net-zero reference house approach, what can be pondered is not site energy which simply calculates the net amount of energy use without taking into account the energy has been used in the process of generation, transmission, and distribution. Instead, source energy use - assessing transmission, delivery, and production losses- alongside full-fuel-cycle (FFC) of energy where possible -counting extracting, processing, and transport of primary fuels- can be considered [4].

- **DETERMINING BUILDINGS' "CARBON FOOTPRINT"**

For a comprehensive reference house approach to be most effective, it needs to address all phases of the building life-cycle. Life-cycle assessments try to profile the environmental performance of materials, components, and buildings as a whole. This approach, defined by William McDonough as "cradle to cradle", considers energy use through all phases of production, operation, maintenance, deconstruction, and re-use. It also aims to estimate a wide range of impacts including the full effects on energy, water, and land use, global warming and ozone depletion potential, toxic emissions (to air, land, and water), and the impact on human health. This process of calculating all emissions or environmental impacts over the lifetime of a building is often referred to as determining its "carbon footprint" or "environmental footprint". Such approaches increase the possibility to make optimal ecologic choices but also increase the complexity and costs of the certification.

Alongside the aforementioned phases of the building life-cycle, the design stage as a pre-construction stage is approximately a net-zero phase in the building lifecycle but can result in a significant difference in energy consumption. Incorporating energy efficiency measures in the design stage benefits the building in all future stages. It is usually easier and far less expensive to integrate energy efficiency measures at the time of construction, as compared to retrofitting those systems or equipment after the building is built and occupied.

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[2] . Please refer to the section 2.2.10 (Being Resilient) of this report for more information.

The build stage includes the actual construction, commissioning and refurbishment of the building. While there is no explicit type of building energy rating that targets the build phase, much can go wrong in the construction or renovation/ refurbishment of a building that can undermine the energy efficiency effectiveness of the design and this will appear in subsequent operational ratings. Appropriate commissioning during and toward the end of the construction period can help ensure the efficiency level remains as intended during the design phase. Furthermore, the huge amount of site energy, source energy, and FFC energy is used during the build phase if net-zero strategies are not placed in the design stage.

The operation stage includes the occupation, management, and maintenance of a building. Energy performance during the operation phase may be greatly affected by the way that occupants use the building, as well as (or even more so) by the efficacy of the operations crew. Nevertheless, considering passive strategies in the design stage can decrease the occupants' effect significantly.

Finally, the demolition stage, similar to construction stage, contains notable amounts of both site energy losses resulting from destruction operations and embodied energy losses resulting from not being reused, recycled, and recovered [1, 7].

- **MEASURING SOURCE ENERGY RATHER THAN SITE ENERGY**

Both IEA (International Energy Agency) and ASTM (formerly American Society for Testing and Materials) define source energy as the amount of fuel that is required to operate a building and incorporates energy consumed by the production of electricity as well as losses due to transmission and delivery [3].

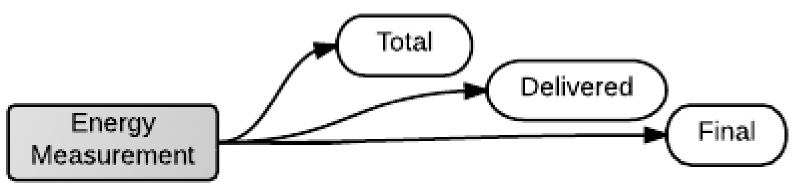

Figure 26: Energy Measurement options [3]

On one hand, site energy use appears to be simple, transparent, and easy to collect using utility bills. However, site energy considers primary energy (such as natural gas directly burned onsite) and secondary energy (such as electricity generated off-site) equivalent. In reality, a unit of raw fuel and a unit of converted fuel do not have the same global impact. Therefore, to provide a fair comparison, all externalities of delivered energy can be accounted for.

On the other hand, source energy incorporates all transmission, delivery, and production losses (Figure 26), thereby enabling a complete assessment of energy efficiency in a building. Although site energy is most closely related to the values that customers see on their energy bills for each fuel type, source energy more closely reflects the cost to the end-users of different fuels and in doing so reveals the long-term cost implications of different energy choices (Table 7).

Thus, in the new net-zero reference house approach source energy use can be determined as the primary metric for the following reasons:

- Accounting based solely on-site energy could lead to illogical decisions such as choosing performance packages that have the same site energy index but different embodied carbon index.
- Source energy metric reduces the likelihood that one energy fuel type will be unintentionally penalized or favored over another by incorporating all transmission, delivery, and production losses.
- Source energy more accurately gauges the global impact of energy consumption, taking into account the impact of the energy supply chain rather than only looking at what occurs at the building level.
- Source energy is more closely correlated with energy cost, and so is more likely to drive investment decisions.
- Source energy metric is aligned with the ENERGY STAR Portfolio Manager [4].

Nevertheless, determining secondary metrics as specific evaluation metrics regarding performance options such as resilience, embodied energy, thermal comfort, passive solutions, etc. can make the new approach complicated but comprehensive enough to achieve the net-zero targets.

Source	Ratio
Electricity (grid purchase)	3.34
Electricity (onsite solar or wind installation)	1.0
Natural gas	1.047
Fuel oil (1, 2, 4, 5, 6, diesel, kerosene)	1.01
Propane and liquid propane	1.01
Steam[(a)]	1.21
Hot water	1.28
Chilled water[(b)]	1.05
Wood	1.0
Coal/coke	1.0
Other (e.g., waste biomass)	1.0

(a) The weighted average of two source-site factors: 1.35 for conventional steam factor and 1.01 for CHP (combined heat and power) steam factor (EPA 2011).
(b) The weighted average of two source-site factors: 1.14 for electric chiller and 1.04 is for natural gas-fired chiller (EPA 2011).

Table 7: Source-site ratios[3] [4]

- **PONDERING FULL FUEL CYCLE ALONGSIDE SOURCE ENERGY WHERE POSSIBLE**

A concept similar to source energy is the full-fuel-cycle (FFC) measure. In addition to site energy use, the FFC measure takes into account the energy consumed in extraction, processing, and transport of primary fuels such as coal, oil, and natural gas; energy losses in the thermal combustion in power-generation plants; and energy losses in transmission and distribution to buildings.

EPA's (Environmental Protection Agency) source energy analysis does not account for the energy that is consumed before the power-generation plan. According to EPA, this type of analysis (energy used in

[3] . The ratios are national numbers and hence, are not accurate for BC. According to the Charron, the 3.34 ratio for electricity would depend on location. In provinces that are decarbonizing, this number would be changing relatively quickly, which in essence, would lead to a changing baseline.

mining, transporting, and refining crude products) may provide an instructive look at the life-cycle costs of energy use, it is beyond the scope of a building-level assessment. However, the life-cycle of energy can have a significant impact on total energy use and GHG emission worldwide. Although DOE (Department of Energy) has proposed the use of FFC measures to estimate the impact of energy conservation standards for consumer products and certain commercial and industrial equipment, the actual life cycle of energy is beyond those considerations. According to DOE, the proposed FFC measures would be based on the greenhouse gases, regulated emissions, and energy use in Transportation (GREET) model, which is used to compare the total energy use and greenhouse gas emissions of vehicle technologies and different fuels. To be honest, besides the constraints of energy transportation, the impact of energy life-cycle is worse than that if we count the amount of energy used in the generation process.

Nevertheless, the EPA claims that the effect of such a transition on the building energy performance is expected to be minimal. The significant energy losses in generation and transmission of electricity are captured in source energy (for example, 100% electricity use on the building site consumes 334% primary energy). Converting from primary energy to FFC energy would only add 2.1 to 14.7% to the source energy use. Even though the industry cannot include FFC measure right now, it could be added to the proposed framework over time.

2.2.10 BEING RESILIENT

Built environment resilience is becoming a more established concept, although there are no schemes yet devised to comprehensively measure building resilience [18]. Resilience will require both building-level actions and a strong focus on its larger context. On one hand, the Climate Ready Boston report demonstrated that the city, its businesses, and its residents need to take climate preparedness actions now. Costs related to the unpreparedness for climate changes are significant and include annualized losses, annualized physical damage, stress factors, and displacement costs [19]. On the other, past disastrous events have highlighted that neighbors are a significant source of help during recovery; the more connected the neighbors, the more resilient the communities [13].

The new reference house approach can achieve some levels of resilience employing strategic shifts towards solutions that simultaneously respond to both self-sufficiency and stressors/shocks-preparedness.

- **THE HOLISTIC CONCEPT OF RESILIENCE**

As one of the ultimate objectives of sustainable design, resilience is a multi-dimensional, multi-scale concept that cuts across the physical,[30] infrastructural,[31] environmental,[32] economic–social,[33] political–regulatory,[34] and organizational,[35] domains (Table 8). The US Department of Homeland Security Risk defines resilience as “the ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption.” Bosher defines a resilient built environment as one “designed, located, built, operated, and maintained in a way that maximizes the ability of built assets, associated support systems (physical and institutional) and the people that reside or work within the built assets, to withstand, recover from, and mitigate the impacts of threats.” Noting the transitioned state of a building performance after a threat, Adger defines the resilience as “the capacity to quickly recover from disturbance and return into original shape or performance to regain equilibrium in a different state after adaptation process.” In the respect of the new reference house, resilience can be defined as Burroughs defines it: "the ability to maintain or restore the functionality of a building after a damaging event/occurrence within a particular time frame" [12, 18].

Dimension	Subdimension
Physical	Characteristics and quality of building information technology systems Quality of architectural design, construction, and materials Physical, mechanical, and electronic security History of building systems, including reported faults, maintenance, and upgrades Present condition of building structure and fabric Present condition of building mechanical, electrical, and plumbing systems Quality of warning and anti-damage systems such as fire alarms and sprinklers
Infrastructural	Characteristics and quality of the surrounding transportation system Characteristics and quality of the grid electricity system Characteristics and quality of the water supply system Characteristics and quality of drainage and wastewater and other infrastructure Characteristics and quality of communications infrastructure Presence and extent of self-sufficient building power and water supply Performance of utility companies for restoring services after a destructive event
Environmental	Availability and quality of environmental information, e.g., hazard maps, forecasts History of exposure to destructive events Hazard presented to the site/building by current or forecast of flooding Hazard presented to the site/building by forecast sea-level rise Hazard presented to the site/building by current or forecast level of bushfire Hazard presented to the site/building by current or forecast intensity of cyclone Hazard presented to the site/building by other natural events or conditions Proximity of site/building to emergency services Features of building incorporated specifically for resilience to hazards Site and positioning of building with respect to adjacent buildings and land uses
Economic–Social	Strength and resilience of local economy Strength and resilience of sectoral economy Social characteristics and social capital of the surrounding community Building use and occupancy Life safety and wellbeing of occupants/users
Political–Regulatory	Local government characteristics favouring built environment resilience Regional government characteristics favouring built environment resilience National government characteristics favouring built environment resilience Characteristics of building code and standards with respect to resilience
Organisational (building owner)	Existence and quality of business continuity plan Risk identification, analysis, assessment, and management Quality and reliability of decision-making processes Communication both internal and external to the organisation Awareness of and compliance with the political and regulatory landscape Economic aspects of organisational decisions regarding building asset

Table 8: Dimensions and subdimensions for measuring individual building resilience [18]

- **BEING RESILIENT TO CLIMATE CHANGES**

Based on some researches, there is a general increase of discomfort hours as the climate years increase from current to 2030, 2050, and 2080. Resilience to climate changes includes three different but interconnected levels: the building, the site, and the region. In other words, a building will not be resilient to climate changes unless its site and region achieve resilience as well. According to the researches, among a wide variety of solutions**, efficient thermal insulation**, **purposeful green areas**, and **adaptable connectivity** are considered the most important ones in response to the climate changes.

On a building level, using **renewable energy**, **appropriate insulation thickness**, and **Passive house standard airtightness** are obtained as design recommendations in response to extreme weather events.

On a site level, research into the effects of **green plants** on and around buildings has increased the understanding of their effect on the reduction of solar heat gain and the increase of internal comfort levels. Plants have a considerable evaporative cooling capacity that is capable of completely balancing or significantly reducing the heating from solar radiation. A site design that is resilient to extreme weather needs to have significant current and future provision for new areas of green plants, including green roofs, to reduce the effects of overheating from solar radiation, and thus mitigate the heat island effect. An ultimate provision for site mitigation would be to achieve 1 m2 of green surface for each m2 of the hard surface [12, 20].

On a region level, the approach to the notion of resilience is the resistance to future uncertainties. This is a qualitative approach to test the future performance of current sustainability interventions. The researches mention that greater recognition of ecological resilience would be required within the planning practice to achieve long term resilience of urban systems. It is also applicable for buildings as one of the subsystems of urban systems. To be regionally resilient, **a densely connected network is required for desirable events** and **a sparsely connected network for undesirable ones** to limit the damage to a small part of the network. To operate normally under desirable events, and limit the damage under undesirable events, a resilient network must be able to switch its connectivity from dense to sparse and vice versa [12].

Given the increasing risks and looming uncertainty of climate change, increasing attention has been directed towards **adaptation,**[36] or the strategies that enable humanity to persist and thrive through climate change the best it can. Exactly what adaptation strategies to take— strategies that are cost-effective, justifiable, and address critical vulnerabilities (such as vulnerable populations) —are largely unknown but, it seems that passive design options that provide the highest level of self-sufficiency, have the potential to be mentioned as the new reference house response to climate change [20].

- **BEING SOCIALLY RESILIENT**

There is a connection between increased neighbor connections and increased resilience. Communities with higher levels of neighborliness and strong social networks are more resilient –that is, they are better at withstanding, adapting to, and recovering from change, stresses, or disturbances. “Resilience” in this case means the ability to respond and adapt to changes or threats in ways that are proactive, that build local capacity, and that enhance well-being.

Research has shown that apartment dwellers experience higher levels of the social isolation from their neighbors compared to those living in townhomes or single detached homes. There are several reasons for social isolation of apartment dwellers and one can be mentioned as the “form-effect”. Based on the Marcus Foth and Paul Sanders research on various ways of neighbors’ encounters, the existence of public space has a key role in likelihood, frequency, and intensity of three groupings of encounters.[37]

Generally speaking, some forms are more public-inclusive than others and so, have the capability of hosting social interactions (Figure 27). Taking into account the stressors/shocks-preparedness importance in response to threats, forms containing an open area can provide a context for kinship networks, strong local connections, and meaningful personal relationships as preparedness requirements; and hence, are prone to create socially resilient communities [13].

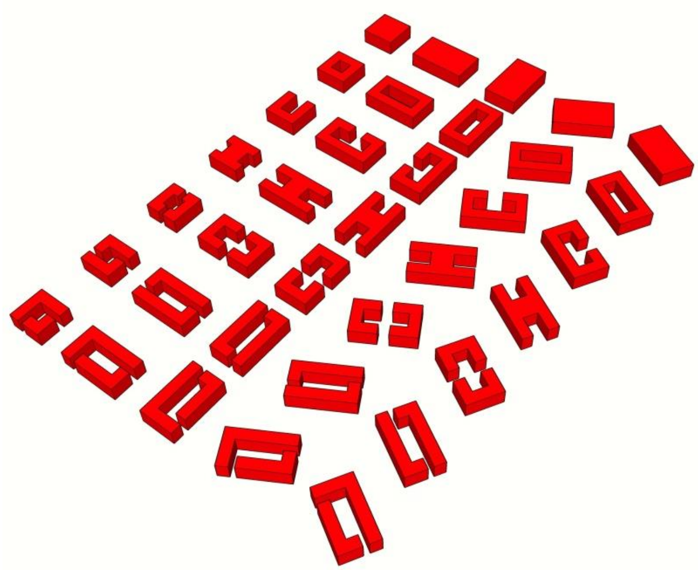

Figure 27: The influence of the building forms on social interactions.

- **BEING RESILIENT TO UNEXPECTED EVENTS, THREATS, AND HAZARDS**

Numerous threats and hazards that can impact a building performance in different levels (routine, expected, and extreme) including slow and fast environmental hazards and threats derived from physical design and condition of the building, surrounding infrastructure, and regulatory, economic, social, and organizational factors [18]. Based on the RELi action list these threats can include extreme weather, wildfire, seismic events, extreme rain, sea rise, and storm surge. What RELi action list proposes is, for the most part, based on passive strategies, embodied energy considerations, components' life-cycle remarks, and 3E/4R approaches. Pondering all the aforementioned aspects, the new reference house can effectively be resilient to a bunch of threats and hazards [21].

- **RELi's passive strategies**
    - Passive thermal safety
    - Landscape based passive cooling
    - Passive lighting
    - Passive heating
    - Passive cooling
    - Expanded indoor air quality (IAQ), daylight, and fresh air
    - Energy optimization, near-zero/ carbon-neutral, net-zero, net positive energy flows
    - Plan the site and orientation for sun, wind harvesting, and natural cooling
    - Near zero / high-efficiency water flows and resilient landscapes

- **RELi's embodied energy considerations**
    - Use regionally sourced and manufactured materials and products

- Material effectiveness: use recycled content materials, salvaged materials, and local materials
- Use legally logged wood from ecologically managed forests
- Reduce net embodied energy, carbon, water and toxins in producing materials and artifacts

- **RELi's life-cycle remarks**
  - Material and artifact effectiveness: full life cycle design for durability, adaptability, and flexibility

- **RELi's 3E/4R approaches**
  - Study and design for advanced resilience using a diversity of ecology-based perspectives
  - Provide for social equity: interdisciplinary/intercultural opportunities
  - Water use reduction, near zero/high efficiency water flows
  - Material and artifact effectiveness: a design for disassembly, reuse, recycling, and composting
  - Plan for rainwater harvesting, resilient landscapes, and food production

- **RESILIENCE ASSESSMENT**

To help owners make better decisions and protect their assets, to better assess the built environment resilience of larger geographic units such as communities and cities, and to complement existing assessments of building sustainability so that weaknesses and gaps can be identified and improved, the building resilience should be measured. Consequently, the built environment sustainability, its functionality, and the connected economic and social domains can be better protected.

Resilience levels (e.g., routine, expected, and extreme) need to be defined for different types of hazard. There are some standards and tools that can be used for resilience assessment but are in their preliminary stages and suffer from a lack of metrics available for measuring resilience [18].

Resilience standards are at a much more nascent stage of development. No single available standard provides sufficient guidance and technical support to implement measures to address multiple hazards. Each of the standards approaches resilience differently -varying in terms of hazards addressed, systems identified, and performance outcomes provided (Table 9 and Figure 28) [19]. They include:

- **Climate Ready Boston report**[38]
- **Building Resilience in LA Framework**[39]
- **Envision**[40]
- **Fortified**[41]
- **LEED Pilot Credits for Resilient Design**[42]
- **PEER (Performance Excellence in Electricity Renewal)**[43]
- **REDi (Resilience-Based Earthquake Design Initiative)**[44]
- **RELi Resilience Action List + Credit Catalog**[45]
- **Sustainable Sites Initiative**[46]

Among the existing standards, the new reference house can be assessed based on LEED Pilot Credits for Resilient Design due to its passive approach, PEER credit because of counting embodied energy for the building life-cycle, REDi credit owing to considering specific arrangements in the building structure in order to provide occupant's safety, RELi credit due to taking into account a comprehensive approach to new buildings and their integration into the surrounding community, and Sustainable Sites Initiative in account of analyzing site-specific features as well as building life-cycle.

STANDARD	TARGET AUDIENCE						IMPACT AND SCOPE			STANDARD DEVELOPMENT PROCESS			
	Facility Type	Scale		Life Cycle		Systems	Hazards Included	Performance Goals	Social Vulnerability	Driver		Verification	
		F	C	New	Retrofit					Industry	Community	Internal	External
BRLA	All	✓			✓	N	Holistic (planning framework)		●	✓	✓		
Envision	Infrastructure		✓	✓	✓	Y	Holistic		◑	✓		✓	✓
FORTIFIED	Commercial	✓		✓	✓	N	Wind, hurricanes, hail	Business continuity	○	✓			✓
LEED Pilot	Commercial	✓		✓		Y	Holistic	Passive survivability	○	✓			✓
PEER	Commercial, campus	✓		✓	✓	N	Power outage	Improving power performance	○	✓			✓
REDi	All	✓		✓		Y	Earthquakes	Building re-occupancy and recovery	○	✓		✓	
RELi	All	✓	✓	✓		Y	Holistic		◑	✓	✓	✓	
SITES	Commercial	✓		✓		N	Sea-level rise, flooding, temperature		○	✓			✓

Target Audience, Scale	F: facility-level; C: community level
Target Audience, Life Cycle	New: new construction; retrofit: existing buildings
Target Audience, Systems	Y: Includes systems beyond site; N: does not address systems beyond site
Impact, Social Vulnerability	○ Impact on community cohesion and/or vulnerable populations not explicitly included within standards ◑ Optional credits addressing community cohesion and/or vulnerable populations ● Addressing community cohesion and/or vulnerable populations required as part of standard

Table 9: standard comparison [19]

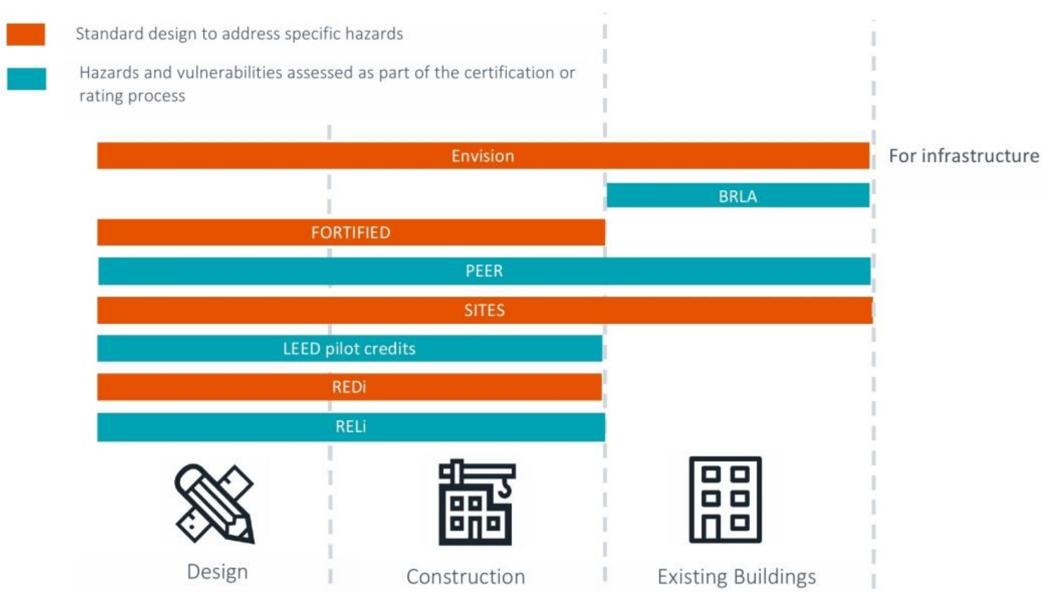

Figure 28: Standards compared by building lifecycle [19]

In addition to the standards, among the two available measurement tools including Australian Resilience Measurement Scheme for buildings (ARMS)[47] and Building Resilience Rating Tool (BRRT)[48] that separately assess different aspects of resilience, it sounds that the new reference house approach may need a combination of both to be evaluated comprehensively [18].

2.3 AN EXAMPLE

To make the new reference house approach more clear, an example of a specific project would be provided here using the proposed performance matrix and its related sub-matrix. This example would illustrate how a baseline building can be ambitiously defined by both constraints and strengths beyond the current borders.

To do so, suppose a residential mid-rise being built on a specific lot located on the north slope of a mountain. This building is shaded by adjacent taller buildings and could be exposed to wildland interface fire.

The first step in defining the reference house would be choosing all applicable elements of the performance matrix that relates to the specific features of the project (Figure 29).

These features include:

- Being mid-rise
- Locating on the north slope of a mountain that would shade the southern elevation
- Being shaded by adjacent taller buildings that would limit daylighting availability in almost every side
- The possibility of being exposed to the wildfire that calls for special arrangements such as cleaning the adjacent areas from trees and combustibles

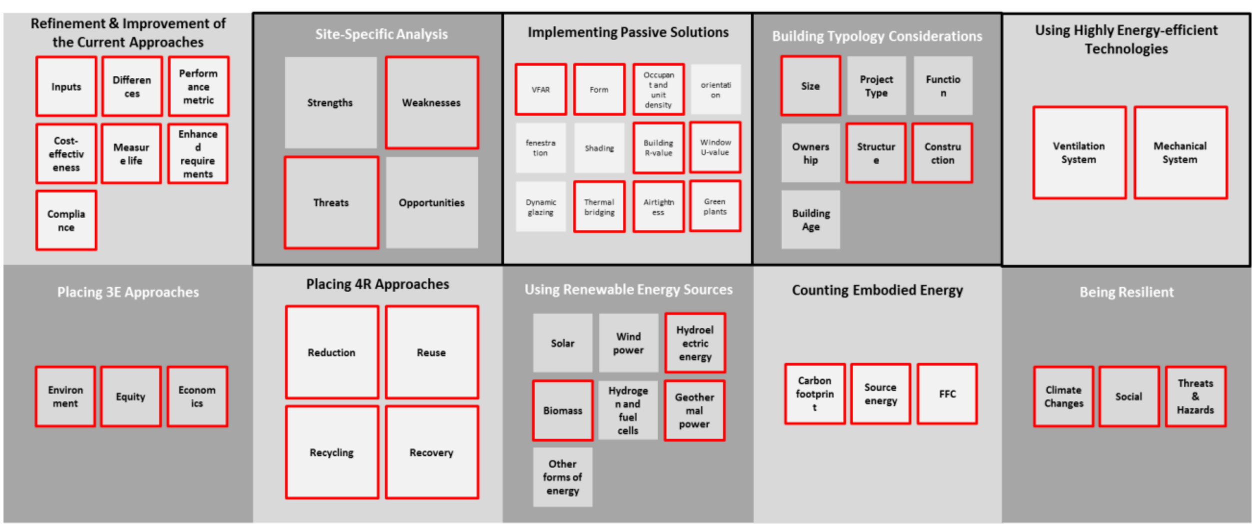

Figure 29: Applicable elements from the performance matrix

The second step is choosing related sub-matrix which would precisely define the reference house (Figure 30).

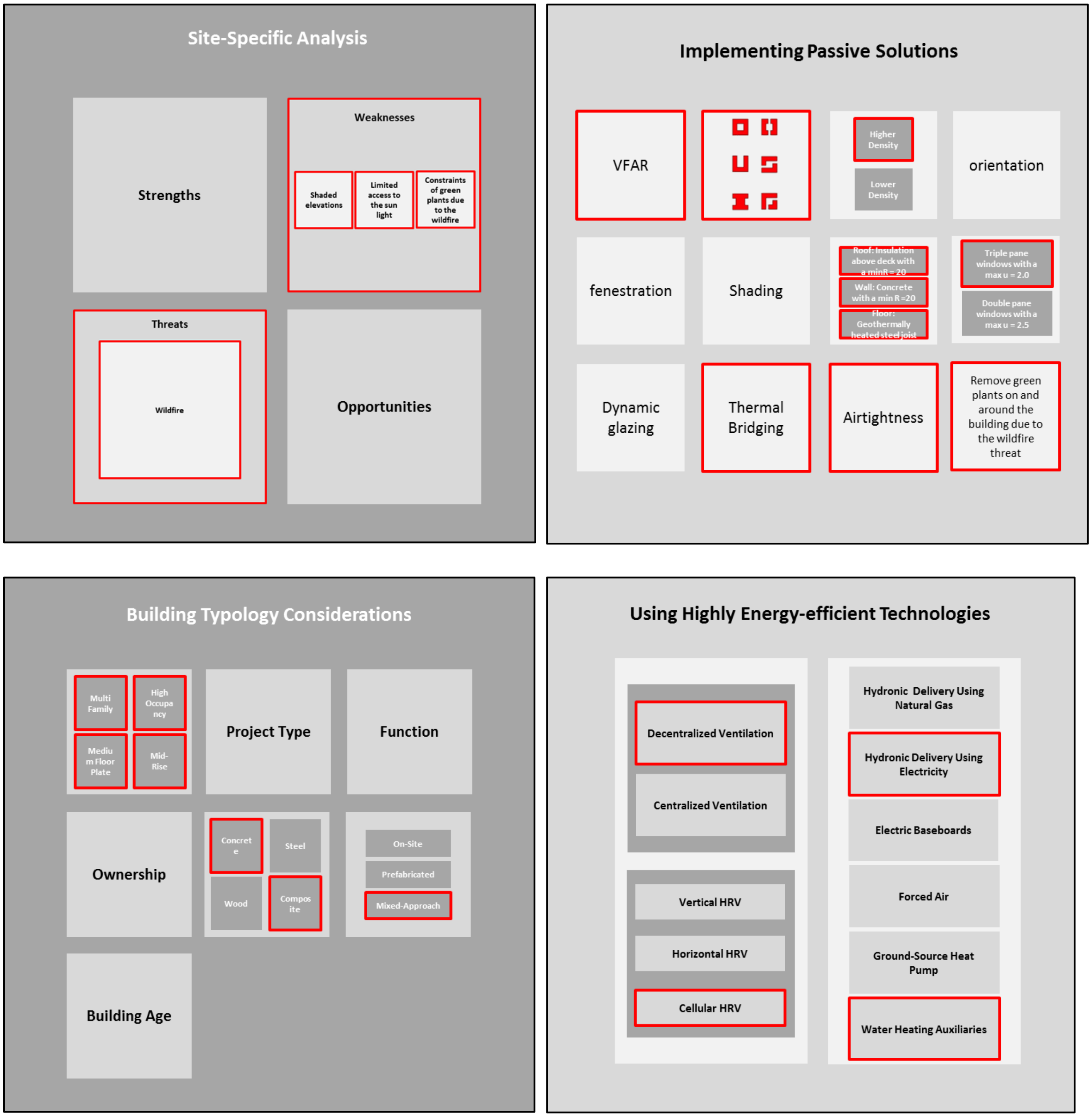

Figure 30. Related sub-matrix

- ✓ Among mass walls, metal building walls, steel-framed walls, and wood-framed and other, mass walls with concrete assemblies can be efficient considering wildfire vulnerabilities.
- ✓ Since the mountain and adjacent taller buildings would shade the proposed mid-rise, the fenestration-related options are not influential.
- ✓ Due to the shaded elevations, the need for the cooling capacity of green plants can be eliminated regarding their threat in the time of wildfire.
- ✓ In addition to the energy efficiency aspect of a high-occupant approach, setting a high-level resilience to the wildfire threat can sound economic.

- ✓ Among concrete, steel, wood, and composite structure, concrete or a fire-resistant composite structure would fit the best with the resilience targets.
- ✓ Having a mixed approach of on-site and prefabricated construction allows the building to rapidly recover from the disturbance.

2.4 PRELIMINARY ANALYSIS

Potential features of the new reference house approach include:

- Being a comprehensive, flexible, and high-compliant approach all contribute to lower energy use of buildings.
- Ensuring low performing design options are eliminated or balanced with high performing options.
- Considering the building as a system, accounting for building system and climate interactions.
- Mentioning on-site renewable energy as a resilience target requirement.
- Counting embodied energy during the life-cycle of a building as one of the possibilities to fully cover the actual energy use.
- Providing a context for enhanced mandatory requirements.
- Being stable enough to not be affected by ever-changing prescriptive paths.
- Resulting in a flexible design approaches giving a trade-off opportunity to designers.
- Balancing occupant's effect on building energy performance by placing passive solutions.
- Considering greenhouse gas emissions as one of the primary metrics.
- Counting on trade-offs between expensive high-tech solutions and passive solutions.
- Integrating mitigation and adaptation.

However, the new approach faces the following challenges:

- Taking more time and money to be modeled and implemented (Figure 31).
- Requiring the contribution of professionals in different fields.
- Requiring either further research or deeper insight in contexts that have not been covered in the previous approaches or not examined profoundly.

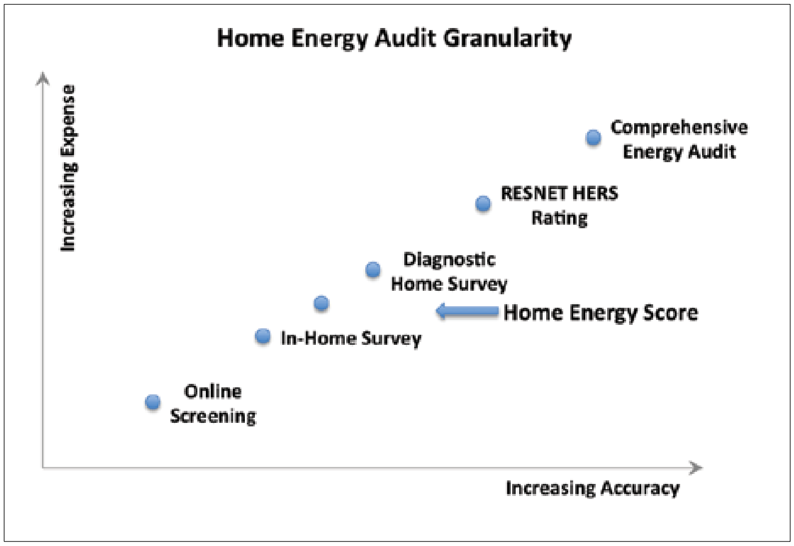

Figure 31: Trade-off between complexity and expense for residential ratings [7]

3 VISION FOR A FUTURE APPROACH

This vision is based on code development being led by a specific approach to predictive energy, ecological, economic, and social performance combined with building-specific prescriptive packages that are designed to be both cost-effective and energy-efficient and to achieve a desired level of performance. To make the proposed vision more clear, it would be beneficial to re-mention the most important challenges in regulating energy efficiency led by current code formats alongside remarking the main potentials of the energy code future vision in defining a forward-looking reference building.

Having the aforementioned considerations and constraints of the proposed reference house approach in mind alongside all the pros and cons of the current code visions (Table 4), we can conclude that:

Significant problems of the current code formats in regulating energy efficiency can include (Table 11):

- **Variation in energy use**

When establishing criteria in the prescriptive path, each component is judged independently, to require the most cost-effective level of efficiency of each component. The result is that two parallel prescriptive requirements don't necessarily guarantee equivalent energy performance. This adds design flexibility but means that decisions made by the design team can result in significant energy impacts (Table 10).

Complicating matters further, prescriptive criteria are usually set at the limit of cost-effectiveness using assumptions that must apply to a wide range of buildings. Calculations use national average energy rates, equipment costs, and other economic assumptions as well as standard operational assumptions and selected climate locations. This results in criteria that are generally cost-effective on a national scale but may not necessarily be for any individual building.

Prescriptive Package Path Method for Office buildings from 5,000 to 50,000 square feet

Compliance with the Prescriptive Package Path method requires that all parameters for one package in the table below be met in addition to the following:

1. All mandatory requirements of Standard 90.1 must be met.
2. All prescriptive requirements not covered below must comply with Sections 5 to 10 of Standard 90.1.
3. HVAC systems shall include economizers in compliance with Section 6.5.1 and Energy Recovery as required by Section 6.5.6.
4. Cooling source shall be direct expansion.

Package	HVAC System	Heating Source	Heating Source Efficiency [1.]	Min Cooling Source Efficiency [2.]	Max Window Wall Ratio	Opaque Construction U-Value [3.]	Fenestration U-Value [3.]	Fenestration SHGC [3.]	Maximum Fan Brake HP (each system) [4.]	Max Interior LPD (W/ft^2)	Minimum Daylight Area [5]	Minimum Occupancy Sensor Coverage Area
Package 1 (Primary)	MZ VAV w/ hydronic Reheat	NG Boiler	100%	100%	33%	100%	100%	100%	100%	0.82	21%	53%
Package 2	MZ VAV w/ hydronic Reheat	NG Boiler	100%	100%	**50%**	100%	100%	100%	100%	0.82	**41%**	53%
Package 3	MZ VAV w/ hydronic Reheat	NG Boiler	**120%**	**115%**	**50%**	**125%**	**125%**	100%	100%	0.82	21%	53%
Package 4	MZ VAV w/ hydronic Reheat	NG Boiler	100%	100%	**40%**	**108%**	**108%**	100%	100%	**1.00**	21%	**91%**
Package 5	MZ VAV w/ hydronic Reheat	NG Boiler	**110%**	**110%**	33%	100%	100%	100%	**135%**	0.82	21%	53%
Package 6	MZ VAV w/ hydronic Reheat	NG Boiler	100%	100%	**40%**	**150%**	**150%**	100%	100%	0.82	21%	**91%**
Package 7	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	**120%**	**40%**	**108%**	**108%**	100%	100%	**0.66**	21%	**91%**
Package 8	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	100%	**40%**	**83%**	**83%**	100%	100%	0.82	**41%**	**91%**
Package 9	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	**115%**	**25%**	**67%**	**67%**	100%	**80%**	**1.00**	21%	**91%**
Package 10	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	**115%**	33%	100%	100%	100%	**135%**	0.82	**41%**	**91%**
Package 11	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	100%	**25%**	**108%**	**108%**	100%	100%	0.82	**41%**	**91%**

1. % of required heating efficiency in Table 6.8.1-6 of Standard 90.1
2. % of EER required efficiency in Table 6.8.1-1 of Standard 90.1
3. % of U-value required in Table 5.5-5 of Standard 90.1
4. % of fan BHP calculated according to 6.5.3.11 Option 2 of Standard 90.1
5. Daylight areas must include controls per Section 9.4.1.1.e and f of Standard 90.1
6. Values in bold differ from the primary package.

Table 10: Sample prescriptive packages for medium office building 5,000 to 50,000 ft2 in climate zone 5A [5]

- **Diminishing returns**

The approach of incrementally improving the efficiency of individual building components is reaching a point of diminishing returns. In other words, simply increasing insulation or equipment efficiency will not achieve net-zero energy targets and it is unlikely that cost-effective improvements can be applied at the same rate as in the past.

- **Limited credit for good design choices**

As discussed above, neither the prescriptive component path nor the predictive performance path using a dependent baseline distinguishes between high and low energy design choices that fall within the prescriptive allowances. For example, the performance path using a dependent baseline would give no tradeoff credit to the more efficient choices, as the baseline assumes the same system type and WWR [5].

Furthermore, even the predictive performance path using an independent baseline may fail to incent more energy-efficient architecture and building form since the reference building typically has the same architecture as the modeled building (except for window distribution and potentially window-to-wall ratio). Complicating the issue is that in some cases, the mechanical systems of the reference building would change with the proposed design, resulting in a shift in the energy target [10].

- **Difficult to track progress**

It is difficult to track the progress of energy codes in their current format. The problem is caused by the fact that the prescriptive baseline changes with each updated version of the code, making it a moving target. This makes it very difficult to compare the performance of buildings of different vintages, or to establish a deliberate improvement goal in performance requirements [5]. To overcome the problem, in ASHRAE standard 90.1-2016, the baseline building is set unchanged to its 2004 version, and a gradual improvement would be pursued in the future upgraded versions. The bottom line is that due to the bottom-up progress, the net-zero targets would be almost improbable to be achieved [8].

- **Performance path rules can't keep pace with prescriptive changes**

With the growing charge to code development bodies to improve energy code performance, the pace of change has increased dramatically. In addition to the number of changes, the scope of regulated equipment has also increased. During the last several code cycles, the performance path has not been fully updated to match prescriptive requirements before the publication of the standard.

Another problem occurs when, in the search for additional savings, prescriptive requirements become more complex. Some prescriptive requirements are expensive exercises in design for a baseline building that will never be constructed.

- **Expected savings may not be realized**

Projections of energy savings from codes are typically estimated by building energy modeling predicting the potential of the codes to save energy. These predictions assume the code is fully complied with, and that the operations and maintenance of building energy using systems are optimized, not only at occupancy but throughout the life of the building. Studies have shown these assumptions may be overly optimistic. Figure 32 shows a comparison between modeled, predicted performance, and post-occupancy energy use for several LEED-accredited buildings. The results show actual energy use varying between about 50% and 275% of predicted energy use.

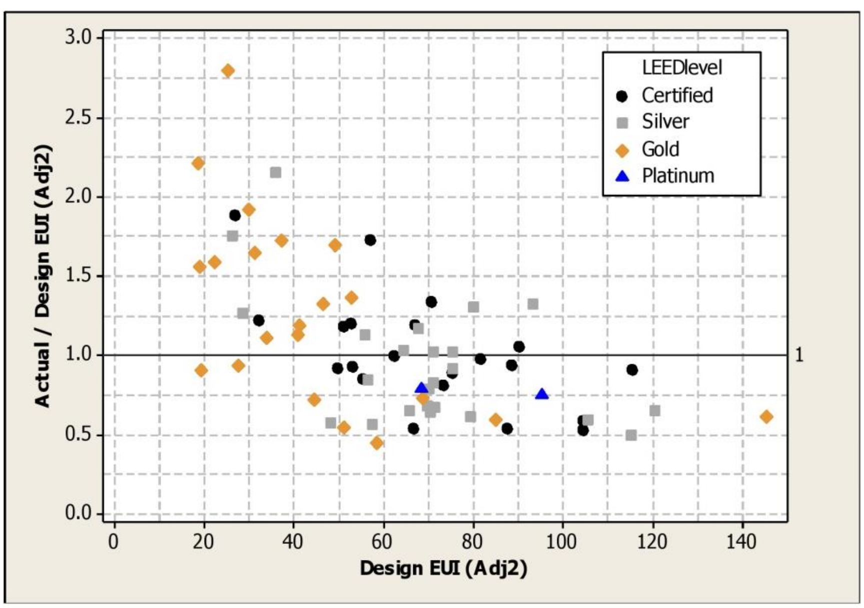

Figure 32: Predicted performance compared to actual performance for LEED-certified buildings [5]

- **Unregulated loads ignored**

Although energy codes are expanding the coverage of unregulated building loads, a problem still exists and solutions using the current approaches are unlikely. It is difficult to regulate plug loads, retail displays, signage, commercial processes, and any unusual use of energy. As we reduce the energy use of those building loads that are regulated by codes, the portion of unregulated energy increases, and further reductions are harder to achieve. It is unlikely that prescriptive building design and construction codes alone will ever regulate all building energy use.

- **Too many performance approach options**

The two performance approaches in Standard 90.1 (Figure 33) combined with the adoption and use of different versions have resulted in a multitude of building performance evaluation methods. To make matters even more confusing, many of the codes or programs add their modifications to the standards and modeling rules. This lack of standardization limits compliance software development and makes it very difficult for software developers and energy modelers to keep up with requirements. A single project that needs to achieve code compliance, LEED certification, utility incentives, and a federal tax incentive would need four separate baseline building models [5]. The proposed top-down reference house approach may contribute to solving the problem by defining an ambitious target while providing flexible packages of performance options with trade-off possibilities among the most efficient options.

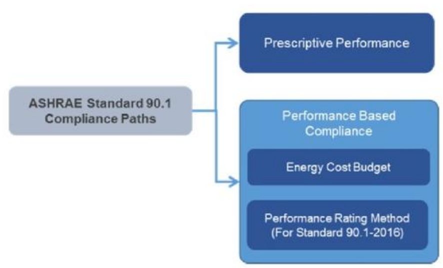

Figure 33: Compliance path for ASHRAE standard 90.1 [8]

- **Modeler influence on building energy modeling**

All buildings are different, and conventional building energy modeling requires each modeler to use a substantial amount of judgment. This judgment leaves room for different interpretations of standards and different approaches to modeling a specific situation. While this flexibility can be a boon to modelers, it can create challenges when trying to compare models created by different individuals [4]. Even though the modeler influence cannot be ignored even in the proposed approach, it can be mitigated by providing an ambitious target alongside defining flexible packages of the most efficient performance options provided in the matrix (Figure 6).

On the other hand, potentials of the future vision of codes in defining a new forward-looking reference building can be (Table 11):

- **Considering greenhouse gas emissions as one of the metrics**

Energy use significantly contributes to greenhouse gas emissions, and the new vision can consider it as an essential indicator for building performance evaluation. Using greenhouse gas as one of the program metrics would most closely link the future vision to environmental impact [4].

- **Counting on trade-offs between expensive high-tech solutions and passive solutions**

Even though the current code regulatory purposes are not much in terms of high-tech systems, and only use them as an option to reduce energy use, but the codes future vision may mostly focus on using high-tech systems to achieve the net-zero targets. Such an approach would result in more expensive houses, and it is in contrary to the affordability policies. Using expensive technologies to recover energy may sound extremely energy efficient but the question is that is it necessary? Are the costs invested on implementing such systems refundable through the effect they would have on energy consumption? To achieve the net-zero approach, there would be some evaluations on how much it worth to count on new technologies as well as passive solutions trade-offs. In other words, considering passive solutions in the future codes regulatory purposes can mitigate the possibility of a biased trend towards high-tech solutions.

- **Integrating mitigation and adaptation**

According to the IPCC, reaching out to integrating mitigation and adaptation deserves the highest priority in urban planning, design, and architecture (Figure 34). Likely, an approach that considers the building as a socially, ecologically, and economically integrated system will be necessary to achieve the next real gains in building efficiency. For example, while adding cooling capacity may represent an effective adaptation strategy for higher temperature extremes, it will most likely increase GHG emissions. By contrast, replacing fossil fuel boilers with electrically powered energy-efficient air source heat pumps may advance mitigation, but could increase occupant risk during a winter power outage (by impacting the electrical grid if they don't have the capacity for the extra loads during extreme heat or cold events) and, if implemented extensively, potentially affect reliability of the electrical grid [5, 11].

Figure 34: The adaptation path from a building scale to a city-scale [11]

- **Including on-site renewable energy**

Continuing past reference house approaches into the future, may not achieve net-zero, resilience-oriented targets. Hence, Future progress may need to include on-site renewable energy and occur at an integrated system level that considers the specific building interactions of systems, utility rate structures, and operational parameters that are not easily regulated with current prescriptive approaches.

- **Considering the social and environmental impacts of buildings form and function**

Buildings are an ecologically, economically, and socially integrated systems and thus, their impacts cannot be limited to the energy consumption and GHG emission. Instead, they have broad environmental and social impacts through their lifecycle, form, function, etc. Hardly can anyone deny that fact the some buildings sound to be more public-inclusive than others and can provide far more interaction opportunities for the dwellers. Future vision will need to provide some levels of resilience to unexpected events, and it won't occur unless integrates social performance with the energy performance of buildings.

- **Pondering site constraints, resilience-oriented approaches, passive approaches necessities, and other objectives**

An effective vision has many goals: comprehensiveness, flexibility, ease of administration, and high compliance rates all contribute to lower energy use of buildings [5]. It also can be technically feasible, economically justified and environmentally beneficial [6]. In other words, targets are ambitious, either in terms of the level of adaptation to sustainability goals or the vision impact on the environment and estimated energy savings. A strong target attracts attention and is easier to promote [1]. Thus,

- ✓ A future vision can ensure low performing design options are eliminated or balanced with high performing options.
- ✓ It can consider the building as a system, accounting for building system and climate interactions.
- ✓ The progress of a future vision can be measured on a fixed scale (a top-down reference house approach) that can more easily track progress toward net-zero energy buildings.
- ✓ The scope of a future vision can be expanded to cover post-occupancy energy use.
- ✓ Existing buildings need to be addressed by a future vision to ensure that, once constructed, buildings are maintained and operated efficiently.
- ✓ A future vision can require or encourage on-site renewable energy to enable a path to net-zero energy buildings [5].

<table>
<tr><td rowspan="8">COMPARING</td><th>ASPECT</th><th>THE PROPOSED APPROACH</th><th>THE CURRENT APPROACHES</th></tr>
<tr><td>Building Typology</td><td>Uses more detailed classification</td><td>What determined as a classification for reference buildings is inefficient. For example, ASHRAE standard's classification is mostly function-based and Energy Step Code's is generally size-based.</td></tr>
<tr><td>Envelop</td><td>In addition to thermal properties, it takes into account different orientations' special requirements such as WWR and shadings, as well as site-specific considerations such as view, proximities, and special features.</td><td>Takes into account thermal properties and some of the orientation-based features</td></tr>
<tr><td>Internal Loads</td><td>Counts regulated and unregulated loads</td><td>Mostly focus on regulated loads</td></tr>
<tr><td>Ventilation</td><td>Mainly focuses on using natural ventilation, and using HRV with an economizer when needed.</td><td>Mainly focuses on mechanical ventilation with an integrated economizer. Energy Step Code mention the possibility of natural ventilation by window-design options as well as using HRV systems</td></tr>
<tr><td>Highly Energy-Efficient Technologies</td><td>Uses Highly Energy-Efficient Technologies.</td><td>Uses Highly Energy-Efficient Technologies.</td></tr>
<tr><td rowspan="2">HVAC Systems</td><td rowspan="2">Uses high performance, the most energy-efficient, carbon-neutral and independent systems.</td><td>Dependent on the proposed building</td></tr>
<tr><td>Independent of the proposed building</td></tr>
</table>

<table>
<tr><td rowspan="11"></td><td rowspan="3">Baseline Dimensions</td><td>Design</td><td>Time</td><td>Test</td><td>Design</td><td>Time</td><td>Test</td></tr>
<tr><td rowspan="2">Independent</td><td rowspan="2">Top-down stable</td><td rowspan="2">Differential</td><td>Independent</td><td>Bottom-up stable</td><td>Differential</td></tr>
<tr><td>Dependent</td><td>Time-variable</td><td>Equivalent</td></tr>
<tr><td>Sustainability Approaches</td><td colspan="3">Ponders 3E and 4R dimensions.</td><td colspan="3">Takes into account the energy sub-dimension of the ecology dimension.</td></tr>
<tr><td>Option Combinations</td><td colspan="3">Uses the least energy-consuming combinations of options.</td><td colspan="3">Uses the most cost-effective combinations of options.</td></tr>
<tr><td>Material</td><td colspan="3">Considers full lifecycle for durability, adaptability, and flexibility.</td><td colspan="3">Uses standard materials.</td></tr>
<tr><td>Environmental Analysis</td><td colspan="3">Considers the impact of all phases of production, operation, maintenance, deconstruction and re-use on energy, water, and land use, global warming and ozone depletion potential, toxic emissions (to air, land, and water), and the impact on human health.</td><td colspan="3">Counts the impact of operational energy.</td></tr>
<tr><td rowspan="4">Vision</td><td colspan="3" rowspan="4">Predictive energy, ecological, economic, and social performance combined with building-specific prescriptive packages that are designed to be both cost-effective and energy-efficient, and to achieve a desired level of performance.</td><td colspan="3">Prescriptive</td></tr>
<tr><td colspan="3">Capacity constraint</td></tr>
<tr><td colspan="3">Predictive energy performance</td></tr>
<tr><td colspan="3">Outcome-based</td></tr>
<tr><td rowspan="11">CONTRASTING</td><td>ASPECT</td><td colspan="3">THE PROPOSED APPROACH</td><td colspan="3">THE CURRENT APPROACHES</td></tr>
<tr><td rowspan="2">Performance Target</td><td colspan="3" rowspan="2">Source Energy Index alongside considering FFC</td><td colspan="3">Energy Cost Index</td></tr>
<tr><td colspan="3">Site Energy Use Index</td></tr>
<tr><td>Geometry</td><td colspan="3">Considers trade-offs between social resilience and energy efficiency.</td><td colspan="3">Solely cares about energy efficiency</td></tr>
<tr><td>Lighting</td><td colspan="3">Gives prominence to passive solutions such as daylighting.</td><td colspan="3">Mostly focuses on electrical lighting</td></tr>
<tr><td>Schedules of Operation</td><td colspan="3">Sets an optimized, fixed schedule based on weather data.</td><td colspan="3">Generally, adjusts the reference house schedules to the proposed building.</td></tr>
<tr><td>Resilience</td><td colspan="3">Ponders social resilience as well as resilience to climate changes and unexpected events, threats, and hazards.</td><td colspan="3">Ignores resilience</td></tr>
<tr><td>Site-Specific Features</td><td colspan="3">The given constraints of a building site would be modeled similarly in both the reference and proposed design (e.g. lot size, orientation, topography, solar access, shading from adjacent structures, etc.)</td><td colspan="3">Ignores site-specific features</td></tr>
<tr><td>Passive Approaches</td><td colspan="3">Mainly concentrates on passive solutions to achieve net-zero targets.</td><td colspan="3">Ignores the passive solutions in defining energy-efficient approaches.</td></tr>
<tr><td>Embodied Energy</td><td colspan="3">Considers buildings and components lifecycle, source energy, and FFC energy while counting the energy consumption and GHG emission.</td><td colspan="3">Counts site energy for energy consumption and GHG emission calculations.</td></tr>
<tr><td>Renewable Energy Sources</td><td colspan="3">Uses renewable energy sources to achieve net-zero targets.</td><td colspan="3">Does not address renewable energy sources.</td></tr>
</table>

Table 11: Comparing and contrasting the current and proposed vision

4 RECOMMENDATIONS

- **Choosing a mandatory approach**

A key benefit of mandatory schemes is that they eliminate the possibility of “hiding” poor performing buildings and help to identify those buildings that have the greatest potential for energy saving. Mandatory schemes will have higher implementation and operational costs, but also much higher capacity to identify larger savings potentials and make a significant contribution to national energy and emission reduction goals [1].

- **Agreed with an ambitious target**

Targets are ambitious, either in terms of the level of adaptation to sustainability goals or the vision impact on the environment and estimated energy savings. A strong target attracts attention and is easier to promote. The Portuguese experience shows that these targets can be promoted through the media, the internet, seminars, and workshops to make industry and the public aware of the benefits of such high expectations [1].

- **Following a synergistic approach**

Following an approach which is synergistic but not conflicting, which does trade-offs to gain opportunities, is essential in defining the new reference house approach. It means keeping the process simple enough while completely addressing the issues. However, taking Maslow approach in defining the new reference house can result in a gap since all aspects should be pondered simultaneously; in other words, we cannot provide bases for one aspect without taking into account the other ones, if so, it would be either impossible or expensive and time-consuming [11].

- **Mainly focusing on passive approaches**
    - Reducing the complexity of the building facade, and increasing the floor plate as much as possible to reduce the potential for heat loss through the envelope.
    - Orienting the longest facade of the building towards the south as much as possible alongside shading south/west-facing facades to mitigate the risk of overheating.
    - Considering trade-offs between TEDI and TEUI carefully in building energy modeling.
    - Targeting a 40% window-to-wall ratio (WWR).
    - Using external shading devices to minimize unwanted solar gains.
    - Natural ventilation and cooling strategies, such as operable windows to mitigate the risk of overheating.
    - Selecting envelope systems with high effective R-values.
    - Selecting windows with low U-values.
    - Breaking all thermal bridges with insulating materials.
    - Installing a continuous air barrier to minimize heat losses through the building envelope.
    - Sealing off residential units from each other and other building uses [2].
    - Incorporating requirements for renewable energy sources [5].

- **Including other environmental issues**

It is to extend the scope beyond energy performance to include assessment of a building's environmental values, measuring aspects such as GHG emission, the use of sustainable materials and components, land use, water use, and waste handling. A key challenge in this regard is developing calculation methods that appropriately measure very different criteria, some of which are quantifiable (such as the use of energy, land or water) and others that are more qualitative in nature (the types of materials used for the building construction and the processes used to produce them). Environmental assessment can be a particularly good choice for large and complex buildings that have a significant impact on the surrounding environment, but it is likely to prove too complicated and expensive for smaller buildings [1].

- **Considering the inclusion of life-cycle and environmental analysis**

It is to include calculations of energy use in construction (and eventual demolition) as a means of reflecting all energy use over a building's life cycle. This makes it possible to relate increased or decreased energy use in construction and demolition with changes in consumption during the building's operational phase. Other life-cycle assessments try to profile the environmental performance of materials and components which determines their "carbon footprint" or "environmental footprint". Such approaches increase the possibility to make optimal ecologic choices but also increase the complexity and costs of the assessments. This is a particular concern for smaller buildings for which the marginal cost increase could make the evaluation process uneconomic [1].

- **Considering the performance matrix and sub-matrix in defining the new reference house approach**

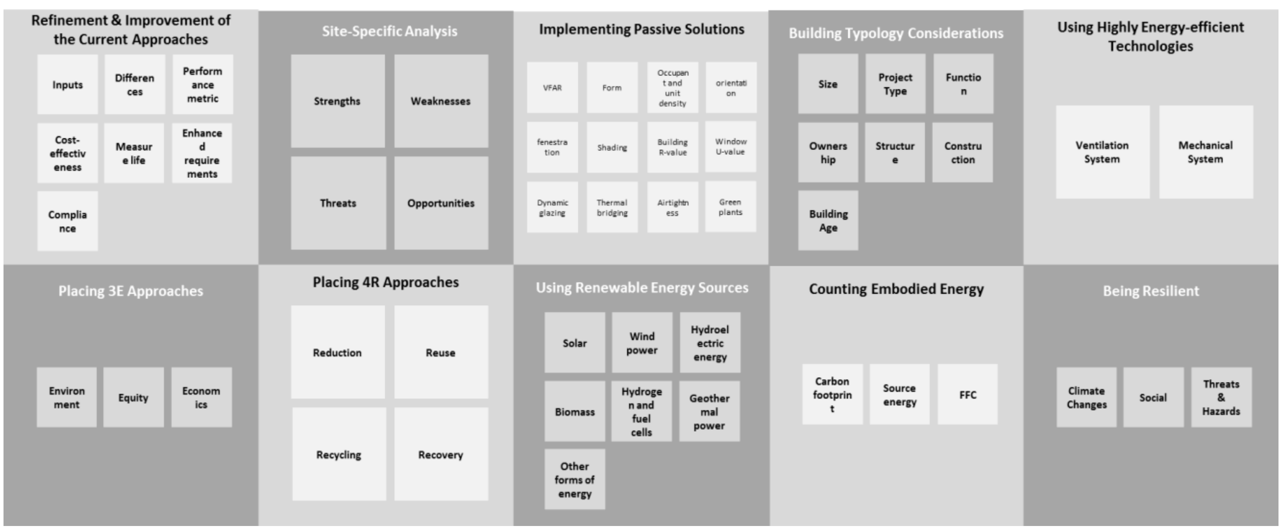

Figure 35: The new reference house performance matrix

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6 APPENDIX

[1] . There are two sub-approaches for the predictive performance approach including Energy Cost Budget (ECB) and Appendix G approach (PRM). The ECB approach (In ASHRAE Standard 90.1 both the 1989 and 1999/2001 versions [8]) establishes compliance by comparing the simulated energy cost of proposed building design to a baseline building design. The ECB baseline building tracks the proposed design with each element in the baseline defined to be the same as the proposed; however, its efficiency is upgraded or downgraded to exactly meet the prescriptive code requirements. The ECB baseline building is non-deterministic since the prescriptive standard has many exceptions and options and not all of these options achieve the same level of energy performance.

Similar to the ECB approach, the PRM provides rules for the definition of the baseline building and compares the performance of the proposed building design against that of the baseline to determine the beyond code performance [8].In other words, it sets a maximum allowable energy consumption level without specification of the methods, materials, and processes to be employed to achieve it [6]. However, the PRM provides more flexibility than the ECB method and offers credit for proper building orientation, window area, HVAC system type and other features not credited by the ECB method. The Appendix G approach intends to recognize efficient design strategies. In contrary to the ECB, in the PRM approach, baseline characteristic is independent of the proposed building characteristics and baseline building is defined with less uncertainty [8].

[2] . The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 is the most widely adopted standard for establishing minimum energy efficiency requirements for the design, construction, operation and maintenance of all buildings except low-rise residential buildings in the United States [8].

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[4] . Senior Manager, Technical Research & Education, BC Housing

[5] . Time period schedules define periods of time for equipment sequencing, utility tariffs, etc. A time period schedule typically breaks the year into two or more seasons. For each season, day types are identified such as weekday, Saturday, Sunday, and holidays. Each day type in each season is then divided into time periods [9].

[6] . The geometry defines the position, orientation, azimuth, and tilt of the roofs, walls, floors, doors, and fenestration. The geometry in the current baseline building is identical to the proposed design. Since some geometry sounds to be more energy-efficient than others, it is worthy to be considered as an essential feature of the new reference house approach [9].

[7] . This data structure describes the dimensions and position of external shading devices such as overhangs, side fins, or louvers that shade the opening. Overhangs are specified in terms of the projection distance, height above the opening, and extension distance on each side of the opening [9].

[8] . This data structure describes the layers that make up the construction of a wall, roof, floor, or partition. Typically, the construction consists of a sequence of materials, described from the outside surface to the inside surface [9].

[9] . This data structure describes the frame, glass, and other features of a window or skylight. Information may be defined in multiple ways, but the criteria themselves are published as a combination of U-factor, solar heat gain coefficient (SHGC), and visible light transmission (VT). Also, the angle of incidence of sun striking the fenestration and other factors, such as the properties of each pane and the fill can be taken into account [9].

[10] . This data structure describes a material that is used to build up a construction assembly. Typical material properties include specific heat, density, conductivity, and thickness. Materials can also be described in terms of their thermal resistance. The latter approach is sometimes used to approximate construction layers that are not homogeneous, such as framing members in combination with cavity insulation [9].

[11] . This data structure describes the composition of a slab-on-grade. The model has building descriptors for the perimeter length and the F-factor, which represents the heat loss per linear foot [9].

[12] . This data structure describes the characteristics of exterior surfaces. Exterior surface properties may include emissivity, reflectivity, and roughness. The first two govern radiation exchange from the surface, while the latter governs the magnitude of the exterior air film resistance [9].

[13] . This data structure represents the rate of heat and moisture generated by building occupants. This is typically specified in terms of a sensible heat rate and a latent heat rate. Both are specified in Btu/h. This depends on the activity level of the occupants and other factors. The heat produced by occupants must be removed by the air conditioning system as well as the outside air ventilation rate and can have a significant impact on energy consumption [9].

[14] . This data structure represents the thermal mass effect of furniture and other building contents. This is expressed in terms of lb/ft^2 for the space in question [9].

[15] . Each envelope component is required to have a description for the baseline and proposed construction, with the assembly U-value or insulation R-value where applicable including [9]:

- Roof construction
- Above-grade exterior wall construction
- Below-grade exterior wall construction
- Exposed floor construction
- Slab-on-grade floor construction
- Opaque doors

[16] . Each unique fenestration assembly (vertical fenestration and skylights) needs to be described and documented for both baseline and proposed model. The assembly U-factor, SHGC, and VT need to be documented [9].

[17] . In the current baseline approach, ventilation is set to mechanical that increases the energy use ignoring the natural passive solutions; such solutions that can be replaced in the new approach.

In the current approach, some proposed building designs might bring in ventilation air during unoccupied hours for night flush or economizer operation. In hot seasons, it could be a great opportunity to save energy by using and trapping the cooler air during the night time; a strategy that can be set in defining the new reference house.

Current baseline building shall be modeled with a fixed ventilation rate which would be equal to the design ventilation rate in which outside air is delivered to the zone at a constant rate. Nevertheless, the new baseline building can follow an opposite procedure which is defining a fixed ventilation rate, as an indicator, for the new baseline building [9].

[18] . HVAC zone temperature schedules in the current baseline building shall be identical to the proposed design. However, factors such as “Elevated AirSpeed”, affecting dry bulb temperature setpoint, make identical schedules for the baseline building and the proposed building as an inappropriate option. Besides, it is worse than that if we take into account the more flexible schedules set for the proposed building in response to the different situations.

In the new reference house approach, an air-side economizer can increases outside air ventilation during periods when cooling loads can be reduced from increased outside airflow. The economizer integration can be re-evaluated in the new reference house approach. Current baseline building has integrated economizer based on which the system can operate with the economizer fully open to outside air and mechanical cooling active (compressor running) simultaneously, even on the lowest cooling stage. However, integrated input sounds to be less energy efficient; first, because of the consistent compressor running and second, due to the extra loads, a compressor would generate to continuously make the zone condition comfortable. Unlike that, with non-integrated economizer, the system runs the economizer as the first stage of cooling. When the economizer is unable to meet the loads, the economizer returns the outside air damper to the minimum position and the compressor turns on as the second stage of cooling.

For HVAC secondary system, among chilled water, DX, and another current/future items for cooling sources and the hot water, steam, electric resistance, electric heat pump, heat recovery, or future options for heating source, the most sustainable one can be chosen regarding the source energy and full-fuel cycle. Gas furnace, gas heat pump, and oil furnace are not appropriate due to their contribution to the GHG emission.

Exhaust air energy recovery can be considered as a mandatory option in defining the new approach.

Since humidification and dehumidification can result in significant energy consumption, among the hot water, steam, electric, evaporative humidification, adiabatic humidification, or future technologies, the most sustainable one can be employed.

In the new approach, electricity or a more sustainable option can be chosen for the boiler fuel source of HVAC primary system. Other options including gas and oil are not appropriate due to their environmental impact. Furthermore, the boiler type can be re-evaluated and among steam boiler, hot water boiler, heat-pump water heater, or any other options, the most energy-efficient one can be set regarding source energy and FFC.

In the new approach, electricity, hot water, steam, or a more sustainable option can be chosen for the chiller fuel source of HVAC primary system. Other options including gas and oil are not appropriate due to their environmental impact. Furthermore, the chiller type can be re-evaluated and among a vapor-compression chiller, absorption chiller, or any other future options, the most energy-efficient one can be set regarding source energy and FFC [9].

[19] . **SHORT CIRCUITING** refers to a design in which ventilation air enters and leaves a space or duct before it has a chance to mix well enough with room air to adequately dilute pollutants and replace stale air. In MURB construction, short circuiting occurs as a result of the placement of the ventilation supply too close to the ventilation exhaust [18].

[20] . **CIRCUITOUS ROUTING** occurs when too many corners and complex runs are placed within the ductwork. This requires an increase in fan power to properly ventilate a space, which in turn reduces the overall effectiveness of the ventilation design. Direct duct routes make the most of fan power and improve the overall efficiency of the system [18].

[21] . **HYDRONIC** refers to the practice of using a water-based medium to distribute heat throughout a building. Hydronic systems can use either radiator, in-floor systems, and in some cases, in-ceiling systems [18].

[22] .

- Use a central natural gas boiler to heat and provide domestic hot water to units
- Is among the lowest cost systems to install and operate
- Handle large loads [2]

[23] .

- Use some form of heat pump to generate heat, including air-source, geo-exchange, and most district energy systems. The most efficient of the available options
- Provide cooling
- Struggle to deliver heating to large buildings when outdoor temperatures are below freezing [2]

[24] .

- The cheapest and most flexible systems to install
- Very climate-friendly given the low carbon intensity of electricity
- Have higher operating costs
- Require an additional solution to heat domestic hot water [2]

[25] .

- Driven by a two or four-pipe fan coil
- Used to heat and cool
- Must be combined with either a centralized or suite-level heat recovery ventilation system [2]

[26] .

- Among the most passive and energy-sufficient ones
- Although it does not apply to the current baseline, it can be given prominence in the new approach
- Is a central heating and/or cooling system using geothermal energy for heating and cooling purposes [2]

[27] .

- **HEAT RECOVERY:** Building equipment such as air conditioners, chillers, gas-fired generators, and others produce thermal energy that may be recovered and used to heat water.

- **SOLAR THERMAL:** A solar thermal water heating system consists of one or more collectors. Water is passed through these collectors and is heated under the right conditions. There are two general types of solar water heaters: integrated collector storage (ICS) systems and active systems [9].

[28] . Compartmentalization refers to the practice of isolating individual suites or units in a building from one another, such that they are individually ventilated.

[29] .

- **SOLAR**

This form of energy relies on nuclear fusion power from the core of the Sun. This energy can be collected and converted in a few different ways. The range is from solar water heating with solar collectors or attic cooling with solar attic fans for domestic use to the complex technologies of direct conversion of sunlight to electrical energy using mirrors and boilers or photovoltaic cells.

- **WIND POWER**

The movement of the atmosphere is driven by differences of temperature at the Earth's surface due to varying temperatures of the Earth's surface when lit by sunlight. Wind energy can be used to pump water or generate electricity but requires extensive areal coverage to produce significant amounts of energy.

- **HYDROELECTRIC ENERGY**

This form uses the gravitational potential of elevated water that was lifted from the oceans by sunlight. It is not strictly speaking renewable since all reservoirs eventually fill up and require very expensive excavation to become useful again. At this time, most of the available locations for hydroelectric dams are already used in the developed world.

- **BIOMASS**

It is the term for energy from plants. The energy in this form is very commonly used throughout the world. Unfortunately the most popular is the burning of trees for cooking and warmth. This process releases copious amounts of carbon dioxide gases into the atmosphere and is a major contributor to unhealthy air in many areas. Some of the more modern forms of biomass energy are methane generation and production of alcohol for automobile fuel and fueling electric power plants.

- **HYDROGEN AND FUEL CELLS**

These are also not strictly renewable energy resources but are very abundant in availability and are very low in pollution when utilized. Hydrogen can be burned as a fuel, typically in a vehicle, with only water as the combustion product. This clean-burning fuel can mean a significant reduction of pollution in cities. Or the hydrogen can be used in fuel cells, which are similar to batteries, to power an electric motor. In either case, significant production of hydrogen requires abundant power. Due to the need for energy to produce the initial hydrogen gas, the result is the relocation of pollution from the cities to the power plants. There are several promising methods to produce hydrogen, such as solar power, that may alter this picture drastically.

- **GEOTHERMAL POWER**

Energy left over from the original accretion of the planet and augmented by heat from radioactive decay seeps out slowly everywhere, every day. In certain areas, the geothermal gradient (increase in temperature with depth) is high enough to exploit to generate electricity. This possibility is limited to a few locations on Earth and many technical problems exist that limit its utility. Another form of geothermal energy is Earth energy, a result of the heat storage in the Earth's surface. Soil everywhere tends to stay at a relatively constant temperature, the yearly average and can be used with heat pumps to heat a building in winter and cool a building in summer. This form of energy can lessen the need for other power to maintain comfortable temperatures in buildings, but cannot be used to produce electricity.

- **OTHER FORMS OF ENERGY**

Energy from tides, the oceans, and hot hydrogen fusion are other forms that can be used to generate electricity. Each of these is discussed in some detail with the final result being that each suffers from one or another significant drawback and cannot be relied upon at this time to solve the upcoming energy crunch [16].

[30] . **PHYSICAL DIMENSION:** Physical resilience refers to the design, physical configuration, materials, and engineering aspects of a building. In this respect, a building's systems include architectural, structural, life safety, mechanical, electrical, plumbing, security, communication, and information technology systems, as well as the connections to external infrastructure and services. Physical resilience also includes accounting for the effects of repairs, material deterioration, and system degradation over time [18].

[31] . **INFRASTRUCTURAL DIMENSION:** The infrastructural aspects of resilience related to the connections to and the quality/reliability of local and regional infrastructural elements. These include systems for electrical power, water, electronic communications, transportation, sewerage, and waste/stormwater [18].

[32] . **ENVIRONMENTAL DIMENSION:** Environmental resilience is the resilience of a building to environmental phenomena. Developing environmental resilience capacity requires quantifying the environmental processes and disturbances that a particular building or site is likely to face, including the frequency and intensity of these events, and identifying how adaptive capacity can be built to cope with them. Environmental resilience also includes site-scale aspects such as building adjacency issues. A resilient built environment considers the desired levels of functionality before, during, and after disruptive hazard events, as well as the steps needed to achieve such performance [18].

[33] . **ECONOMIC–SOCIAL DIMENSION:** Economic aspects here refer to the wider economic environment as a context for the value and use of a building, including economic change and disturbance. Social resilience has two aspects. One is the characteristics of the community in which the building is located, including its social capital. The second

aspect considers the building-specific measures of use and occupancy, as well as the life safety and well-being of occupants and users, which are human aspects of social resilience. As a whole, economic-social dimension refers to the time and cost of recovery of partial and full functionality and occupancy of building after a destructive event in terms of usability and safety [18].

[34] . **POLITICAL–REGULATORY DIMENSION:** The political sphere includes the influence of legal frameworks, legislation, and policies applying to the design and operation and function of buildings, as well as those applying to the various activities of built environment stakeholders/actors. A key component is the building code and the standards and guidelines contained therein. The building regulation process inherently involves a trade-off between the rights of individuals to build in the manner that best suits them and the rights of society to have safe buildings in which to conduct commerce, work, and reside. Building codes represent a compromise between acceptable safety and reliability and economic practicality. This dimension also includes the capabilities and responsibilities of the various levels of government (local, regional, and national) with respect to formulating policies and actions that promote resilience, as well as the effectiveness of their planning and performance in dealing with events and emergencies, and the quality of their relationship with built environment stakeholders [18].

[35] . **ORGANIZATIONAL DIMENSION:** A more resilient organization protects itself, its activities, and its interests by proactively anticipating change and disruption, and responding and adapting to externalities. Key aspects of organizational resilience are its ability to identify and manage risk and to develop high-quality decision-making processes. One way of modifying or managing risk is through insurance [18].

[36] . Intergovernmental Panel on Climate Change (IPCC) definition of adaptation: “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploit beneficial opportunities.” [20]

[37] . Marcus Foth and Paul Sanders have explored the various ways that neighbors in apartments get to know each other, and they have categorized these encounters into three groupings. The first is *serendipitous encounters*, which takes place in the elevator, at the pool, in the car park, while taking out the garbage, and other routine activities. Repeated encounters in these settings can encourage lengthier chats between residents. The design of public space in residential apartments is vital in influencing the likelihood, frequency, and intensity of serendipitous encounters. The second type is *sociocultural animation*, which has various forms such as community barbecues, donation appeals, landscape rejuvenation programs, and resident associations. The facilitation of these activities requires public space and also heavily relies on residents to take the initiative to organize collective events. Lastly, there is *digital augmentation*, which is defined as a community network system that acts as a virtual space for social interaction that complements existing public spaces. Examples include resident directories with member profiles, private social networks, and interactive community displays [13].

[38] . **CLIMATE READY BOSTON REPORT [19]**

- For new buildings, the report recommends updating zoning and building regulations to support climate readiness
- For existing buildings, it recommends retrofitting to protect against climate hazards.
- Some proposed strategies are:
    - Making portable flood barrier
    - Elevating the first floors
    - Locating critical equipment on higher floors (above projected rising sea levels), rather than in the basement
    - Featuring back-up generators
    - Improving the resilience of buildings and infrastructure simultaneously

[39] . **BUILDING RESILIENCE IN LA FRAMEWORK [19]**

- It is one of the few standards reviewed with a specific focus on existing buildings.

- Requires existing facilities to assess their hazards as part of the framework.
- It is designed to build community-wide resilience, develop benchmarking methodologies, and create a peer to peer learning network for existing facilities.
- It can be utilized to assess internal capacity for responding to climate risks and fostering resilience and identify areas for process improvements.

40 . **ENVISION [19]**
- Plans for short- and long-term hazards, as well as reducing emissions and environmental impacts and improving quality of life.
- It is a rating system for public infrastructure projects of transportation, waste, water, energy, information systems, and landscapes.
- Guides project planning, design, construction, operation, and deconstruction.
- Offers a process and tools for evaluating and rating projects of different sizes and types based on their community, environmental, and economic benefits.

41 . **FORTIFIED [19]**
- Address roof performance, building envelope protections, structural performance, and business continuity and operations.
- To address flooding, it requires electrical and mechanical systems to be protected.
- Offers process guidance, design criteria, and checklists for creating a compliant building.

42 . **LEED PILOT CREDITS FOR RESILIENT DESIGN [19]**
  - There are three types of credits:
    - The first requires a climate change assessment or emergency planning for New or existing facilities to strengthen their preparedness.
    - The second requires a design for the top three hazards relevant to an area
    - The third requires a passive design for survivability, such as backup power, access to potable water, and/or thermal resilience

43 . **PEER (PERFORMANCE EXCELLENCE IN ELECTRICITY RENEWAL) [19]**
  - Helps energy professionals evaluate power generation, transmission, and distribution systems based on four outcome-based categories:
    - Reliability and resilience
    - Energy efficiency and environment
    - Operational effectiveness
    - Customer contribution

44 . **REDI (RESILIENCE-BASED EARTHQUAKE DESIGN INITIATIVE) [19]**
  - Utilizes performance-based criteria which could be helpful for operational planning
  - Prioritizes occupant safety.
  - Focuses on the adaptive capacity and recovery of the building and its operations.
  - Its four main categories are:
    - Organizational resilience: contingency planning for utilities and the business community
    - Building resilience: using advanced design to minimize damage to a building's structure and equipment thus improving occupant safety
    - Ambient resilience: using site planning to reduce risks from external hazards during seismic events
    - Loss assessment: evaluating direct financial losses and downtime

45 . **RELI RESILIENCE ACTION LIST + CREDIT CATALOG [19]**

- Provides a comprehensive process for incorporating resilience into new building design and planning.
- Can be applied to homes, buildings, infrastructure, districts, neighborhoods, and campuses.
- It is one of the most comprehensive new building standards reviewed, combining principles of resilience and sustainability at the building and community level.
- Addresses facility planning, design, operations, and maintenance as well as site selection, emergency operations, and planning, and adaptive design based on hazards (Sea level rise, storms, extreme temperatures, and extreme precipitation)
- Encourages a comprehensive approach to new buildings and their integration into the surrounding community.
- Provides guidance for a variety of different risks across the building cycle, including climate impacts

46 . **SUSTAINABLE SITES INITIATIVE [19]**

- Offers a comprehensive rating system for developing sustainable landscapes.
- Credit categories include:
  - Pre-design assessment and planning
  - Water, soil, and vegetation
  - Materials selection
  - Human health and well-being
  - Construction, operations, and maintenance
  - Education and performance monitoring
- Proposed strategies include:
  - Site selection and design
  - Managing on-site precipitation
  - Supporting social connections and site accessibility
  - Providing on-site safety and food production
  - Reducing heat island effects
  - Using appropriate plants

47 . **AUSTRALIAN RESILIENCE MEASUREMENT SCHEME FOR BUILDINGS (ARMS):** The scheme adopts resilience as a holistic concept incorporating physical, infrastructural, environmental, economic–social, political– regulatory, and organizational resilience, and is rated according to dimensions, subdimensions, and items scored on a points system. It measures the resilience of commercial buildings from the point of view of a building owner [18].

48 . **BUILDING RESILIENCE RATING TOOL (BRRT):** Developed by the Insurance Council of Australia, the BRRT is aimed at measuring and assessing the resilience of residential homes from the perspective of insurers. The tool uses hazard data in a GIS database format. These data are overlaid on data about building design and material characteristics that reflect resilience. In other words, it measures the physical characteristics of the building in response to natural hazards [18].