Phius REVIVE 2024

RETROFIT STANDARD FOR BUILDINGS v24.1.1

Good for the planet | Good for your buildings | Quality assured results

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Good for the planet
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(This foreword is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard.)

Foreword

This foreword documents a thought process about what to do about existing buildings, starting over from a Phius vision statement. The perspective changes a bit as it moves from Initial Concepts to a Program Vision and then to Key Requirements Concepts. After that the Standard proper begins to manifest those concepts into actual requirements. This material is included so that readers can judge how well or strongly the initial ideas got expressed in the succeeding requirements language.

Initial concepts
Phius' vision is that every building supports the health of people and the planet. Development of this standard began with a recognition that our existing retrofit standard, that held retrofit projects to almost the same standards as new construction, might not be the right idea at the scale of "all existing buildings." Though the operational impact of the buildings on the planet would be greatly reduced, the cost of the retrofit work would be high and the impact near-term, front-loaded. Avoiding such near-term impacts is important because our planet is so close to climate tipping-points.(CLF, 2020)

Accordingly, our initial thinking proceeded from three goals for all existing buildings:

1. *Decarbonize building operation.*
2. *Getting rid of the embodied carbon or upfront emissions of the building delivery (and maintenance) process.*
3. *Operate buildings on local renewable energy.*

As to Goal 1, decarbonizing building operation, that could be achieved for any building with two steps:

- *Electrify everything.*
- *Power the building with zero-emission renewable electricity.*

For all-electric buildings in some places, this can be done without installing anything, just by signing up for a "green power" program from the electric utility or "community choice aggregation" program from the local government. Arguably, this takes care of the building's civic duty to the planet, though there is a difference between "100% renewable" programs and "24/7 carbon-free" programs.

However, such an approach puts most of the responsibility for impact onto the utility, and it does "nothing" for the building. In cold climates it is likely to actually increase the energy bills, perhaps greatly. When done at scale in heating-dominated climates it will tend to shift the peak season for the grid from summer to winter.

Therefore a question arises as to what is the best balance among these kinds of actions or investments:

1. *Reducing the load, especially the winter peak, with passive measures such as air-sealing, insulation, superwindows.*
2. *Reducing the load with equipment efficiencies such as heat pumps and LED lights, and perhaps time-shifting the load with smart-grid interactive controls or thermal energy networks.*
3. *Generating and storing renewable energy on-site.*
4. *Procuring carbon-free renewable energy from off-site.*

The idea for this program was to decide this question primarily using building simulation with a resilience lens, and on a project-specific basis.

There would be two performance criteria:
Firstly, that the building remains habitable during both a winter storm power outage and a summer heat wave power outage of some days duration. This outage use-case constitutes most of the response to Goal 3 - functioning on local renewable energy. (Functioning on local RE in normal operation is also desirable. Larger buildings will have difficulty doing that with onsite generation alone and probably need the support of a microgrid.)

Secondly, and to Goal 2, getting rid of the embodied carbon or upfront emissions of the building delivery (and maintenance) process, the program would eschew the idea of "offsets" for the embodied carbon of the building sector of the economy, and hold Absolute Zero as the ideal – that no emissions ever happen: nowhere in its supply chain, none are caused by anyone involved, neither directly or indirectly, neither in their personal or professional life. As that absolute zero ideal cannot be done in the current system of industrial civilization, the idea is to start by keeping score, from a zero base, and in light of that, make efforts to reduce the upfront emissions. Because of the all-encompassing scope, there are many opportunities to improve and anyone involved can contribute.

That implied two aspects to the scoring:

- *Life-cycle carbon emissions.*
- *Life-cycle “full-cost”, including cost of carbon.*

The inclusion of a life-cycle cost metric keeps the principle of economic feasibility involved, but this metric internalizes the cost of carbon emissions, so as to motivate more effort to reduce them.

The cost metric should also include operating energy cost and the cost of any implied capacity additions to the grid. Rate structures that are strongly tiered and seasonal or time-of-use-dependent could be used, in anticipation that these will become more common as the grid decarbonizes.

Another way to think about this would be that minimizing the expanded life cycle cost is the objective, and outage resilience are the constraints on that optimization problem. Conceptually, the calculation could be done with some clever optimization-under-constraints algorithm or by a brute-force parametric dragnet followed by filtering - for upgrade packages that "meet resilience" and are "best n-th percentile" for life-cycle cost.

Program vision

A missing piece in the initial thinking above was the fact that existing buildings have various problems that need to be fixed. Consideration of what kinds of problems to address within the scope of this program, and distillation of the above, led to this five point vision for the program:

1. *The retrofitted buildings do not cause greenhouse gas (GHG) emissions in operation, directly or indirectly. This entails electrification and the use of carbon-free renewable electricity, but those steps alone are not sufficient. If those are the only measures taken to decarbonize operations, there is no benefit to the building, its utility bills might actually increase, and dependence on the electric grid / utility is increased.*
2. *Therefore, building enclosure improvements and equipment efficiency improvements are designed such that the building can function using locally-generated renewable energy. This is true in both normal operation, maintaining comfortable conditions, and for some degree of reduced function but still habitable conditions during utility outages, summer or winter. The outage-resilience consideration is a key factor determining the design of the envelope improvements. We also view it as a characteristic that every building should have, as a matter of fairness or equity.*
3. *The emissions associated with the retrofit process itself are "low". Ideally, they would be zero, without the use of offsets, even with the widest possible lens – in space: materials and labor throughout the entire global supply chain; in time: from the moment of project conception through the rest of the life of the building. Together with 1), this would mean* ***absolute zero – no GHG emissions occurring anywhere in the building renovation process, supply chain, or future operating life, at any time****. Although this cannot currently be done, some steps can be taken, such as beginning to calculate carbon scores. It is appropriate to keep in mind both radical ideals like "no emissions ever happen", and practical realities.*
4. *Existing deficiencies are fixed. These include risks to indoor air quality per US EPA, such as radon and pests, and site hazards per US FEMA such as seismic and flood risk, including emerging extreme-weather hazards due to climate change.*
5. *Unlike previous Phius programs, the time horizon extends beyond design and construction into operations, and can encompass phased retrofits. Like previous programs, a quality-assurance process verifies and documents that the facility meets our requirements, and closely-related Owner's requirements. Data is captured on how well the retrofitted building performs, on project costs, and on solutions to retrofit issues.*

Key requirements concepts

This standard aspires to be adoptable as mandatory by authorities having powers of enforcement, to issue and withhold permits for building construction and certificates of

occupancy, and even to impose fines for poor performance in operation. As such it must feature "hard" requirements, and be transparent and open.[1]

These are the 7 concepts for the key hard requirements:

1) *There is a commissioning / quality-assurance process that covers all phases, from pre-design through operations, and through all the renovation phases. Planning for an end state that eventually meets all the requirements is done in the beginning. The plan could be revised, but the planning cannot be deferred.*
2) *Early in the process, the existing building is assessed in these ways:*
    a) *Whether it is a good candidate for retrofit, as opposed to redeveloping or rewilding its site.*
    b) *Energy performance.*
    c) *Risks to indoor air quality (per US EPA) and site hazards (per US FEMA.)*
3) *Direct emissions cease soon (electrification preferably in the first construction phase.)*
4) *In both summer and winter grid outage situations, the building remains habitable and critical loads are covered by on-site or local-microgrid generation / storage, with priority to renewable generation.*
5) *Fix any existing deficiencies that pose risks to indoor air quality. (The fortification against site hazards mentioned above is mostly elective.)*
6) *Life-cycle calculations are done for both carbon emissions and for cost, for a full-cost metric called ADORB (or FCALC) that includes a cost of carbon.*
    a) *This is done for a baseline case of continuing to operate the building as-is, and for the retrofit scenario.*
    b) *The life-cycle cost of the retrofit scenario must be lower than the baseline scenario.*
    c) *A decarbonization challenge is accepted: Efforts are made to find ways to reduce the upfront emissions from the materials and labor of the retrofit work, compared to usual practice. (Phius will figure out (or facilitate a consensus process on) how to credit these practices in the life cycle carbon calculation – let us see how low we can go.) Such measures could include using refrigerant gases in mechanical systems that have low global warming potential (GWP), and avoiding cellular plastic insulation types that are foamed using high GWP gases.*
7) *Project cost data and post-retrofit measured energy performance are reported, at least to some minimum level of granularity.*

<u>Administration / compliance / enforcement concepts</u>

The scope of the specific alterations / improvements implied by the above concepts could vary greatly from project to project, in terms of the <u>specific</u> envelope, systems, and controls changes needed. A good quality-assurance process will focus the effort and resources on the elements that need to be addressed to meet the goals. Therefore, the main idea is that enforcement is

[1] *A voluntary standard may have additional "tiers" of performance above a mandatory minimum level, to which greater incentives can be applied, and could require proprietary software or proprietary credentialed professionals. A rating system need not set any criteria on performance at all, only rating methods.*

closely tied to the quality-assurance process - in jargon: the determination of compliance leverages commissioning.

ASHRAE has developed a number of guidelines/standards for "commissioning", by which they mean quality assurance - commissioning is defined as, e.g. "a quality-focused process for enhancing the delivery of a project. The process focuses on verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements (OPR) [or in the case of retrofits, Current Facility Requirements (CFR)]."

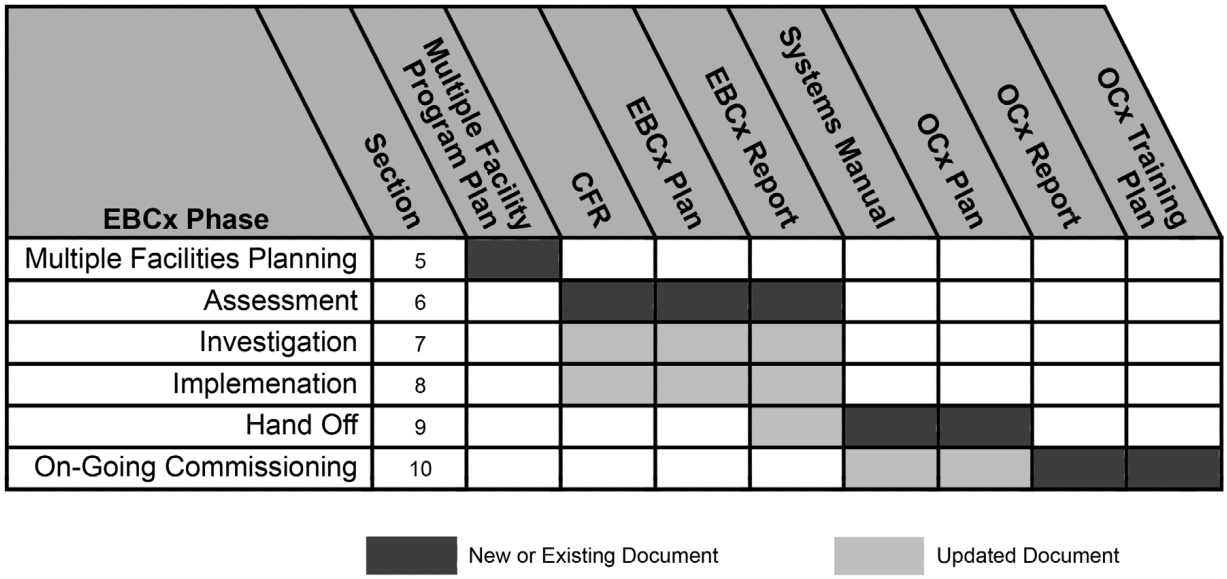
This Standard relies upon the commissioning process as structured by ASHRAE – particularly ASHRAE Guideline 0.2 and ASHRAE Standards 230, 202 – as a quality control/quality assurance mechanism. It is thus imperative that a user of this Standard be comfortably familiar with the ASHRAE commissioning process. ASHRAE Standard 230, ASHRAE Guideline 0.2, and several supporting commissioning guidelines are available from the ASHRAE Bookstore: https://www.techstreet.com/ashrae/pages/home

The adaptations of these guidelines for use in enforcement or certification are that:
Although the Owner does still have some input, the requirements in the OPR / CFR consist mostly of the requirements of this standard, and therefore:

- *The documentation is mainly focused on documenting compliance with this standard.*
- *The major process gates labeled "Obtain Owner acceptance and decision to proceed" and the like require the concurrence of both the Authority and the Owner.*

Guideline 0.2 has the feature that it integrates the investigation of the existing conditions and focuses them on relevance to the requirements, rather than defaulting to a more generic "energy audit" standard.

Figure D-1 in Guideline 0.2 (reproduced below) provides a graphical representation of the documentation to be provided as formal deliverables at each phase of the commissioning process.. The figure can be used to understand which documents are generated in which phase of the process and at what intervals they are updated.



ASHRAE Guideline 0.2 Figure D-1. EBCx documentation matrix. In this standard the Multiple Facilities Planning phase is renamed Programming, and EBCx is just Cx.

The scope of Standard 230 is rather narrow - repairs, in-kind replacements, and adjustments to the systems. The treatment of the planning phase seems more apt in 230, but herein some of its content has been moved to the Assessment phase to focus the first phase on building selection and ranking. Because the scope of the required improvements might extend into design work and "capital projects" that are outside the scope of 0.2 and 230, Standard 202 is looked to in those cases.

In its own use of this standard in the voluntary REVIVE Pilot certification program:

- *Phius acts in the role of the Authority.*
- *Phius Certified Consultants (CPHC®) act in the role of the Commissioning Provider.*
    - *Owner contributions to the OPR / CFR beyond the requirements of this standard are limited (mostly to the electives spelled out in this standard, and on a case by case basis.)*
- *The required verification and testing providers are Phius Raters and Verifiers.*
- *Large additions outside the scope of this standard must meet Phius' new construction standards.*

Other Phius-specific practices appear herein with this highlight color.

In the case of adoption of this standard by an authority with funding to incentivize a voluntary program, or with powers of legal enforcement for a mandatory code, CPHCs could provide services as commissioning providers, not to the exclusion of others, and Phius credentialed professionals would likewise offer their services as design, verification and testing providers, not to the exclusion of others. Phius itself would maintain the standard, provide training for professionals, and provide quality assurance services for authorities.

1 Purpose

1.1

To establish:

- Requirements for retrofit improvement work on existing buildings.
- Criteria for the selection of buildings for retrofit (as opposed to razing or replacement with new buildings.)

1.2

The purposes of the improvements are to:

- Eliminate direct and indirect greenhouse gas emissions, in normal operation.
- Provide resilience to winter and summer power outages.
- Fix defects of concern to the US EPA, that pose risks to indoor air quality.
- Where appropriate, fortify the building against certain site hazards of concern to US FEMA, and insurers.
- Meet elective requirements that are described in this Standard, as selected by the Owner.

1.3

And in addition:

- To employ a *commissioning* / quality assurance process.
- To calculate the climate impact of the retrofit work and make efforts to reduce it.
- To collect data on project costs, post-retrofit performance, and lessons learned.

2 Scope

2.1

This standard provides requirements for:

- The assessment and investigation of existing buildings.
- The planning of retrofit phases.
- The design, installation, and testing of retrofit improvements.
- The operation, monitoring, and maintenance of the buildings after each retrofit phase.

2.2

This standard applies to all kinds of existing buildings.

2.3

Its provisions also apply to additions having an *interior conditioned floor area* no greater than 20% of: the existing building including (prior-to) any planned demolitions.

3 Definitions

ADORB cost: *Annualized Decarbonization Of Retrofitted Buildings cost* - a “full-cost-accounted” annualized life-cycle cost metric for building projects. It includes the direct costs of retrofit and maintenance, direct energy costs, a carbon cost for both operating and embodied/upfront greenhouse gas emissions, and a renewable-energy system-transition cost based on the required electrical service capacity. See Appendix A for calculation protocol details.

Authority: the agency or agent that adopts this standard, or the agency or agent responsible for enforcing this standard, or the officer charged with the administration and enforcement of this standard, or a duly authorized representative.

Commissioning (Cx): a quality-focused process for enhancing the delivery of a project. The process focuses on verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet specified requirements.

Commissioning Provider (CxP): an entity who manages the *Commissioning Team* to implement building *commissioning*.

Commissioning Teams:
Cx Team: individuals who through coordinated actions are responsible for implementing the Cx Process - Owner staff, *operations and maintenance* entity, and *CxP Team* working in collaboration.
CxP Team: The smaller *CxP Team* comprises the *CxP* and subcontractors to the *CxP* who acts as the contact to the Owner.
OCx Team: Similarly, the *OCx Team* includes internal facility staff, service contractors, external professionals, *commissioning* contractors, and Cx Process providers.

community solar: any solar project or purchasing program, within a geographic area, in which the benefits of a solar project flow to multiple customers such as individuals, businesses, nonprofits, and other groups. In most cases, customers are benefitting from energy generated by solar panels at an off-site array. Community solar customers can either buy or lease a portion of the solar panels in the array, and they typically receive an electric bill credit for electricity generated by their share of the community solar system – similar to someone who has rooftop panels installed on their home.

conditioned space: An area, room or space that is enclosed within the building thermal envelope and that is directly or indirectly heated or cooled. Spaces are indirectly heated or cooled where they communicate through openings with *conditioned spaces*, where they are separated from *conditioned spaces* by uninsulated walls, floors or ceilings, or where they contain uninsulated ducts, piping or other sources of heating or cooling.

Construction Team: consists of professionals responsible for providing materials and labor to construct the systems and assemblies in the project. Where a construction project follows a design/build approach, the *Construction Team* includes licensed design professionals who are part of the *Design Team*.

Current Facility Requirements (CFR): a written document in which the Owner details the current functional requirements of a facility and the expectations of how it should be used and operated. *Informative: Elsewhere termed Owner's Project Requirements (OPR) for new construction.*

Design Team: the licensed professionals responsible for producing the complete set of permit documents required for construction.

Facility Guide (FG): a subsection of the *Systems Manual*. The *Facility Guide* is intended to provide the basic information necessary for the building operations staff to operate the building on a day-to-day basis. It includes a simple description of the building systems and their normal operation, schedules, set points, and limitations. The *Facility Guide* also includes routine maintenance for the systems to keep them in good condition, but not major maintenance or repair functions. Scheduled start-up and shutdown functions should be included. *Informative: Refer to ASHRAE Guideline 1.4, Preparing Systems Manuals for Facilities, for additional information.*

functional performance testing (FPT): a systematic process to verify that controls and other elements of the building project are capable of and configured to operate or perform as required.

hospitality or transient dwelling units: Occupancy classifications among those defined in the International Building Code, Section 310 Residential Group R.

HVAC zone: a space or group of spaces within a building with heating and cooling requirements that are sufficiently similar that desired conditions (e.g., temperature) can be maintained throughout using a single sensor (e.g., thermostat or temperature sensor).

hurricane-prone regions: areas vulnerable to hurricanes as defined in ASCE 7.

- For ASCE 7-05, hurricane-prone regions are locations along the Gulf of Mexico and Atlantic coasts where the design wind speed is greater than 90 mph, plus Hawaii, Puerto Rico, the Virgin Islands, Guam, and American Samoa.
- For ASCE 7-10 and ASCE 7-16, hurricane-prone regions are locations along the Gulf of Mexico and Atlantic coasts where the wind speed for Risk Category II buildings is greater than 115 mph, plus Hawaii, Puerto Rico, the Virgin Islands, Guam, and American Samoa.

interior conditioned floor area (iCFA): The interior-dimension (drywall-to-drywall) projected floor area of the *conditioned spaces* with at least 7 feet (2.1m) ceiling height. It includes stairs, cabinets, interior walls, mechanical spaces, storage, but excludes open-to-below.
More specifically:
● Include the floor area of interior spaces at least 7 feet (2.1m) in height, measured from the interior finished surfaces that comprise the thermal boundary of the building. Spaces that are open-to-below shall not be counted. *Informative: The general concept is "walkable."*
● Other than open-to-below, the projected floor area of all spaces shall count toward the iCFA measurement, including walls, cabinets, mechanical spaces, storage, etc.
● Projected floor area of the stair treads counts toward iCFA on all floors, that is, once per floor. (By the 7 foot (2.1m) height rule, some floor area under the stairs on the first floor would be excluded. This conflict is resolved by including it).

island: A part of an electric power system that is disconnected from the remainder of the interconnected system, but remains energized. An *island* can be either the result of the action of automatic protections or the result of a manual action.

islanding: The process whereby a *microgrid* separates itself electrically from the main power grid and operates independently, using its own internal power source(s); it may later rejoin the main grid.

Measurement and Verification (M&V) Plan: a plan for gathering relevant data over time to evaluate performance and benefits.

microgrid: a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A *microgrid* can connect and disconnect from the grid to enable it to operate in both grid-connected or *island* mode.''

miscellaneous electric load (MEL): Electric load from televisions and other occupant-installed electrical appliances that do not fall under: heating, cooling, ventilation, domestic water heating, major appliances, or lighting.

Ongoing Commissioning (OCx): a continuation of Cx well into occupancy and operations to continually improve the operation and performance of a facility to meet current and evolving *CFR* or *OPR*. Ongoing Cx activities occur throughout the life of the facility; some of these will be close to continuous in implementation, and others will be either scheduled or unscheduled as needed.

operations and maintenance (O&M): decisions and actions regarding the control and upkeep of property and equipment.

Project Team: select members of all the teams defined in this standard. The *Project Team* provides a venue for coordinating actions and information flows between all staff who are involved in the project and Cx Activities.

semiheated space: an enclosed space within a building that is heated by a heating system whose output capacity is greater than or equal to 3.4 Btu/h·ft2 of floor area but is not a *conditioned space*.

standard effective temperature (SET): the temperature of an imaginary environment at 50% relative humidity, < 20 fpm (0.1 m/s) average air speed (Va), and mean radiant temperature equal to air temperature, in which the total heat loss from the skin of an imaginary occupant with an activity level of 1.0 met and a clothing level of 0.6 clo is the same as that from a person in the actual environment, with actual clothing and activity level.

Systems Manual: a system-focused composite document that includes the design and construction documentation, *Facility Guide* and *operations and maintenance* manual, maintenance information, training information, Cx records, and additional information of use to the Owner during occupancy and operations.

thermal block: a collection of one or more *HVAC zones* grouped together for simulation purposes. Spaces need not be contiguous to be combined within a single *thermal block*.

thermal energy network: an ambient temperature loop system that connects multiple buildings by using some combination of ground-source heat pumps, geothermal infrastructure, waste heat energy, and utility-owned load balancing systems.

unconditioned space: an enclosed space within a building that is not a conditioned space or a *semiheated space*. Crawlspaces, attics, and parking garages with natural or mechanical ventilation are not considered enclosed spaces.

verification and testing provider (V&T provider): an entity who completes the activities needed to implement the building *functional performance testing (FPT)* activities or verify that elements of the building project meet stated requirements.

4 Process, Part One

4.1 General

4.1.1 Changes in Space Conditioning

Whenever *unconditioned space* or *semiheated space* in a building is converted to a conditioned space, such *conditioned space* shall be brought into compliance with all the applicable requirements of this standard.

4.1.2 Interpretations, Exemptions and Appeals

Interpretations, claims of exemption, and rights of appeal are specified by the *Authority*.

4.1.3 Validity

If any term, part, provision, section, paragraph, subdivision, table, chart, or referenced standard of this standard shall be held unconstitutional, invalid, or ineffective, in whole or in part, such determination shall not be deemed to invalidate any remaining term, part, provision, section, paragraph, subdivision, table, chart, or referenced standard of this standard.

4.1.4 Other Laws

The provisions of this standard shall not be deemed to nullify any provisions of local, state, or federal law. Where there is a conflict between a requirement of this standard and such other law affecting construction of the building, precedence shall be determined by the *Authority*.

4.1.5 Normative Appendices

The normative appendices to this standard are considered to be integral parts of the mandatory requirements of this standard, which, for reasons of convenience, are placed apart from all other normative elements.

4.1.6 Informative Appendices

The informative appendices to this standard and informative notes located within this standard contain additional information and are not mandatory or part of this standard.

4.2 *Commissioning* and Compliance

Informative: ASHRAE Guideline 0.2 is the primary framework for the quality assurance process in this standard, and a general familiarity with it is recommended.
Commissioning shall be performed and documented per the provisions of this standard.

Commissioning shall use specific sections of ASHRAE Guideline 0.2 *Commissioning Process*

for Existing Systems and Assemblies and ASHRAE Standard 230 *Commissioning Process for Existing Buildings and Systems*, as detailed and modified in this standard.

Projects that include additions and/or modifications requiring design and construction during the Implementation Phase shall utilize specific sections of ANSI/ASHRAE/IES Standard 202, *Commissioning Process for New Buildings and New Systems*, for new design and construction activities performed to an existing building - again as detailed in this standard.

Some of the process gates and requirements in Guideline 0.2 and Standard 202 and 230 labeled “Obtain Owner acceptance and decision to proceed” require the concurrence of both the *Authority* and the Owner, as noted herein.

The corresponding documentation deliverables are to be produced by the *Cx Team*.

The documentation deliverables are to be provided to both the *Authority* and the Owner.

4.2.1 Qualifications

The *Commissioning Provider* shall be (1) a third-party entity not associated with the building project, or (2) an individual associated with the design firm or contractor but not directly associated with design or installation of the elements being commissioned.

The *commissioning team* shall include *V&T providers* with the necessary *FPT* equipment.

V&T providers shall be *commissioning* providers, design professionals, qualified designers, or qualified technicians experienced with verification or *FPT* of the designated systems. *V&T providers* shall not be individuals who performed design or installation of the systems or assemblies being verified or tested.
Informative Appendix V contains a list of *V&T provider* credentials.

Phius practice is that there is a CPHC acting as an independent *Commissioning Provider* that has overall responsibility for Cx; Phius Raters and Verifiers are used for V&T.

4.2.2 Fees

Fees shall be paid to the *Authority* as required by its schedules.
Informative: Depending on the project delivery business model, the Owner might also need to pay an independent commissioning provider *and/or* V&T providers*.*

4.3 Owner’s Participation

The Owner shall develop the Cx scope on which the *CxP* will base their service proposal (see Facility Summary in section 8.6.1).

The Owner and *Cxp* shall develop the scope of work on which the *V&T providers* will base their service proposal.

Owner and/or their designated representatives shall do the following:

a. Provide direction, reviews, and acceptance as required throughout the Cx project.
b. Reserved.
c. Attend Cx planning meetings.
d. Provide contact information and access to the Owner's team leader (main point of contact), building manager, and support staff involved in the Cx project to the *CxP*.
e. Make Owner's team members, including related staff and vendors, participate in Cx Activities (interviews, *CFR* development).
f. Confirm that the *CxP* develops the Cx Plan and provide approval prior to the start of the Cx Investigation Phase.
g. Review submittals and develop contracts with designers and contractors for implementation of upgrades and changes to the building.
   Informative note: some implementation work may be done by Owner's representatives or in-house staff.
h. Provide occupant schedules and limitations of access for performing Cx Activities to the *CxP*.
i. Provide the *Cx Team* access required to perform Cx activities.
j. Disseminate surveys, schedule of Cx activities, and communication protocols provided by the *CxP* to stakeholders.
k. Review and approve *commissioning* program plan and the assessment, investigation, implementation, and hand-off reports.
l. Together with the *Authority*, review and approve the *Ongoing Commissioning (OCx)* implementation plan.
m. Participate in staff and occupant training.

4.4 Reserved

4.5 Programming Phase – Building Triage and Ranking

Informative: The objective of the Programming phase is to make an initial determination of which buildings to retrofit, and if the Owner has more than one, in what order. The reasoning is recorded in a Program Plan document.

4.5.1 Buildings excused from retrofit

Determine whether the building should be retrofitted at all:

In addition to doing "nothing" - continuing to use and maintain the building as-is - there are three general options:

Repair and retrofit the building.
Replace the building or redevelop the site.

Raze the building and rewild the site.

Make this decision only after considering the building and site factors in sections 4.5.1.1-3.

4.5.1.1 Intended building life

Establish the intended life of the retrofitted or replacement building.
Informative note: The limits on the assumed life for purposes of life cycle analysis are in section 6.5.1 Life Cycle Cost Limit.

4.5.1.2 Building functionality

With regard to its floor plan, decide whether the building is basically functional and suitable for the intended uses or can be made so with a modest addition (within the scope of section 2.3.) If not, the building might be a candidate for replacement instead of retrofit.

4.5.1.3 Site and Land Use

4.5.1.3.1 Climate migration

Informative: Research suggests that climate change "will profoundly interrupt the way we live and farm in the United States. ... Across the United States, some 162 million people — nearly 1 in 2 — will most likely experience a decline in the quality of their environment, namely more heat and less water. ... In much of the developing world, vulnerable people will attempt to flee the emerging perils of global warming, seeking cooler temperatures, more fresh water and safety. But here in the United States, people have largely gravitated toward environmental danger, building along coastlines from New Jersey to Florida and settling across the cloudless deserts of the Southwest."

Review this climate migration reporting and consider whether it bears on the decision to retrofit the building. Figure 4.5-1 shows a map of climate damage as a percent of GDP.

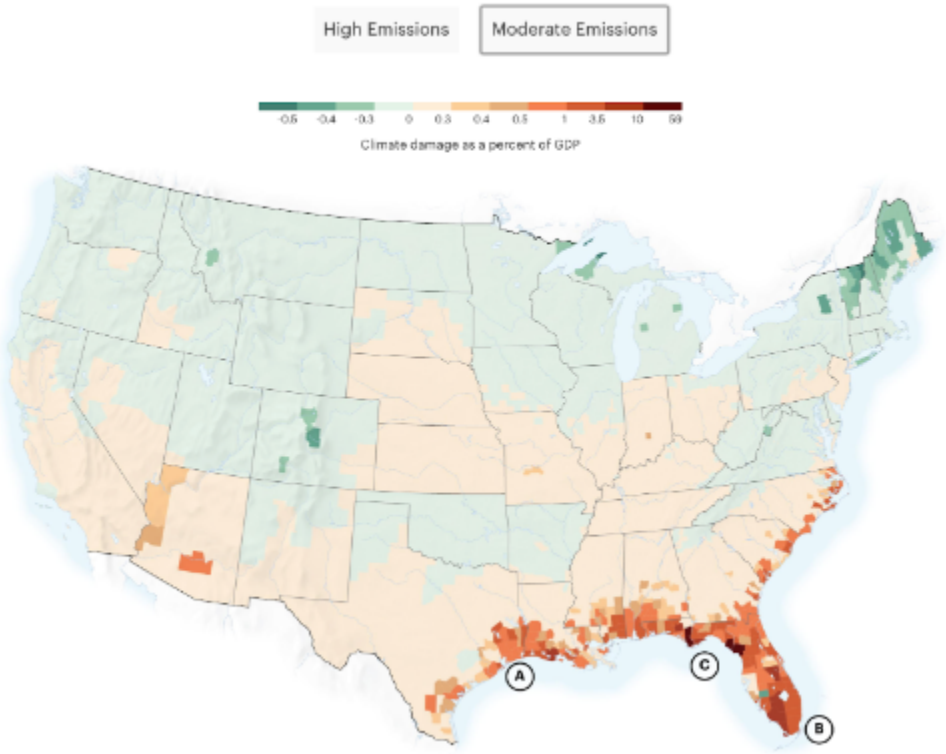


Figure 4.5-1 Climate Damage Map, Propublica

For projects in Pacific coastal areas, also consider whether tsunami risk bears on the decision to retrofit the building.

4.5.1.3.2 Zoning

Decide whether the building makes the best use of its site:
Determine the zoning designation and record the zoning code's definition of the zone.
Determine whether zoning would allow higher density or more uses, or if a variance could be sought to allow such.

4.5.2 Multiple-Facility Planning

If there are multiple facilities and a need to decide the order in which they will be addressed, establish a protocol for ranking the order.

Informative note: It is recommended to follow the guidance in ASHRAE Guideline 0.2, Chapter 5 and Annex H.

Develop a plan for benchmarking the performance of the buildings around the metrics used for evaluation.

If the metrics include the Resilience and ADORB metrics of this standard, discuss and define an approach to sampling and the use of simplified representative buildings for purposes of this planning phase.

4.5.2.1 Funding

If this standard is being used in a voluntary program, discuss potential grants or incentive programs that may be available from government, utility, or other entities that may apply to the project.

4.5.3 Programming Phase Deliverables

4.5.3.1 Multiple buildings: Program Plan

In the case of multiple facilities, assemble a Program Plan document containing the following:

a. Facility identification
b. Ranking metrics
c. Prioritized list of facilities
d. Phase plan or execution schedule
e. Program Planning Team (names, affiliation, and title)

4.5.3.2 Each building: Rationale to Retrofit

For each building, collect narrative responses to the determinations and decisions called for in sections 4.5.1.1-3 into a rationale to retrofit.

The development of a Cx Plan for each of the prioritized individual buildings is discussed in Section 8 – Process, Part Two, after the technical requirements in Sections 5, 6, and 7.

4.5.4 Acceptance and Decision to Proceed

Submit the deliverables to the *Authority* and the Owner. If they approve, the *Cx Team* proceeds to the Assessment Phase per section 8.6 Assessment.
If they do not approve, assemble the Program Planning Team to discuss and resolve the issues raised, and resubmit the plan.

Informative: The Authority *has discretion to establish criteria.*

5 Mitigate Existing Deficiencies

Upon completion of the final Implementation phase of the Cx Process, all the requirements stated in this section, and any of the electives included in the *CFR*, shall have been fulfilled.

5.1 Indoor Air Quality and Moisture Risk Mitigation

5.1.1 Indoor Air Quality

Perform all the Minimum Actions described in the EPA Energy Savings Plus Health Guidelines. See Informative Appendix E for a summary of the scope of said EPA Guidelines.

Single-family Residential
Refer to Publication No. EPA 402K21001.

Multifamily Residential
Refer to Publication No. EPA 402K21002.

Nonresidential
Refer to Publication No. EPA 402K21002.

Informative note: Additional guidance for nonresidential buildings can be found in ASHRAE Guideline 42 - Enhanced Indoor Air Quality in Commercial and Institutional Buildings. "As a minimum standard intended for international code adoption, ANSI/ASHRAE Standard 62.1 cannot mandate the abundance of evidence-based, improved indoor air quality (IAQ) practices. ASHRAE Guideline 42 was developed to fill this gap."

5.1.1.1 Indoor Air Quality Electives

Consider the Expanded Actions in the EPA Energy Savings Plus Health documents.

Consider complying with ASHRAE Standard 241 - Control of Infectious Aerosols.
Informative: Recirculating air filtration and upper room UV are the preferred approaches.

Informative: See also section 5.2.6.2 Wildfire Smoke.

5.1.2 Moisture Risk Mitigation

5.1.2.1 Comply with Phius Certification Guidebook Appendix B - Moisture Control for Opaque Assemblies, or ASHRAE Standard 227P - Passive Building Design, Advisory Public Review Draft, section 7.5.5.

5.1.2.2 Comply with the Condensation Risk part of Phius Certification Guidebook section 1.3.3.3 Moisture Risk Mitigation & Comfort Requirements.

5.1.3 New Additions

New additions shall comply with the requirements of US EPA Indoor airPLUS and US EPA ENERGY STAR for New Homes.
Exceptions:

a. The eligibility limitations do not apply.
b. The verification, partnership, training, and credentialing requirements do not apply; they are superseded by the *commissioning* requirements of this standard (section 4.2).
c. Conversions that create new *conditioned space* but do not entail the construction of new enclosure elements.

Informative: There are separate ENERGY STAR requirements documents for single-family, multifamily, and manufactured housing.

Single-family Residential
Comply with Energy Star SFNH requirements.

Multifamily Residential
Comply with Energy Star MFNC requirements.

Nonresidential
Comply with Energy Star MFNC requirements.

5.2 Hazard Mitigation

Informative note: With regard to section 4.1.4 Other Laws, it may often be that other laws cover similar ground as the requirements of this section in particular. It will be the designer-of-record's responsibility to coordinate with other building code requirements.

5.2.1 Earthquake

Informative: according to FEMA P-50, The International Building Code (IBC) provides engineered design guidance that can be applied to any retrofit.

Single-family Residential

Buildings in locations with a Seismic Design Category (SDC) of C through E (as specified in the *International Residential Code*), and within the scope of FEMA P-50, shall be improved to a Seismic Performance Grade of B-minus or higher. Use FEMA P-50-1 *Seismic Retrofit Guidelines for Detached, Single-Family, Wood-Frame Dwellings* and the resources cited therein to develop the seismic part of the Cx Plan.

Multifamily Residential and Nonresidential
For buildings in locations with an SDC C through E, but outside the scope of FEMA P-50, the design of improvements requires the involvement of a licensed structural engineer.

5.2.1.1 Earthquake Electives

Consider upgrades beyond the minimum B-minus level.

5.2.2 Flood

For all projects, electrical and mechanical systems shall be protected from flood according to the requirements of IBHS FORTIFIED Commercial Silver, sections 3.2.4 and 3.2.5, as modified below:

Electrical and Mechanical Systems and Connections (Flood Protection)
All electrical and mechanical equipment and connections necessary to operate critical systems shall be elevated at minimum above the 500-year flood level, if known, or 3 ft (1 m) above the base flood elevation (BFE) for the property. If the equipment cannot be sufficiently elevated as described above, permanent dry flood protection such as flood gates, walls, doors, or similar devices shall be used to prevent water intrusion to the heights described above. Flood depth, duration, velocity, and condition of water shall be considered (including floating debris).

Electrical Connections for Backup Power
In FEMA designated flood zones V, A, B, D, and X-shaded, electrical connections shall be installed with a transfer switch or docking station (sometimes referred to as a storm switch) in order to support connection of backup power for critical electrical and mechanical systems. All connections shall be located above the 500-year flood level if known, or 3 ft (1 m) above the known base flood elevation (BFE) or design flood elevation (DFE) for the property.

5.2.2.1 Flood Electives

In FEMA designated flood zones including V, A, B, D, and X-shaded, consider:

- The flood protection measures in FEMA P-1037 - Reducing Flood Risk to Residential Buildings That Cannot be Elevated.
- FEMA P-348 *Protecting Building Utility Systems From Flood Damage.*

If funding is being sought from FEMA's Hazard Mitigation Assistance Program, see also FEMA's Guidance for Applying ASCE 24 Engineering Standards to HMA Flood Retrofitting and Reconstruction Projects.

5.2.2.1.1 Tsunami Elective

For pacific coastal areas, Consider FEMA P-646 - Guidelines for Design of Structures for Vertical Evacuation from Tsunamis, Third Edition. This map shows the tsunami risk level according to FEMA.

5.2.3 Hail

Roof-mounted photovoltaic (PV) systems require the following:

- Flexible PV modules that are FM Approved for hail or meet FM Approval Standard 4476 that includes a Severe Hail rating.
- Rigid PV modules that are FM Approved for hail or meet FM Approval Standard 4478 that includes a Class 4 rating.
- See also section 5.2.6 Wildfire.

5.2.3.1 Hail Electives

Consider including additional requirements of the IBHS FORTIFIED Hail Supplement material in addition to the PV system requirements. Section 8.6.7.1 contains a map of hail-prone counties for the US.

Informative: Following the FORTIFIED requirements referred to herein DOES NOT constitute compliance with FORTIFIED or imply that the property is a FORTIFIED property. In order to be considered as a FORTIFIED Home™, FORTIFIED Commercial Building or FORTIFIED Multifamily, the properties would have to participate in the FORTIFIED program, which requires formal documentation and review by IBHS.

5.2.4 Structural and High Wind Concerns

5.2.4.1 Structural and High Wind - Single-family residential

This section applies to single-family detached homes, duplexes, HUD manufactured homes on permanent foundations, and townhouses.

a. Homes on a foundation constructed of unrestrained stacked masonry or stone (a dry-stack foundation) shall be retrofitted in accordance with a professional engineering plan and comply with HUD-Code Manufactured Home foundation requirements - US Department of Housing and Urban Development (HUD) Permanent Foundation Guide for Manufactured Housing (HUD4930.3G) dated September 1996 or later.

See Figures 2.1, 2.2, and 2.3 in IBHS FORTIFIED Home, reproduced below:

☐ **Unreinforced (dry-stack) foundations**

Figure 2.1. Ineligible dry-stack foundation

Figure 2.2. Ineligible dry-stack foundation

Figure 2.3. Ineligible dry-stack foundation

b. Homes shall meet the requirements of i. or ii. below:
    i. IBHS FORTIFIED Home Standard, Section 3 - Existing Roof.
        1. The requirements for hurricane designation apply where the ultimate design wind speed (Vult) is greater than 115 mph as specified in ASCE 7-10 through ASCE 7-16 or the nominal design wind speed (Vasd) is greater than 90 mph as specified in ASCE 7-98 through ASCE 7-05.
        2. Elsewhere, the requirements for high wind designation apply.
    ii. FEMA P-804 Wind Retrofit Guide for Residential Buildings, section 4.1 - Basic Mitigation Package
c. Homes must comply with any applicable local structural codes.

5.2.4.1.1 Residential Structural and High Wind Electives

Consider the Intermediate, Advanced, and Additional wind retrofit mitigation packages in FEMA P-804, Chapter 4.

Consider IBHS FORTIFIED Home Standard, Section 6.5 Continuous Load Path for Retrofit of Existing Homes.
Informative: FORTIFIED Home, Section 6.5, is aimed at getting existing buildings to the Gold level.

For new additions in *hurricane-prone regions*, consider the higher tiers of the IBHS FORTIFIED Home Standard.

5.2.4.2 Structural and High Wind - Multifamily Residential and Nonresidential

Buildings shall meet the requirements of IBHS FORTIFIED Commercial, Section 3.1 - FORTIFIED Roof.

5.2.4.2.1 Structural and High Wind Electives, Multifamily Residential and Nonresidential

For new additions in *hurricane-prone regions*, consider higher tiers of IBHS FORTIFIED Commercial.

Consider the additional improvements described in:

- FEMA P-1000 A Guide to Improving School Natural Hazard Safety, Supplement W, and
- FEMA P-424 Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds, Chapter 6.

5.2.5 Snow Load and Ice Dams

If ice dams have been a regular occurrence, diagnose and mitigate them.
Informative: See Lstiburek (2018).

5.2.5.1 Snow Load Electives

Consider the additional improvements described in:
FEMA P-957 Snow Load Safety Guide
FEMA Roof Snowdrift Design Guide

5.2.6 Wildfire

In areas where the FEMA designated wildfire risk is “Relatively Moderate” or higher, take the actions listed in or implied by the Defensible Space & Home Hardening Self-Inspection Checklist of the City of Berkeley Fire Department, reproduced below:

- Do you have any accumulated vegetation waste?
- Is your car blocking any fire apparatus access to roads? Fire trucks need a minimum lane of 26 feet wide and 13’ 6” tall for clearance. We recommend backing your vehicle into driveways on Red Flag warning days.
- Can you see your address from the street? Address identification must be seen from the street in the day or night time and contrast in color from their background.
- Are the power lines cleared? There must be a minimum of 4 feet of clearance from the high voltage conductor. If the power lines are obstructed, contact [electric utility] to request trimming around the power lines.
- Is there clearance of brush from roadways? Minimum of 10-feet on each side of the roadway must be cleared of vegetation such as tall grass, weeds or brush.
- Is there defensible space around your home? Some things to consider:
    - Cut grass and flammable vegetation
    - Remove combustible items from areas such as decks, overhangs and stairs
    - Relocate combustible outdoor furniture
    - Create space between plants and between plants and structures
    - Trim trees 10 feet back from chimney(s) and if possible from overhanging your roof
    - Remove old leaves and pine needles from roofs, eaves and gutters
    - Remove branches within 10 feet from the ground (limbing)
    - Remove dead wood / or thin overly dense tree crowns
    - Remove understory, brush and ground fuel beneath trees
    - Thin stands of trees / shrubs by removing individual stems or plants
    - Strip loose bark 8-feet from the ground (eucalyptus)
- Do you have Spark Arrestors installed? Spark arrestors are required for chimneys, fireplaces, barbecues, incinerators or heating appliances (Berkeley Building Code 704A1.6 for specifications).
- Can you maintain an effective fire break by removing anything combustible 30 feet from the structure?
- Remember, brush and debris does not need to be completely removed but may be chipped into pieces less than 3 inches in size.

Roof-mounted photovoltaic (PV) systems require the following:

- Rigid PV modules that meet UL 1703 Standards for Flat-Plate Photovoltaic Modules and Panels.
  Informative: UL 1703 is for fire performance characterization of modules and panels.

5.2.6.1 Wildfire Electives

In areas where the FEMA designated wildfire risk is “Relatively Moderate” or higher, and for new additions, consider:

- The mitigations listed in FEMA P-737 - Home Builder's Guide to Construction in Wildfire Zones.
- The IBHS Wildfire Prepared Home standard.

5.2.6.2 Wildfire Smoke

Informative note: The air needs to be cleaned as much as reasonably achievable whether ventilating with outdoor air or recirculating indoor air. To help building managers accomplish this, members of the ASHRAE committee drafting the Guideline 44P for Protecting Building Occupants from Smoke during Wildfire and Prescribed Burn Events developed this planning framework. The document outlines a process for making a building Smoke Ready, including assessing whether these actions have been effective in reducing indoor PM2.5 levels. The document explains how and why these actions should be taken before and during wildfire smoke episodes.

6 Performance Requirements

6.1 Simulation Requirements

Informative: An input-file driven calculation engine compliant with this standard is available open-source at the Github Repository here.

6.1.1 General Capabilities

6.1.1.1
The simulation program shall be a computer-based program for the analysis of energy consumption in buildings.

6.1.1.2
The simulation program shall be approved by the *Authority* and shall, at a minimum, have the ability to explicitly model all of the following:

a. 8760 hours per year
b. Hourly variations in occupancy, lighting power, miscellaneous equipment power, thermostat set points, and HVAC system operation, defined separately for each day of the week and holidays
c. Thermal mass effects
d. Ten or more thermal zones
e. Part-load performance curves for mechanical equipment
f. Capacity and efficiency correction curves for mechanical heating and mechanical cooling equipment
g. Air-side economizer and fluid economizer with integrated control
h. An outage in which the mechanical and electrical equipment is not available

The simulation program shall have the ability to either

a. directly determine the design energy cost and baseline (per section 6.5.1) energy cost or
b. produce hourly reports of energy use by energy source suitable for determining the design energy cost and baseline energy cost using a separate calculation.

6.1.1.3
The simulation program shall be capable of performing design load calculations in accordance with Section 6.1.9, to determine required HVAC equipment capacities and air and water flow rates for both the proposed design and the baseline building design.

6.1.1.4
The simulation program shall be tested according to ASHRAE Standard 140, except for Sections 7 and 8 of Standard 140. The test results and modeler reports shall be posted on a publicly available website and shall include the test results of the simulation program along with the results of the other simulation programs included in ASHRAE Standard 140, Annexes B8

and B16. The modeler report in Standard 140, Annex A2, Attachment A2.7, shall be completed for results exceeding the maximum or falling below the minimum of the reference values or for missing results.
Informative: There are no pass/fail criteria established by this requirement.

6.1.2 Weather / Climatic Data

The simulation program shall perform the simulation using hourly values of climatic data, such as temperature and humidity from representative climatic data, for the site where the proposed design is to be located. For cities or urban regions with several climatic data entries, and for locations where weather data are not available, the designer shall select available weather data that best represent the climate at the building site. The selected weather data shall be approved by the *Authority*.

US locations:
The weather data for annual simulations shall be EPW.
Phius practices:

- The number of design days in the DDY file is limited to four.
- Custom weather data is generated if the available station location is too different in altitude or too distant from the building site.

The weather data for the outage resilience tests shall comply with 6.1.2.1 or 6.1.2.2.

6.1.2.1 Resilience Extreme Week Morphing Algorithm

For both Dry bulb and Dew point temps:

Txweek2_dry_h = Txweek_dry_h + Delta_dry*sin(phase)
Txweek2_dew_h = Txweek_dew_h + Delta_dew*sin(phase)

Txweek is the temperature history in the extreme week period of the EPW STAT file.
Txweek2 is the morphed temperature history.

h is the hour within the outage period, $0 \le h \le hout$
hout is the outage duration in hours minus 1
hout = 167
Phase_h = pi * h / hout

Iteration to determine Delta_dry and Delta_dew:
Delta_init = Treturn - avg(Txweek)
Treturn are the n-year return extreme values of DB and dewpoint, converted from DB and Wet bulb, from ASHRAE Climatic Design Conditions data.

For winter, use the 10-year return values.
For summer, use the 20-year return values.

Delta = Delta_init
Repeat

Txweek2_h = Txweek_h + Delta*sin(phase_h)
K is a relaxation factor = 0.1
X = [max(Txweek2) for hot week,
min(Txweek2) for cold week]
Deltanext = Delta+K*(Treturn-X)
Delta = Deltanext
Until abs(Treturn-X) < tolerance ~ 0.01 F

Then, limit the dew point to be less than or equal to the dry bulb temperature, for all hours.

6.1.2.2 Reserved

6.1.3 *Thermal Blocks*

Multifamily and mixed-use buildings shall be modeled in multiple *thermal blocks*, with each dwelling unit as a *thermal block*.

For attached row houses with party/demising walls, model them as adiabatic on the outer surface.

6.1.4 Accounting for Thermal Bridges

Account for thermal bridges in accordance with ASHRAE Standard 227P - *Passive Building Design, Advisory Public Review Draft*, sections 5.2.2 through 5.2.5.
Exceptions:

- In cases where 227P would require the calculation of a linear thermal bridge coefficient, such as weakly-insulated sills and top plates, these may be represented instead by assemblies (high-aspect ratio areas with U-values.)
- Point thermal bridges may likewise be represented by a small area of weakly-insulated assembly.

6.1.5 Contact to the Ground

Building ground contact shall be modeled using the Kiva™ method.

6.1.6 Thermal Mass of Interior Partitions and Furnishings

Thermal mass shall be accounted for in the simulation, calculated by the design of the building in situ, and as designed for the proposed case.

Exception: For the interior partition wall mass, use either a) the actual design / existing condition, or b) a partition wall assembly of light construction and area equal to the floor area of the *thermal block*.

6.1.7 Infiltration Model

Use the Design Flow Rate model with NIST parameters.

Informative: According to the EnergyPlus Engineering Reference, "The "Design Flow Rate" model … was inherited from EnergyPlus' predecessor programs. It ... is based on environmental conditions modifying a design flow rate. The basic equation [is from] Coblenz and Achenbach (1963)."

6.1.7.1 Existing Building Air-Tightness Assumption

If there is pre-existing building air tightness test data (according to ANSI 380, ASTM E779, ASTM E1827, ASTM E3158, ABAA T0001, or ISO 9972) use that data for modeling the baseline case. Otherwise, use 12 ACH50.
Informative: pre-retrofit air tightness testing for compartmentalization of dwelling units will usually be required in the Investigation Phase, but pre-retrofit whole-building testing is not required.

Single-family Residential
Informative: For single family homes, a possible improvement is to use the median value (at y=0.5 on the cumulative distribution plot) from the LBNL Residential Diagnostics Database (ResDB) calculator, with inputs appropriate to the specific case.

6.1.8 Schedules for Annual / Normal-Operation Calculation

Single-family and Multifamily Residential
For residential buildings use the schedules in Normative Appendix SC for:

- Occupancy
- Hot water
- Lighting
- Major appliances
- *Miscellaneous electric loads*
- Miscellaneous gas loads

Nonresidential
Informative note: Schedules for nonresidential space types can be obtained from the BEMcyclopedia Lookup Tables.

6.1.9 Design Load Calculations

6.1.9.1 General

Equipment sizing and design loads shall be calculated using a dynamic heat balance method, and shall account for design air ventilation rates, design occupancy, and interior thermal mass.

6.1.9.2 Residential Internal Gains

Internal gains for residential spaces are to be calculated according to the RLF method from ASHRAE RP-1199, equations (18) and (19), applied per dwelling unit, as follows.

The contributions of internal gains to peak sensible and latent loads are:
$Q_{ig,s} = G0,s + Gcf,s*Acf + Goc,s*Noc$

$Q_{ig,l} = G0,l + Gcf,l*Acf + Goc,l*Noc$

Where

$Q_{ig,s}$ is the sensible cooling load due to internal gains, Btu/h (W)
$Q_{ig,l}$ is the latent cooling load due to internal gains, Btu/h (W)

Gx coefficients as follows:

	Sensible IP (SI)	Latent IP (SI)
G0	464 (136)	68 (20)
Gcf	0.7 (2.2)	0.07 (0.22)
Goc	75 (22)	41 (12)

Acf = conditioned floor area of building, ft2 (m2)
Noc = number of occupants; if not known, use the number of bedrooms plus one, per dwelling unit.

The internal gains shall be active during the cooling sizing, but absent from the heating sizing period. Occupants are present for both sizing periods.

6.1.10 Reflectance of Blinds

Effectiveness of exterior blinds for shading shall be either “medium” or “high” as follows:
Medium: 0.4 solar transmittance, 0.5 solar reflectance
High: 0.1 solar transmittance, 0.8 solar reflectance

6.2 General Resilience

6.2.1 Enclosure Air-Sealing

The post-retrofit whole-building air-tightness shall meet the requirements of IECC 2021, that is, 0.28 cfm50/ft2 for residential (per section R402.4.1.2) and 0.4 cfm75/ft2 for commercial (per section C402.5.3) as defined in the IECC.
Exception: See section 8.9.4.1 Air-tightness testing, for allowed methods.

Informative: Air-sealing for compartmentalization is also required by the ASHRAE 62.2 standard referenced in the EPA Energy Savings Plus Health protocol referred to in Section 5.1. See also section 8.7.6.1 Indoor Air Quality Investigation.

6.2.2 *Islanding*

On-site renewable energy generation systems shall have the capability to disconnect from the grid and to operate without a grid connection.

6.2.3 Battery-Readiness

The electrical system shall have attached battery storage or space reserved for the same.

6.2.4 Photovoltaic (PV) Readiness

The provisions of the applicable U.S. DOE Zero Energy Ready Home PV-Ready Checklist Version 2 shall be met, unless one or more of the exceptions noted below (from the applicable program requirements documents) applies.

Single Family
The U.S. DOE Zero Energy Ready Home Single Family Homes PV-Ready Checklist Version 2 (Rev. 1) applies.

Exceptions:

a. The home already includes an on-site PV system.
b. The home receives renewable energy from a community solar system, and there is a legally binding agreement in place for the provision of this energy to the home with a duration ≥ 15 years and written to survive a full or partial transfer of ownership of the property.
c. The location has significant natural shading (e.g., trees, tall buildings impacting the south-facing roof).
d. The home as designed does not have at least 500 square feet of roof area oriented in between 110 degrees to 270 degrees of true north.

Multifamily and Nonresidential
The U.S. DOE Zero Energy Ready Home Multifamily PV-Ready Checklist Version 2 applies.

Exceptions:

a. The building already includes an on-site PV system with a capacity of at least 1 Watt per square foot of roof area. Documentation of the system must be retained by the rater.
b. The building receives renewable energy from a community solar system, and there is a legally binding agreement in place for the provision of this energy to the building with a duration ≥ 15 years and written to survive a full or partial transfer of ownership of the property. Documentation of this agreement must be retained by the rater.
c. A building with a solar-ready zone that is shaded for more than 70 percent of daylight hours annually. Documentation of the analysis concluding that the 70 percent threshold is not met must be retained by the rater.

d. Buildings where 75% or more of the roof (by surface area) has a slope of 4:12 or greater and no portion of the 4:12 or greater roof section is oriented in between 110 degrees to 270 degrees of true north. Documentation must be retained by the rater.
e. A building where the licensed professional certifies that the solar zone area required by this checklist cannot be met because of extensive rooftop equipment, skylights, vegetated roof areas, or other obstructions. CxP must retain this documentation.

6.3 Winter Resilience

6.3.1 Winter Resilience Requirements

In its final configuration, the post-retrofitted building shall:

1. Be capable of meeting the winter thermal resilience criteria outlined in section 6.3.2 and calculated in accordance with the evaluation protocol of section 6.3.3 AND
2. Meet the requirements outlined in section 6.3.1.1 Tier A or section 6.3.1.2 Tier B as required by the *Authority*:

6.3.1.1 Tier A Winter Resilience - Decarbonized

In its final configuration, the post-retrofitted building shall be capable of covering winter-critical electrical and process loads, using energy only from on-site sources that are renewable, without resorting to combustion (or fuel cells) directly or indirectly.

Informative: This effectively requires non-fuel-based and electrically-interacting energy storage such as electrochemical or gravity batteries, flywheels, compressed air, pumped hydroelectric.

Residential

> Electrical loads to be covered: Fan energy for energy recovery ventilation, plus 33 W per dwelling unit for miscellaneous electrical loads.
> *Informative: equivalent to the class of off-grid refrigerator formerly known as SunFrost.*

Nonresidential including *hospitality or transient dwelling units*

> Electrical loads to be covered: Fan energy for energy recovery ventilation, plus winter-critical electrical and process loads as defined in the *CFR*.
>
> Exception: In addition to on-site sources, the winter-critical electrical loads may be covered via a local electrical microgrid having primary energy sources that are renewable and do not use combustion.

Informative: If an active solar thermal system is involved in meeting the winter resilience criteria, that is also a winter-critical electrical load.

6.3.1.2 Tier B Winter Resilience

In its final configuration, the post-retrofitted building shall be capable of covering winter-critical electrical and process loads using energy from on-site sources, but the means of covering said loads are not otherwise restricted.

Residential

Electrical loads to be covered: Fan energy for energy recovery ventilation, plus 33 W per dwelling unit for miscellaneous electrical loads.
Informative: equivalent to the class of off-grid refrigerator formerly known as SunFrost.

Nonresidential including *hospitality or transient dwelling units*

Electrical loads to be covered: Fan energy for energy recovery ventilation, plus winter-critical electrical and process loads as defined in the *CFR*.

Informative: If an active solar thermal system is involved in meeting the winter resilience criteria, that is also a winter-critical electrical load.

6.3.2 Winter Thermal Resilience Criteria

During the simulated outage, each *thermal block* shall have:

a. Zero hours below 36 °F (2C), and
b. No more than 216 °F-hours, below 54 °F, in terms of *standard effective temperature (SET)*, at 1 clo, 120 W/person, 31 fpm (0.16 m/s) air speed.

Nonresidential

In *thermal blocks* that are intended to be unoccupied during a winter outage, only 6.3.2.a applies.

6.3.3 Winter Resilience Evaluation Protocol

Outage duration 7 days.
HRV/ERV operates at 5 cfm (8.5 m3/h) per person.

Residential

Occupancy: Full occupancy throughout the outage.

Electrical loads to be covered: Fan energy for energy recovery ventilation, plus 33 W per dwelling unit for miscellaneous electrical loads.

Informative: equivalent to the class of off-grid refrigerator formerly known as SunFrost.

No active space heating systems or equipment that use energy or fuel imported from off-site operate during the outage. Energy for space heating comes only from sources that are on-site (internal gains and passive or active solar thermal).

Nonresidential
Occupancy: As defined in the *CFR*, and same as for the summer outage.

Electrical loads to be covered: Fan energy for energy recovery ventilation, plus winter-critical electrical and process loads as defined in the *CFR*.

Nonresidential internal heat gains are to be consistent with the nonresidential winter-critical electrical loads as defined in the *CFR*.

The energy for space heating comes only from sources that are either
a. On-site (internal gains and passive or active solar thermal), or
b. Provided by a local electrical *microgrid* or *thermal energy network* having primary energy sources that are all renewable.

6.4 Summer Resilience

6.4.1 Summer Resilience Requirements

In its final configuration, the post-retrofitted building shall:
1. Be capable of meeting the summer thermal resilience criteria outlined in section 6.4.2 and calculated in accordance with the evaluation protocol of section 6.4.3 AND
2. Meet the requirements outlined in section 6.4.1.1 Tier A or section 6.4.1.2 Tier B as required by the *Authority*:

6.4.1.1 Tier A Summer Resilience - Decarbonized
a. In its final configuration, the post-retrofitted building shall be capable of covering summer-critical electrical and process loads, using energy only from on-site sources that are renewable, without resorting to combustion (or fuel cells) directly or indirectly.

Informative: This will often require non-fuel-based thermal and electrical energy storage such as ice storage, electrochemical or gravity batteries, flywheels, compressed air, pumped hydroelectric.

Residential
Electrical loads to be covered: Fan energy for energy recovery ventilation, plus 33 W per dwelling unit for miscellaneous electrical loads.

Nonresidential including *hospitality or transient dwelling units*
Electrical loads to be covered: Fan energy for energy recovery ventilation, plus summer-critical electrical and process loads as defined in the *CFR*.

Exception: In addition to on-site sources, the summer-critical electrical loads may be covered via a local electrical microgrid having primary energy sources that are renewable and do not use combustion.

Informative: If heat pump or evaporative cooler operation is needed to meet the summer thermal resilience criteria, that is also a summer-critical electrical load.

6.4.1.2 Tier B Summer Resilience
In its final configuration, the post-retrofitted building shall be capable of meeting the summer thermal resilience criteria and covering the summer-critical electrical and process loads using energy from on-site sources, but the means of doing so are not otherwise restricted..

Residential

Electrical loads to be covered: Fan energy for energy recovery ventilation, plus 33 W per dwelling unit for miscellaneous electrical loads.

Nonresidential including *hospitality or transient dwelling units*

Electrical loads to be covered: Fan energy for energy recovery ventilation, plus summer-critical electrical and process loads as defined in the *CFR*.

Informative: If heat pump or evaporative cooler operation is needed to meet the summer thermal resilience criteria, that is also a summer-critical electrical load.

6.4.2 Summer Thermal Resilience Criteria

During the simulated outage, each *thermal block* shall have:

a. Heat Index: Zero hours in Danger, Extreme Danger, and
b. Zero deadly days per Mora et al.

Deadly day criterion:
During the summer outage,

Tday <= Tdead, where

Tdead [F] = 121.91 - 87.444*RHday + 46.597*RHday^2
Tdead [C] = 49.593 - 48.580*RHday + 25.887*RHday^2
Tday is the mean daily temperature in the *thermal block*.
RHday is the mean relative humidity in the *thermal block*, as a fraction 0 ≤ RHday ≤ 1.

Nonresidential

In *thermal blocks* that are intended to be unoccupied during a summer outage, the summer-outage heat exposure criteria defined in the *CFR* shall be met.

6.4.3 Summer Resilience Evaluation Protocol

Outage duration, Occupancy schedule, ventilation rate, residential *MEL*, and PV all the same as for the winter outage.

Residential

The energy for space cooling comes only from sources that are on-site (natural ventilation cooling, forced ventilation cooling, or other active systems operated with on-site electrical power)

Nonresidential

Nonresidential internal heat gains are to be consistent with the nonresidential summer-critical electrical loads as defined in the *CFR*.

The energy for space cooling comes only from sources that are either

a. On-site, or
b. Provided by a local electrical *microgrid* or *thermal energy network* having primary energy sources that are all renewable

Evaluate the following building operation modes:

a. Shading & Natural ventilation
   Open area - Use operable window areas for natural ventilation based on a 2.7 F (1.5°C) delta dry bulb to passively cool the space
   Control logic - Use above operable windows and delta dry bulb controls, but only allow for natural ventilation based upon photocell control, not allowing for any ventilation during the day while the sun is up
   Reduction factors for interior and exterior blinds, see 6.1.9. - use exterior blinds to keep solar heat gains from entering the space, triggered to close if there is greater than 100 W/m2 of incident radiation on the window
b. Shading & heat pump cooling
   Control logic - Set the heat pump to run when on-site renewable power makes its usage possible. When no renewable power is available, run the heat pump on a setback of 80.6°F (27°C).
   Informative - The aim is to keep the space heat index at Caution or below (heat index of 90°F : 84 F dry bulb at 70% RH).
c. Evaporative cooling - Supply active cooling by an evaporative cooler (dry climates only.)

A cooling battery sizing calculation is to be done: Any electrical energy purchased through the simulated meter is added to the battery size.

6.5 Life Cycle Cost and Impact Control

6.5.1 Life Cycle Cost Limit

The *ADORB cost* of the proposed retrofit is to be no greater than that of a baseline case, in which the building is operated and maintained as-is. The calculation protocol for *ADORB cost* is in Appendix A.

Exception: If the project involves changes to the number of dwelling units, number of bedrooms, or conditioned floor area, then the *ADORB cost* shall not exceed that of the baseline on one of the following bases (whichever is least stringent):

a. Cost per unit of conditioned floor area
b. Cost per bedroom
c. Cost per dwelling unit

6.5.1.1 The analysis period for the life cycle calculation shall be between 30 and 100 years, at the discretion of the *Authority*. The starting year is the planned year of completion of the first retrofit phase.
Informative note: Recommended value is 70 years.

6.5.2 Additional Decarbonization Effort

6.5.2.1 Operational Decarbonization

Comply with Tier A or Tier B Below as directed by the Authority:

a. Tier A. Fossil-combustion-free:
   Comply with i or ii below:
   i. Electrify building operation by the final retrofit phase and comply with the requirements for Phius ZERO in the Renewable Energy Appendix of the Phius Certification Guidebook.
   ii. From the first implementation phase onward, subscribe to a *community solar* project or program at a level of commitment that would cover at least 100% of the building's expected annual electrical energy consumption in its post-retrofit condition for each phase, net of any on-site renewable energy production.

6.5.2.1.1 Community Solar Plus Storage Elective

The *community solar* project includes community-scale storage or constitutes a *microgrid*.

Informative:
See the US DOE Community Solar Resource Page for more information.

According to Utility Dive, "Community-scale solar and storage could also form an anchor for a community-level microgrid that could isolate from the larger grid in such situations, but doesn't require waiting for these plans to materialize before creating a basic community resilience resource."

b. Tier B. Electrified in normal operation:
Electrify building operation by the final retrofit phase. exceptions:
On-site stored combustion fuel for emergency backup electricity generation.
On-site stored combustion fuel for outdoor cooking.

6.5.2.2 Embodied Decarbonization

Include at least one Level 2 embodied carbon measure - a material substitution, business practice change, or personal choice change. The substitutions and changes are relative to a business-as-usual retrofit practice, not relative to new construction - reusing parts of the building is taken as the given context and does not get credit.

The calculation protocol for Level 2 embodied carbon measures is further elaborated in Appendix A, and implemented in the example worksheet linked below. Download a copy to edit.
https://docs.google.com/spreadsheets/d/1xcI1zpPAcboNRSyDyfOptMsiaZhPgXulhF5ozSGP9bU/edit?usp=sharing

7 Monitoring Requirements, Measurement & Verification

Informative notes:
For additional guidance about monitoring, see the ASHRAE Handbook: HVAC Applications. Chapter 42 - Building Energy and Water Monitoring.

There is some value to also making the IEQ and energy monitoring data accessible to building occupants (a "dashboard").

7.1 Monitoring Minimum Requirements

Residential
No requirement.

Nonresidential
Register the building with Energy Star Portfolio Manager and track its energy and water utility meters.
Share with or grant access to the data, for both the *CxP* and the *Authority*.
Continue monitoring for the period of time directed by the *Authority*.

7.2 Indoor Environment Monitoring Electives

Consider monitoring some chosen quantities listed in this section at least hourly and maintain a data log going back at least 15 months.

7.2.1 Hazardous Gas Monitoring Elective

- Carbon monoxide
- Radon

7.2.2 Indoor Environment Quality (IEQ) Monitoring Elective

Informative: The following measurements are aligned in scope with the RESET Air standard. If actually pursuing RESET Air certification, the core-and-shell option seems preferable.

- Temperature
- RH
- Carbon dioxide (CO2)
- PM2.5
- TVOC

Informative: Additional measurements within the scope of Building 4 Health:

- NO2
- Ozone
- PM10
- PM1.0
- SO2

7.3 Energy End-Use Monitoring Elective

Consider monitoring for energy end use breakdown in the following priority order:

1. Other miscellaneous loads
2. Supplemental dehumidification
3. Space heating
4. Space cooling
5. Domestic / service hot water heating
6. Lighting
7. Major appliances
8. Humidification

7.4 Water Quality Monitoring Elective

Consider RESET Water quality

Informative note: the current scope of RESET Water is for water used by the occupants of commercial interior spaces, or for the water quality of central water systems and public spaces in a building.

7.5 Waste/Materials Tracking Elective

Consider using Energy Star Portfolio Manager to track Waste/Materials, or RESET Waste

8 Process, Part Two

8.6 Assessment Phase

Informative:
The Assessment Phase consists of preparatory activities of the Cx Process in which Current Facility Requirements (CFR) *and a* Commissioning (Cx) *Plan are developed and defined for a single facility, and an assessment of the facility is performed. The purpose of the Assessment Phase is to gain enough of an understanding about the individual facility to develop an initial scope, schedule, budget, and general approach for the Investigation Phase as well as a general estimate of the cost and timeline for the total project.*

It is not a full evaluation but rather a cursory data gathering and brief walkthrough of the facility, resulting in sufficient information to develop the Cx Plan and assess the benefits of proceeding with the process.

This phase concludes with the completion of the Cx Plan and acceptance of the Assessment Phase report.

8.6.1 Facility Information

The Owner shall provide to the *CxP*:

- Facility Summary. A narrative describing facility location, size, occupancy type, construction, systems, and facility usage.
- All available facility information, including the following:

a. Construction documents (drawings; specifications; submittals, HVAC and lighting controls; as-builts; previous modifications to the facility).
b. Annual maintenance cost breakdown of interior building costs, building enclosure maintenance cost, and repair budget.
c. Utility rates, suppliers, and meter (and submeter) locations, data availability (hard copy or electronic).
d. Onsite energy production (as applicable).
e. Whether there are current occupants that will occupy the post-retrofit building.
f. A budget for low-cost repairs to be performed within the *operations and maintenance (O&M)* budget for the facility, where such a budget exists. If no budget exists, the Owner shall develop a budget for low-cost repairs. (for safety, security, health, or operational issues that can be easily remedied, do not require further investigation, and thus can be immediately implemented as the team develops the initial information on the facility.

Residential

g. Include information about any ice damming problems.
h. For multifamily residential buildings, and to the best of the Owner's ability, fill out the US DOE Multifamily Building Efficiency Screening Tool (MBEST) workbook.

Nonresidential

i. Any occupant surveys conducted.
j. *O&M* report of operating problems, malfunctioning equipment, maintenance costs, and revisions to *O&M* procedures pertaining to systems included in Cx scope.
k. Scheduled maintenance worksheets and work order history for systems included in the Cx scope.
l. Previous new-construction *commissioning Systems Manual*, including its final *commissioning* report, or previous Cx systems and facility manuals (as applicable, from previous projects).
m. Any previous consultant reports for systems included in the Cx scope (as applicable).
n. *Operations and maintenance (O&M)* plan.

8.6.2 Occupant Survey

Prepare an occupant satisfaction survey for Owner distribution.
The occupant survey shall ask questions to evaluate the level of satisfaction of the occupants and the impact their living space or workspace has on their activities.
If the occupant survey is conducted verbally, record the responses in writing.

8.6.2.1 Occupant Survey Minimum Content

a. Reserved
b. Age range (e.g. under 14, 14 to 22, 35 to 50, over 80, etc.)

c. Type of space (dwelling, office, classroom, retail shop, etc.)
d. Acoustical privacy
e. Ambient noise negatively impacting concentration
f. Perception of thermal comfort (hot, warm, slightly warm, neutral, slightly cold, cold) and areas of the body affected (neck, back, arms, hands, thighs, lower legs, feet)
g. Adequate lighting for tasks and activities
h. Visual comfort
    1. Light quality impacting tasks and activities
    2. Lighting color discrimination
    3. Problematic light flicker
    4. Glare
    5. Difficulty seeing computer screen
    6. Adequacy of light levels in common areas
i. Indoor air quality
    1. Air quality (stuffy/stale conditions)
    2. Unpleasant odors (food, carpet, other occupants, perfume, cleaning products, outside sources)
j. Approximate or specific location in building (except for single-family detached)
k. Typical number of hours per day spent in the building.
l. Is it generally safe to open windows on summer nights for natural ventilation cooling? Can the windows prevent unlawful entry while open?

8.6.3 Processing Owner-Provided Information

The *CxP* shall:

a. Assemble a *CxP Team* with the technical expertise required to perform the Cx scope of work.
   Informative: Each team member needs a clear understanding of the overall Cx goals and objectives, what is expected of them, and where their portion of the work fits in the process. The CxP *plays a vital role in ensuring that the roles and responsibilities are properly defined, well communicated, and continually met by the team members .*
b. reserved.
c. The *CxP* shall assist the Owner with development of the *CFR* in accordance with this standard, and with approval of the *CFR* document developed by the *CxP*.
d. Evaluate Owner-provided input to the *CFR* and verify that the information is clear in meaning and defines measurable project criteria.

8.6.4 Development of *Current Facility Requirements* - Round 1

Informative: A cornerstone of the Cx Plan is the establishment of a document defining the CFR*. The* CFR *is a living document. The latest version of the* CFR *will remain the standard for evaluating decisions throughout the Cx Process. Documentation of changes in each update of the* CFR *shall be maintained along with the reasons for modification to prevent incorrectly going*

back to a prior statement of requirements without justification. These documents are included in the deliverables from this and all other phases of the process.

Write the *CFR* using the outline given in Appendix T-1.

This first round is to capture Facility requirements, and *M&V* requirements and electives from section 7. The *CFR* is to be updated with additional electives after performing the Assessment, per section 8.6.7.5.

Give each owner-determined and owner-elected requirement a unique identifier. For the IAQ electives per section 5.1, use the codes from the referenced EPA documents.

8.6.4.1 Facility Requirements

For both the existing building and any intended additions, capture facility requirements including:

a. Regulatory and jurisdictional requirements (any violations of codes that need to be addressed).
b. Financial requirements.
c. Functional uses, functional activities/tasks performed in the building and associated requirements to facilitate efficient execution of occupant mission.
d. Space needs.
e. Occupancy requirements and occupancy schedules in normal operation.
f. Indoor environmental requirements (temperature, humidity, air quality, ventilation, lighting).
g. Level of systems control.
h. Preferred vendors / contractors.

8.6.4.1.1 Nonresidential - Critical Loads and other Outage Resilience Requirements

Describe the critical electrical and process loads - those to be kept operational during the winter outage scenario per section 6.3.3, and during the summer outage scenario per section 6.4.3. Tabulate the peak power and estimate a diversity factor for each critical load.

Define the nonresidential occupancy schedule for the outage scenarios, if different from the normal-operation occupancy. Per section 6.4.3, the outage occupancy is to be the same for summer and winter.

For *thermal blocks* that are intended to be unoccupied during a summer outage, define the heat exposure criteria to be met.

8.6.4.2 *OCx* / *Measurement and Verification (M&V)* Electives

Determine the level of implementation: Review the *measurement and verification* electives in section 7, make an initial determination of which ones to include, if any.

8.6.5 Development of *Commissioning* Plan (Cx Plan)

Informative: The efforts and documents developed throughout the Assessment phase compose the groundwork for the Cx Plan. The Cx Plan provides the foundation from which the Investigation and Implementation Phases proceed. The initial Cx scope, schedule, and budget are developed based on the Cx Plan, the assessment, and other criteria established by the Cx Team. *The Cx Plan is first developed prior to the assessment and then updated after the assessment is complete.*

Use Normative Appendix T-2 as the framework for developing the commissioning plan.

Analyze occupant survey data to identify areas needing investigation.

8.6.5.1 Site Visit Planning

Review the assessment protocols in the US EPA *Energy Savings Plus Health Indoor Air Quality Guidelines* to identify locations to be inspected on site.

- Identify pertinent unknowns about the existing condition that could be discovered in a walkthrough, and record these in the Assessment section of the Cx Plan.
- Rearrange the order of the IAQ Assessment items in the Cx Plan Outline to make the best use of time on site.

Informative note: Per Normative Appendix T-2, Facility Requirements and Occupant Concerns related assessment is also part of the site visit planning.
As to site hazards, Assessment-phase work on site hazards is covered below in section 8.6.7.1 Site Hazard Risk Assessments, and does not necessarily require site visit. An on-site look at structural and seismic issues is part of the following Investigation phase, per section 8.7.6.2 Structural and Seismic Investigation.

8.6.5.2 Initial Modeling to Meet Performance Requirements

Review utility rate schedules and incentives from government and utilities that could benefit the project, for inclusion in the *ADORB cost* calculation.

Simulate the existing building according to the protocol in section 6.1 to determine its performance versus the resilience and *ADORB cost* metrics of section 6.3, 6.4, 6.5.

Begin modeling of retrofit upgrade packages with a view to determining a final post-retrofit configuration that meets the resilience requirements of section 6.3 and 6.4. See Informative Appendix P - retrofit package tiers.

Nominal/default PV system for initial modeling: 2 watts of rated power per square foot of roof area (22 W/m2), tilted latitude+15 degrees, facing south.

Determine at least one post-retrofit configuration that meets the performance requirements of section 6. Give each package or case a unique identifier.

Informative: Ground source heat pumps are not out of the question for retrofit and might be applicable to low rise multifamily buildings.

Record the results for the baseline and post-retrofit cases in the Assessment Report.

- Include energy end-use breakdown and *ADORB cost* component breakdown.
- Further break down the direct costs, per the budget categories for performance-related upgrades in Appendix T-6.

8.6.5.3 Retrofit Phase Plan for Performance-Related Measures

Review the decarbonization compliance paths and electives in section 6.5.2. Make an initial determination of which approaches to take, record them in the *CFR*, and capture any related Investigation actions in the Cx Plan.

In the Assessment Phase of the Cx Plan, include an initial strategic plan as to the sequence in which the performance-related upgrades will be implemented. Retrofit phases comprise sets of upgrades separated by periods of time during which the building is put fully back in service.

Informative note: It is preferable that envelope upgrades and other measures to reduce heating and cooling load are done before heating/cooling equipment changes. If not, the equipment should be sized for the final phase retrofit conditions, and if more capacity is needed prior to that, a plan for covering the extra load in the interim should be made. The controls should prioritize heat pump operation over combustion equipment operation.

If the phase plan involves replacing heating/cooling equipment prior to envelope upgrades and other load reduction measures, include rationale for doing so.

Ventilation (EPA issue 17) shall be addressed prior to, or in the same phase as, air-sealing.

Informative: More comprehensive planning that includes the upgrades to meet other requirements takes place in the Investigation phase.

8.6.5.4 *M&V* Plan

Make an initial plan to fulfill the minimum and elected *M&V* requirements (see section 7 and 8.6.4.2) for inclusion in the Cx Plan

8.6.5.5 Approach to Maintenance and Persistence of Benefits

Outline an approach to ensuring that improvements remain in place, as appropriate, over time - through training and putting mechanisms in place to regularly check the performance and the improvements.

8.6.5.6 Process Elective: Lessons-Learned Workshop

Consider conducting a lessons-learned workshop in the Hand-off phase, per section 8.10.6. Record the intent in the Hand-Off section of the Cx Plan.

8.6.6 Begin the *Systems Manual*

The *CxP* is to organize pertinent facility information received from the Owner in the format of the *Systems Manual*. See Appendix T-4. If information defined in Section 8.6.1 is incomplete, identify missing information and discuss the issue with the Owner.

8.6.7 Perform Assessment

8.6.7.1 Site-Hazard Risk Assessments

Informative: This section pertains to the requirements of section 5.2. Some of the assessments pertain to properties of the location rather than the building and do not require a site visit. But see also section 8.7.6.2 Structural and Seismic Investigation.

Determine the Seismic Design Category of the building location using FEMA's earthquake hazard map.
Alternatively, a licensed engineer experienced in geotechnical engineering can provide reassessment of the Seismic Hazard Score.

Follow FEMA P-154 - Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, Third Edition.

Determine the FEMA designated flood zone.
Informative: How to read a flood map

For pacific coastal areas, also determine the tsunami risk level according to FEMA. Figure 8.6-1 shows the overview map.

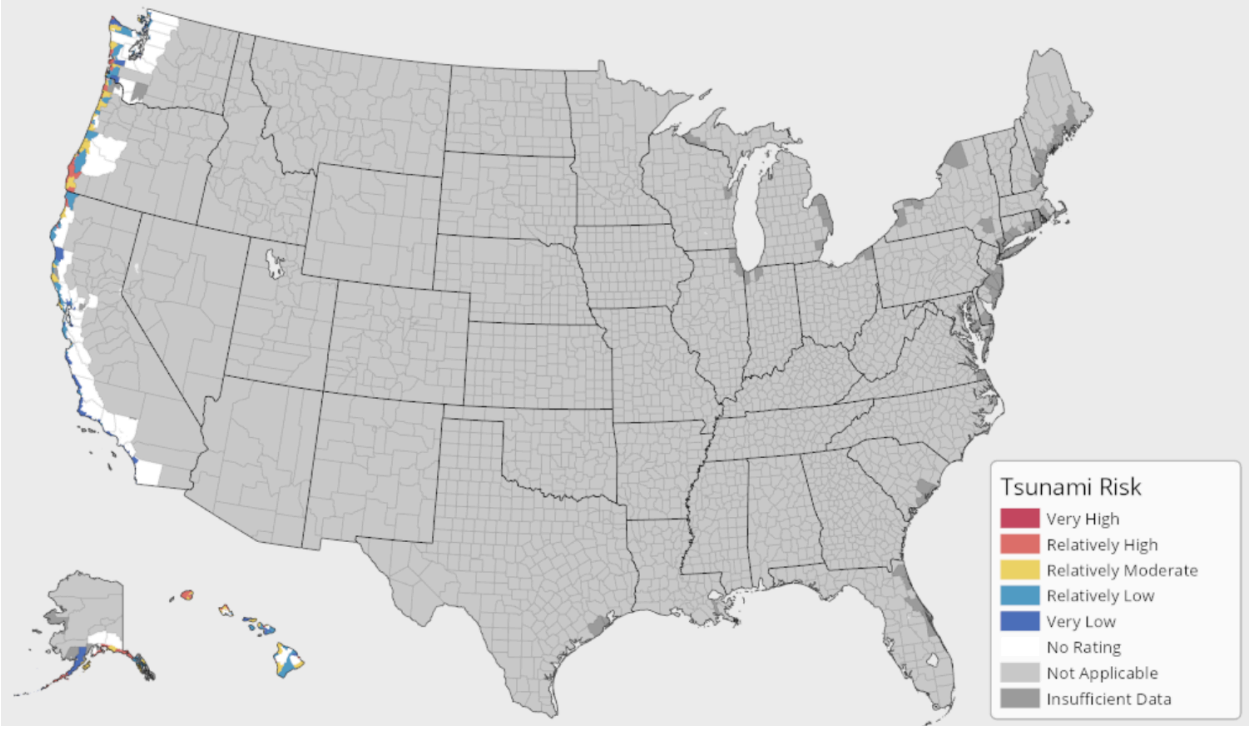


Figure 8.6-1 US FEMA National Risk Index map - tsunami overview.

Determine whether the project location is in a hail-prone county according to the map in Figure 1 of IBHS 2020 FORTIFIED Commercial Wind Standards, reproduced below as Figure 8.6-2

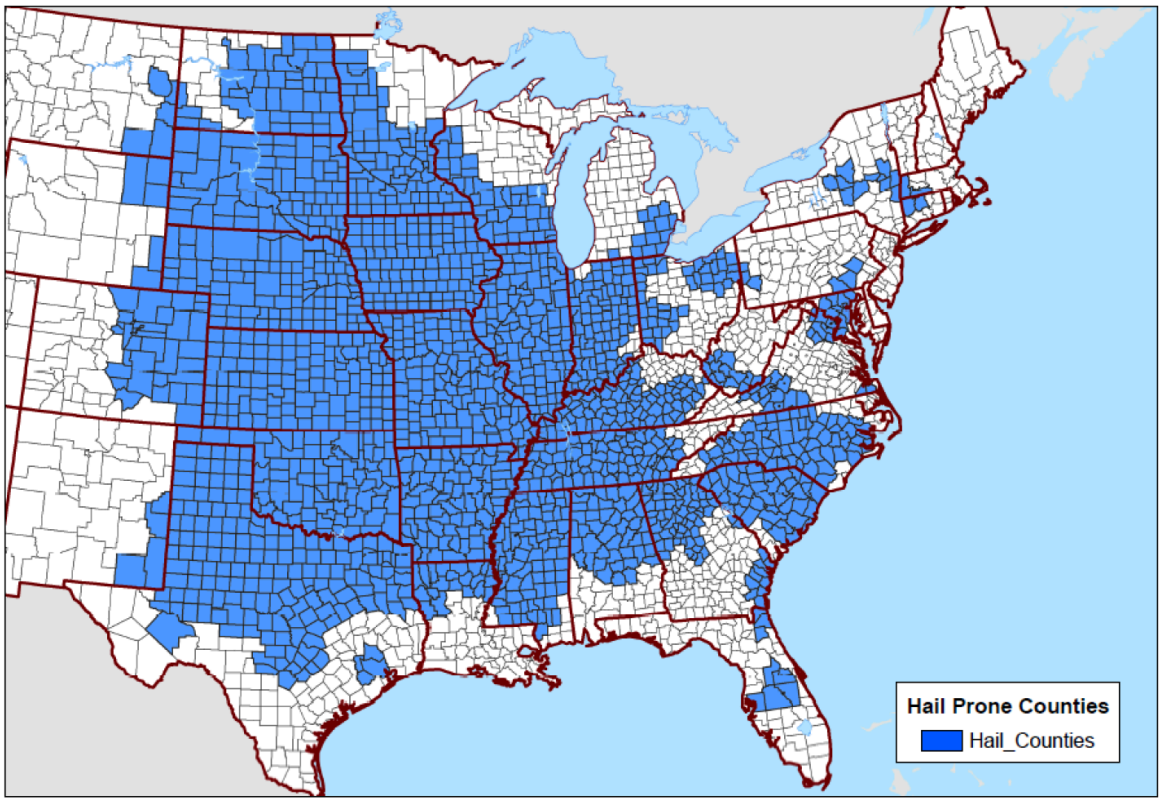


Figure 8.6-2 The hail-prone counties shown here are based on hail reports compiled by the Storm Prediction Center. Counties in blue are subject to a high frequency of damaging hailstorms with a maximum hailstone size of 1 in. or larger. Source: IBHS

Determine whether the project location is in a hurricane or special wind region according to Figure 2-1 of FEMA P-804, reproduced below as Figure 8.6-3

Use the Applied Technology Council online tool ATC Hazards by Location to determine design wind speed based on site address per ASCE 7-16, 7-10, and 7-05 (Refer to Risk Category II wind speeds):

Check local code requirements for wind speed as well, in case they differ from the wind speeds provided by the ATC website.
Informative: Appendix W summarizes some wind retrofit structural code compliance checks.

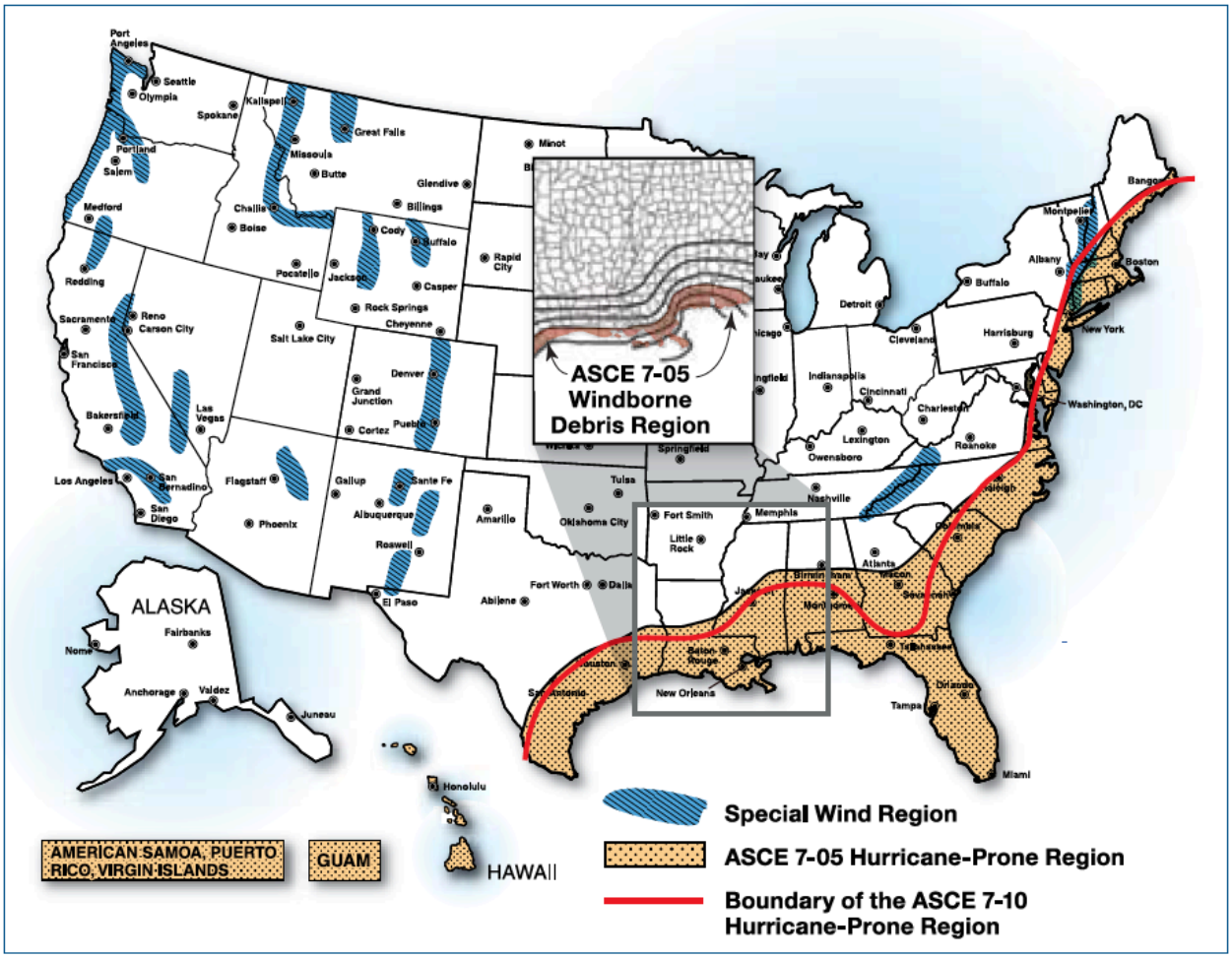


Figure 8.6-3 Illustration of the *hurricane-prone region* of the United States

Assess whether ice dam or snow load needs to be addressed, in light of the info from the FEMA P-957 Fact Sheet, particularly:

“If the roof drainage system is blocked, improperly designed or maintained, ice dams may form, which creates a concentrated load at the eaves and reduces the ability of sloped roofs to shed snow. On flat or low slope roof systems, snow melt may accumulate in low areas on roofs, creating a concentrated load.”

“Simple roofs with steep slopes shed snow most easily. Roofs with geometric irregularities and obstructions collect snow drifts in an unbalanced pattern. These roof geometries include flat roofs with parapets, stepped roofs, saw-tooth roofs, and roofs with obstructions such as equipment or chimneys.” Illustration from the FEMA P-957 Fact Sheet in Figure 8.6-4.

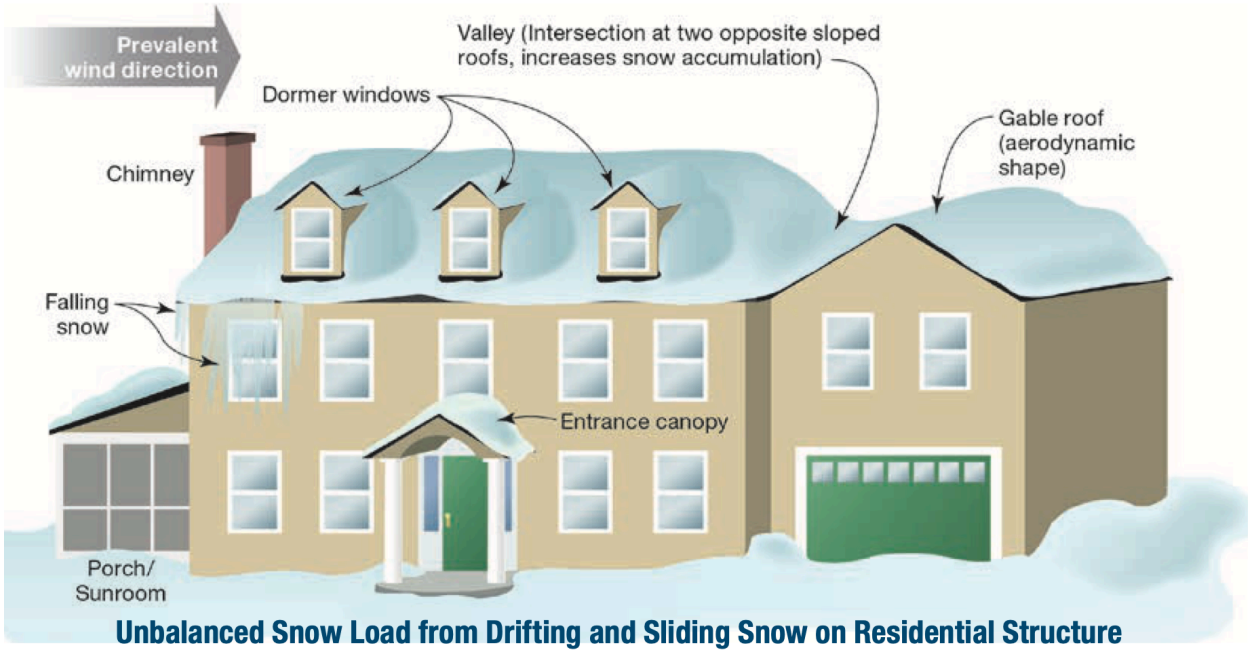


Figure 8.6-4 Unbalanced snow load from drifting and sliding snow on residential structure.

Determine the Wildfire risk level according to FEMA. Figure 8.6-5 shows the overview map. Use the Census Tract view in the interactive map unless that view shows No Rating, N/A, or Insufficient Data, in which case use the County view.

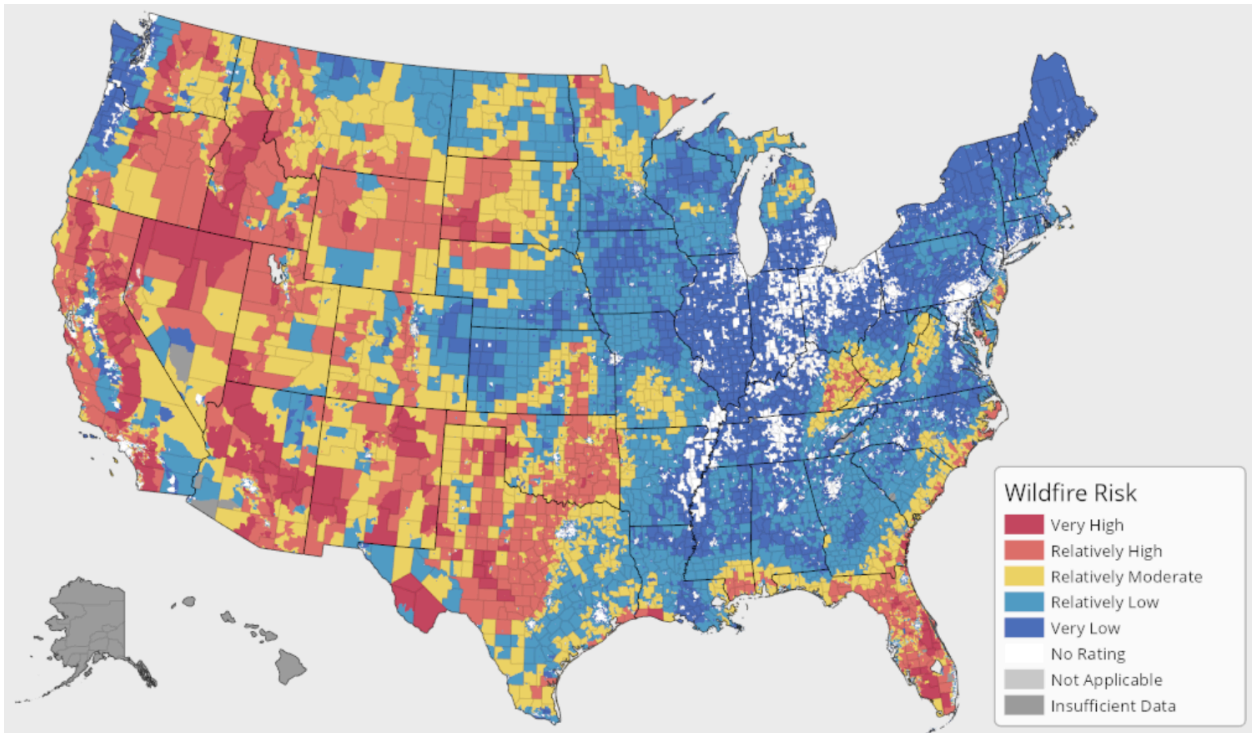


Figure 8.6-5 US FEMA National Risk Index map - wildfire overview.

8.6.7.2 Indoor Air Quality Risk Assessments

Informative: This section pertains to the requirements of section 5.1.

Visit the site and perform all the Assessment Protocols of the US EPA *Energy Savings Plus Health Indoor Air Quality Guidelines* that can be done in a walkthrough.

Capture assessments into the Assessment Report part of the Cx Report.

Capture items that need further attention in the Investigation Phase, into the Investigation Plan section of the Cx Plan.

8.6.7.3 Reserved

8.6.7.4 Issues and Resolution Log

Set up an Issues and Resolution Log. Include the following items (from ASHRAE SSPC 300 Informative Annex 11) in the Issues and Resolution Log:

a. Project title
b. Project location
c. Name of the *Commissioning Provider (CxP)* managing the Issues and Resolution Log, with e-mail address and phone number
d. Issue number
e. Issue description
f. Pictures of item if available and appropriate
g. Date issue discovered
h. Issue found by name
i. Effects of issue on project or building operation
j. Possible cause of issue or problem
k. Recommendation for resolution if available
l. Person(s) assigned to resolve issue
m. Actions taken
n. Approvals of issue resolution, including approver's name"

Informative: The CxP *maintains an issues log for commissioned systems. The general contractor typically maintains logs for RFIs and punchlist items on all systems (commissioned or not). There may be duplication between these logs, so finding a mechanism which reduces duplication while still allowing easy access to up-to-date information for all stakeholders is desirable. It is up to the Owner, the* CxP*, and the* Project Team *in general to decide how the various project elements requiring resolution are tracked, and by whom. All three types of document are commonly employed, and multiple instances of each may also be used.*

8.6.7.5 Update the *CFR* with Electives

Review the Expanded Actions in the EPA Energy Savings Plus Health Guidelines referenced in section 5.1, and make an initial determination of which ones to include in the *CFR*.

Review the hazard mitigation electives listed in section 5.2 and make an initial determination of which ones to include in the *CFR*.

8.6.7.6 Implement Immediate Improvements

Issues of safety, security, health, or operational issues, identified during the walkthroughs or discussions with building occupants or operating staff that can be easily remedied and that do not require further evaluation (i.e., will obviously not adversely impact other systems), are to be immediately implemented as the team develops the initial information on the facility. These modifications and actions shall be immediately documented and included in the Assessment Report.

8.6.8 Initiate Cx Report with Assessment Report

Use Normative Appendix T-6 as the framework for writing the Assessment Report.

8.6.9 Assessment Phase Deliverables

- *CFR*
- Cx Plan
- *Systems Manual* First Draft
- Cx Report, including the Assessment Report
- Issues & Resolution Log
- Updated Program plan (if applicable and affected)

8.6.10 Acceptance and Decision to Proceed

Submit the deliverables to the Owner, and to the *Authority* if so required. If they approve, the *Cx Team* proceeds to the Investigation Phase per section 8.7. If they do not approve, the *Cx Team* is to change the *CFR* and Cx Plan so as to resolve the comments.

8.7 Investigation Phase

Informative: The Investigation Phase consists of the detailed site investigation, which compares the actual building conditions and system performance with the Current Facility Requirements (CFR)*. Some issues that are discovered during the Investigation Phase can be corrected with minimal time and effort, do not require additional evaluation, and can be documented immediately. This phase concludes with the completion of the Investigation Report, which*

identifies scope and benefits of recommended facility modifications and improvements as well as the improvements already implemented during the Investigation.

8.7.1 Roles and Responsibilities

The Owner and the *CxP Team* shall work collaboratively to:

Resolve conditions impeding the execution of the Investigation Plan.
Resolve issues identified during the Investigation Phase.

8.7.1.1 Owner

a. Review the initial test procedures in the Investigation Plan with regard to changes in operating conditions and risks to Owner's property or production means.
b. Provide access to areas required to perform Cx Activities. If the *CxP* is required to be accompanied by the Owner's staff, that staff shall be dedicated to the *CxP Team* during the duration of Cx Activities.
c. Review field reports and Issues and Resolution Log, and attend meetings with the *CxP* to resolve conditions impeding the execution of the Cx Plan.
d. Review the Investigation Report and provide comments as appropriate.

8.7.1.2 *CxP Team*

a. Execute the investigation as defined in the Investigation Plan.
b. Develop project-specific test procedures.
c. Provide field and test reports on a weekly basis with the Issues and Resolution Log.
d. Provide regular progress reports as the Investigation Plan is executed, and identify conditions impeding the execution of the Plan.

8.7.2 Update the *Cx Team*

Identify personnel to compose the *Cx Team*.
Review roles and responsibilities of continuing team members.
Assign roles and responsibilities of new team members.
Include revised roles and responsibilities in the updated Cx Plan.

Informative: A structural engineer will often be needed.

Informative: Facility operating staff and service contractors can make the Investigation Phase more effective through their knowledge of the facility systems and assemblies. The knowledge gained by O&M *staff increases their ability to maintain persistence of benefits and encourages continued identification of performance enhancements during the* OCx *Phase.*

8.7.3 Update the *CFR*

If the *CFR* is older than one year, or if there are known changes since the *CFR* was developed, verify that the conditions on which the *CFR* was based are still valid. If the needs and requirements have changed since the initial *CFR* was prepared, update the *CFR*.

8.7.4 Review Facility Documentation

Review the documentation gathered during the Assessment phase to determine whether there are any additional documents or information required for the Investigation activities.

8.7.5 Update Cx Plan

Do the following activities and update the Investigation Plan part of the Cx Plan.

8.7.5.1 Reserved

8.7.5.2 Pre-Site-Visit Tests

Determine if any tests are required prior to the site investigations. Develop a list of pre-site-visit tests with written descriptions, who will do the tests, and when they will be completed.

8.7.5.2.1 Potential Disruptions

Identify any changes to the operational state of existing systems planned as part of the tests, and identify potential risks and disruptions.

8.7.5.3 Stakeholder Interviews

Describe the interviews to be conducted with facility stakeholders to augment direct investigation. Identify stakeholders to be interviewed and outline or script the interview procedures.

8.7.5.4 Reserved

8.7.5.5 Reserved

8.7.5.6 Develop Test Procedures

The *CxP Team* is to use information gathered during the Assessment Phase to create test procedures applicable to the scope of work. Include initial test procedures in the investigation plan and transmit them to the Owner for review.

The Owner is to propose modifications to test procedures if required by considerations of building access and security systems, disturbance of occupants, interactions with housekeeping staff, and shutdown of facilities.

Informative Appendix T-2.1 has forms for documenting the condition of equipment, and for writing test procedures.

8.7.5.7 Acceptance of the Investigation Plan

If the Owner approves the Investigation Plan and updated *CFR*, the *Cx Team* shall proceed with the investigation. If the Owner does not approve, the *Cx Team* shall resolve comments and obtain the Owner's approval.

8.7.6 Perform Site Investigation and Testing

Informative: Site investigation may not be a linear process. Often, multiple iterations are necessary due to new understanding of existing conditions that drive the team back to Assessment Phase activities.

Keep a list of deferred testing and investigation to remind the team of what may need to be completed after the bulk of the investigation is finished.

Implement and document immediate improvements to the operation of the facility to eliminate obvious issues so they do not mask underlying major issues, especially as they relate to achieving the *CFR*.

8.7.6.1 Indoor Air Quality Investigation

Perform all the Assessment Protocols of the US EPA *Energy Savings Plus Health Indoor Air Quality Guidelines* that require more than a walkthrough and were omitted from the Assessment Phase.

References to ASHRAE 62.2-2019 therein are to be read as 2019 or later.

Informative:
In the single family version, the first point under AP 17.2 Determine Whether the Home Meets Ventilation Requirements of ASHRAE Standard 62.2 *states:*

> *"Use ASHRAE 62.2-2019 Section 4 requirements **OR** Appendix A – Existing Buildings if local exhaust ventilation in bathrooms and kitchens is deficient. Blower door testing, and measuring fan flows (e.g., bathroom or kitchen exhaust) will be required."*

But in fact, the blower door testing required by ASHRAE 62.2-2019 is aimed at compartmentalization of attached dwelling units, and is not absolutely required - Appendix A refers back to section 6.1.1 where the blower door test appears for attached units, but there is a prescriptive air-sealing path in Appendix A itself. Section 4 does not absolutely require it, if no infiltration credit is being taken in the ventilation rate design.

The corresponding section in the multifamily protocol AP 18.2 Determine Whether Dwelling Unit Mechanical Ventilation Systems Meet ASHRAE Standard 62.2-2019 Requirements *states:*

> *"Determine whether the mechanical ventilation systems in dwelling units meet ASHRAE Standard 62.2-2019 requirements (**including** Appendix A for existing buildings). This includes…"*

In the multifamily EPA protocol, AP 16.2 Assess Spaces for Compartmentalization refers to ASTM E1186 as useful in guiding the assessment work. ASTM E1186-22 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems *covers several methods including:*

1. *Combined building pressurization / depressurization and infrared scanning*
2. *Building pressurization / depressurization and smoke tracers or theatrical fog*
3. *Building pressurization / depressurization and airflow measuring devices*
4. *Generated sound and sound detection*
5. *Tracer gas detection*

Methods 1, 3, 4 are preferred over the methods 2, 5 that introduce compounds into the air.

8.7.6.2 Structural and Seismic Investigation

8.7.6.2.1 Earthquake Hazard Investigation

For locations with an SDC of C through E, perform a simplified seismic assessment as described in FEMA P-50 *Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings*, and determine the Seismic Performance Grade, for building types within its scope (light-wood-frame single-family detached, duplexes and modular/panelized, but not manufactured housing.)

For buildings outside the scope of FEMA P-50, use one of the resources listed in Section 1.3 of FEMA P-154, quoted below in Informative Appendix S.

8.7.6.2.2 General Structural and High wind

For Single-family, Duplex, HUD manufactured, and Townhouses:

- Investigate to determine the alterations needed to comply with section 5.2.4.
- Do the code compliance checks listed in Table 5-1 of FEMA P-804, reproduced in Informative Appendix W.

For other buildings types follow a, b, or c below:

a. ASCE 11-99 - Guideline For Structural Condition Assessment Of Existing Buildings. A professional engineer must perform site inspections(s) to identify structural components that need retrofitting to meet minimum structural safety requirements.
b. FEMA P-424 - Design Guideline for Improving School Safety in Earthquakes, Floods, and High Winds, Section 6.6, Table 6-2, Checklist for Building Vulnerability of Schools Exposed to High Winds.
c. FEMA P-2062 - Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities.

8.7.7 Issues Analysis and Recommendations

Update the Issues and Resolution Log with identified issues and related recommendations.

Develop initial cost estimates for implementation.

Near the end of the Investigation phase, organize the major findings and recommendations requiring review and decisions from the Owner into a list. Derive this list from the Issues and Resolution Log.
Informative: Multiple issues may be addressed with one recommendation.

Include, in the list of findings and recommendations, only key information useful to the Owner in making decisions about the approach to meeting the *CFR* - additional information goes into the Investigation Report.

The *CxP* shall assist the Owner in narrowing the possible approaches to meeting the performance criteria, and the *CFR* overall, by selecting specific approaches for more information gathering or by removing approaches deemed undesirable by the Owner.

Include in the approaches any strategy for implementing the project in phases, that is, update the retrofit phase plan from section 8.6.5.3.

Also update:

- The *M&V* plan from section 8.6.5.4
- The approach to maintenance and persistence of benefits from section 8.6.5.5

Informative: The list prepared for the Owner serves as a tool that is updated through a refinement period during which approaches to meeting the performance criteria and electives are evaluated. This refinement period may include several iterations through the Assessment and Investigation phases.

Include in the list of findings and recommendations the *ADORB cost* breakdown.

8.7.8 Update Cx Report with Investigation Report

At the end of a review period during which the previous steps may be repeated iteratively, create an Investigation Report. The report contains the approaches that meet the *CFR* criteria and initial budgetary requirements.
Use the Investigation Report section of Normative Appendix T-6 to create the report.

8.7.8.1 New Discovery

In the event new information is discovered that requires more site investigation, the *Cx Team* shall further update the Cx Plan for investigation and the *CFR*, if necessary, and then proceed with activities needed to substantiate the new information and include it in the final Investigation Report.

8.7.9 Investigation Phase Deliverables

- Updated Cx Plan.
- Updated Cx Report including the addition of the Investigation Report.

8.7.10 Acceptance and Decision to Proceed

8.7.10.1 The Owner and *Authority* shall review the deliverables and unresolved issues from this phase and either accept them in total or make comments. The comments shall be addressed by the *Cx Team*.
Informative: The resolution of the comments may result in changes to the Cx Plan, CFR*, scope, and budget of the work.*

8.7.10.2 If the Investigation Report is acceptable to the Owner and the *Authority*, then the *Cx Team* will continue the process as described in the Cx Plan for the Implementation Phase.

8.7.10.3 If the Investigation Report is not acceptable, the Investigation Phase *Cx Team* shall, if possible, resolve the issues raised and resubmit the Investigation Report for the Owner and *Authority's* review. If the Owner decides not to proceed with the Implementation Phase for the specific facility just assessed, the process stops for this facility.
Informative: The CFR*, Cx Plan, Assessment Phase and Investigation Phase reports for the facility just assessed should be filed for future reference. If a Cx Program Plan was developed for multiple facilities, the Owner and* CxP Team *shall refer back to the Program Plan to determine the next facility to be assessed and begin the Assessment Phase for that facility.*

8.8 Design Phase

8.8.1 Select a Specific Approach

The *Cx Team* shall review the Investigation report and the Owner shall select a specific approach to meeting the performance requirements of this standard and the other requirements of the *CFR*.

8.8.2 Basis of Design

If the services of design professionals are involved, comply with ASHRAE Standard 202 Section 8 - Basis of Design, with the following Exceptions:

- Read "OPR" therein as *CFR* in the context of this standard.
- Clause 8.2.3c does not apply.

Informative: ASHRAE 202 Section 9 and ASHRAE SSPC 300 Informative Common Annex 07 concern the inclusion of requirements to cooperate with a Cx process in the contracts and specifications for Contractors, Suppliers, and Manufacturers. This is likely moot in the case that this standard is being enforced as a code. Otherwise, it might be appropriate to write such Cx specifications, referring to the process requirements of this standard, in the case of large or complex projects.

8.8.3 Design Review

Comply with ASHRAE Standard 202, Section 10 - Design Review, as amended below.

Exceptions:

- Regarding clause 10.2.2, the design review is considered a code or regulatory design review in the case that the standard is being used as a code.

8.8.1 Introduction. A *Commissioning* Process (Cx) Design Review shall be performed to evaluate compliance with the *CFR*.

8.8.2 Requirements

8.8.2.1 The *Authority* shall perform a review of the commissioned systems and assemblies in the design documents to evaluate compliance with the OPR. Cx Design Review shall be completed, and issues resolved, prior to the issuing of contract documents for systems being commissioned. The *CFR* and the Cx Plan shall define any sampling strategies for Cx Design Review.

8.8.2.2 The *Authority* shall conduct Cx Design Reviews, as contained in the Cx scope, and develop corresponding reports with comments, suggestions, clarifying questions, and observations in a Cx Progress Report to the Owner and *Design Teams* evaluating compliance with the *CFR*.

8.8.2.3 The *Cx Team*, and/or other responsible party shall respond to the Design Review report with necessary responses and agreed-to revisions to the project design documents. Revised documents shall be back-checked by the *CxP*. Any unresolved issues shall be reported to the Owner for direction to the design and *Project Team* on final disposition and direction.

8.8.2.4 A copy of the Cx Design Review reports and response shall be included in the final Cx Report.

8.8.3 Acceptance. The Owner and the *Authority* shall approve the *Design Team's* response to the Design Review report before the start of construction.

8.9 Implementation Phase

Informative: The objectives of the Implementation Phase are to execute the approach selected by the Owner from the Investigation reports, verify that performance meets the CFR*, and report the results of implementation.*

8.9.1 Update the *Cx Team*

Informative: Essential team members during the Implementation Phase include Owner's representatives, the CxP*, Owner's* operations and maintenance (O&M) *staff and any design professionals, and contractors or suppliers/vendors needed to implement the selected measures.*

8.9.1.1 Select Implementation Providers

Prepare a package of any selected measures that require design services or supply and installation by contractors.

Include the *Cx Team* in the preparation of requests for proposal (RFPs), development of electronic bids, or negotiations with contractors for services.

Define specific roles and responsibilities of any contractors, designers, and in-house staff for the implementation and verification of the selected measures, including any unique contract document requirements.

The *Cx Team* shall review any proposals and contracts for services and make recommendations on the selection of contractors and designers. The Owner shall make the final selection of the contractors and designers and establish the necessary contracts for services.

8.9.2 Create Implementation Plan 4.1

For each measure, the Implementation Plan includes the following:

a. Participants in the implementation and their roles and responsibilities
b. Schedule of implementation coordinated with occupants, security, housekeeping, utilities, etc., for schedule impacts, outages and shutdowns, etc.
c. Scope of work with details of the work, including
    1. method of implementation,
    2. work required for enhancing persistence (maintenance) in support of the *OCx*, and
    3. verification procedures and responsibilities

Informative note: Training is to take place in the Hand-Off Phase but, per Section 8.9.5.3.9 Training Documentation, there may be opportunities for training during implementation and verification and those should be documented if they occur.

8.9.2.1 Air-sealing

Air-sealing, to the level upon which compliance with the performance requirements of Section 5 and 6 is predicated, shall be included among the measures in the Implementation Plan.

8.9.2.2 Acceptance

The Owner shall review and accept the Implementation Plan prior to implementation.

8.9.3 Implement Selected Measures

Implement each of the selected measures. Update the Cx Report with the progress and results as they become available.

8.9.3.1 *Commissioning* Submittal Review

Comply with ASHRAE Standard 202 Section 11 - *Commissioning* Submittal Review, with the following Exceptions:

- Read “OPR” therein as *CFR* in the context of this standard.

8.9.4 Implementation Observation and Testing

Comply with ASHRAE Standard 202 Section 12.1 and 12.2 in Construction Observation and Testing, as amended below.

8.9.4.1 Introduction. The proper installation, coordination, testing, and interaction among commissioned systems and assemblies shall be evaluated by the *V&T Provider*.
8.9.4.2 Requirements
8.9.4.2.1 The systems and assemblies to be commissioned, identified in the *CFR* and Cx Plan, shall be confirmed to comply with the *CFR* and with the contract documents.
8.9.4.2.2 Checklists and test procedures with necessary report forms shall be developed after submittal approval and used during equipment or assembly installation. All completed checklists and test reports shall be included in the final Cx Report.

a. Project-specific construction checklists and testing procedures shall be established for review by the Owner and appropriate team members.
b. The test procedures shall list the entities responsible for executing each of the tests.
c. Whenever a test data result is required for a specific system or assembly, there shall be an item in the associated construction checklist for the test data to be submitted to the *Cx Provider (CxP)*.
d. Sampling procedures shall be used if required and defined in the Cx specifications.

8.9.4.2.3 There shall be a uniform and effective process for documenting the Cx testing of commissioned equipment, systems, and assemblies and their interactions. The term *Project Team* shall refer to applicable Cx technical resources tailored to their specific projects.
8.9.4.2.4

Implementation Kick-off Meeting. The *CxP* shall coordinate Cx Activities at the beginning of the construction process and at other times as necessary. After updating and creating the Cx Plan documents noted above, and prior to commencing actual implementation of the recommendations, the *Cx Team* shall conduct a kick-off meeting with the Owner's representative, *V&T Provider*, and any selected outside providers and/or contractors. The purpose of the meeting is to review the roles of each party, resolve any misunderstandings, finalize the schedule, and ensure the updated Cx Plan is as complete as needed by the Owner and the Authority. During the meeting the following shall take place:

a. Review the updated Cx Plan.
b. Review the specific roles and responsibilities of contractors or consultants and the Owner's in-house staff to clarify who will implement.

8.9.4.2.5 Evaluation of the systems and assemblies by the *Project Team* shall include the following:

a. Vital information on the equipment or materials being supplied. Information shall detail what equipment/material was specified and submitted. What was actually delivered on the site shall be documented and verified.
b. The condition of the equipment at the time it is delivered at the site and prior to its installation.

c. Proper installation of the systems and assemblies. Evaluation shall focus on the physical installation of the systems and assemblies, on their ability to meet the contract documents requirements, and on accessibility for Cx, testing, and maintenance operations.
d. Successful testing results of systems and assemblies.

Informative: Conducting site visits for verification. Periodically, appropriate Cx Team *members should visit the job site to verify installation of the selected measures. These visits provide an opportunity to identify issues early in the implementation that may not be able to be resolved later or cost more to resolve later.*

8.9.4.2.6 Executing Test Procedures

a. Once construction checklists and test procedures are established, the responsible entities shall execute relevant test protocols and repeat testing as necessary until equipment, systems, or assemblies being tested pass all tests.
b. The *V&T Provider* directs, witnesses, and documents the tests conducted by the *Project Team* as required by the Cx Plan.
c. Completed test reports shall be submitted to the *Project Team* for review and to the *CxP* for evaluation.

8.9.4.2.7 Any commissioned system or assembly that fails to meet requirements and that cannot be resolved in a timely manner shall be given an issue number and recorded in the Issues and Resolution Log to facilitate follow-up.
8.9.4.2.8 All checklists and test procedure results shall be compiled into the final Cx Report.

8.9.4.1 Enclosure Air-Tightness Testing

The post-retrofit whole-building air-tightness called for in the Implementation Plan shall be verified by one of the following methods:
ANSI 380
ASTM E779
ASTM E1827, two-point method.
ASTM E3158
ASTM E741
CAN/CGSB-149.10-2019, as-operated, guarded.
ZMPT
For the methods that involve testing the enclosure zone by zone, enough zones shall be tested to cover the entire enclosure.
The testing shall be done after any changes that affect the air barrier, such as fenestration changes and penetrations for pipes, ducts, and wiring, or the installation of sleeves for such penetrations.

Informative note: Only doing blower door compartmentalization tests might create an unsafe condition for occupants by disturbing asbestos-containing materials - driving it into neighboring units or pulling friable asbestos into occupiable space, from interstitial space. A whole-building pressurization test may mitigate risk of disturbing asbestos and migrating into occupiable space.

8.9.5 Update the Cx Documentation

8.9.5.1 *CFR*

Update the *CFR* to include any changes that occurred during the Implementation Phase.

8.9.5.2 Cx Plan

Upon completion of deferred and seasonal tests (if any), update the Cx Plan to include test procedures and results.

8.9.5.2.1 Updated Phase Plan

List measures to be implemented and *CFR* items to be addressed in later phases of the project.

8.9.5.2.2 *M&V* Documentation

Update the *M&V* Plan to point out which portions of the *M&V* requirements have been completed and what will be completed in the future.

8.9.5.2.3 Updated Maintenance Strategies

For each measure, include an updated strategy for persistence of the improvement (maintenance).

8.9.5.3 Cx Report

Update the Cx Report with the Implementation Report. Include the items described in sections 8.9.5.3.0 through 8.9.5.3.9 below:

8.9.5.3.0 Executive Summary

An executive summary of the measures implemented and those yet to be done in later phases of the retrofit project.

8.9.5.3.1 Updated List of Findings and Recommendations

An update to the performance analysis.
Informative: The final implemented recommendations may differ from the original recommendations due to conditions uncovered during the implementation process.

8.9.5.3.2 Reserved

8.9.5.3.3 New Discovery

If any new discoveries are made during Implementation activities, the *Authority* decides, based on *Cx Team* recommendations, if additional investigation work is required. If a discovery during implementation requires additional investigation, the process for this specific discovery begins at the Investigation Phase. If the *Authority* chooses not to

proceed with further investigation at this time, the item will be documented in the information transferred at hand-off.

8.9.5.3.4 Reserved

8.9.5.3.5 Test Documentation

Test procedures, documentation, and results. This includes the original test procedures and data forms, plus data such as photos, computerized documentation, and other records of the tests. Both the final accepted test and earlier tests that failed to meet the specified
criteria are to be included. Once deferred/seasonal testing is completed, the report shall be updated to include the deferred testing results.

8.9.5.3.6 Updated Issues and Resolution Log

The completed / updated Issues and Resolution Log with all issues discovered and addressed.
Informative note: Some issues may be addressed by deferment to the next retrofit phase.

8.9.5.3.7 Site Visit Records

Records of site visits and any significant reports and meeting minutes generated throughout the process.

8.9.5.3.8 Verification Documentation

Evaluations of the performance of the systems, equipment, and assemblies at the time of test completion, and the ability of the system to meet the *CFR*.

8.9.5.3.9 Training Documentation

Information on any Owner training that occurred during implementation and verification, including who attended, dates, length of time, training subjects, training materials, and trainer.

8.9.5.4 Owner Electives

In the Cx Report, list the elective *CFR* items that were to be addressed through Cx (from the Cx Plan), and the level to which those *CFR* items were achieved by the
end of the Implementation Phase. For any elective *CFR* items that were not fully achieved, describe why those items were not achieved and include recommended next steps.
Informative: This should supplement the verification documentation discussed in Section 8.9.5.3.8.

8.9.5.5 Updated *Systems Manual* Materials

Include with the Cx Report materials to update the *Systems Manual* in the Hand-Off Phase, per section 8.10.3. The *Systems Manual* is to be updated to include any new information for

components, assemblies, and systems that have been modified or installed as part of the implementation process.
Update the *Facility Guide* to include any changes to operating procedures that occurred during the Implementation Phase.

8.9.6 Implementation Phase Deliverables

- Updated Cx Plan
- Design Review Report and the *Design Team's* response
- Submittal Review Report
- Updated Cx Report, including the addition of the Implementation Report
- Updated *Systems Manual* materials

8.9.7 Acceptance and Decision to Proceed

8.9.7.1 Submit the deliverables to the Owner upon completion of each phase of the retrofit phase plan, and to the *Authority* upon completion of the final phase of the retrofit phase plan, and for any earlier retrofit phases for which the *Authority* requires review. The Owner and *Authority* shall review the deliverables and unresolved issues from this phase and either accept them in total or make comments. The comments shall be addressed by the *Cx Team*.
Informative: The resolution of the comments may result in changes to the Cx Plan, CFR*, scope, and budget of the work.*

8.9.7.2 If the Cx Plan and Implementation Report are acceptable to the Owner and the *Authority* then the team will continue the process as described in Section 9 - Hand-off. If either is unacceptable, the team shall discuss and, if possible, resolve the issues raised and resubmit the plan and report for review. Do not continue to the Hand-Off Phase until the Owner and the *Authority* have approved the Implementation work and its report along with the updated Cx Plan.

Informative: The Owner and team should evaluate the process used. Changes that could improve the process may be added to the Cx Plan. It is good to document issues, benefits, and process recommendations while the information is fresh in the minds of team members.

8.10 Hand-off Phase

Informative: The Hand-Off Phase is the transition between the Commissioning (Cx) Team and personnel responsible for operating and maintaining the facility until the next phase of the retrofit, or indefinitely into the future.

The objectives of the Hand-Off Phase are to provide the completed documents from the Cx to the Owner, provide training to the Owner's personnel, and to incorporate lessons learned from the Cx Process into the day-to-day O&M *procedures in the facility.*

The Systems Manual *and the* OCx *Plan are used in conjunction with the training of facility* operations and maintenance (O&M) *personnel and occupants to ensure the persistence of the benefits.*

8.10.1 Roles and Responsibilities

8.10.1.1 Owner's Responsibilities

a. Ensure *O&M* entity participation in training and use of the *Systems Manual*.
b. Verify that records are being kept for future evaluation of building performance.
c. Review monitored data analysis at least annually, and provide direction to the *O&M* entity.

8.10.1.2 *Cx Team* Responsibilities

a. Deliver the *Systems Manual*, and conduct training. Training shall include avoiding operation mistakes, modifications implemented, and associated reasoning associated with the modifications.
b. Conduct lessons-learned workshop/meeting (per section 8.10.6, if elected per section 8.6.5.6.)

8.10.2 Develop *OCx* Plan

The *OCx* Plan is the guiding document for how the facility's condition and performance will be monitored and evaluated, what systems or features will be included, what parameters will be tracked, and how deviations from the *CFR* will be corrected.

The *OCx* Plan shall address the following:
8.10.2.1 Establishing a scope of work that clearly defines the activities to be conducted, a schedule for when activities will take place, and what documentation will be provided.
8.10.2.2 Defining the roles and responsibilities of all team members and how communication will be routed.
8.10.2.3 The measures that remain to be implemented in later phases of the retrofit project.
8.10.2.4 reserved.
8.10.2.5 Maintaining the *Current Facility Requirements (CFR)* to reflect changes in use and operation of the facility.
8.10.2.6 Maintaining the *Facility Guide (FG)* to reflect changes in systems and assemblies due to renovation or in response to changes in the *CFR*.
8.10.2.7 Maintaining the *Systems Manual* to reflect changes in the *CFR*, *FG*, and systems/assemblies.
8.10.2.8 Monitoring and evaluating system performance regularly to verify compliance with the *CFR* and against previously established benchmarks.
Informative: For example, through review of occupant satisfaction surveys, trend logs, complaint logs, service tickets, and utility use. The CFR *or* M&V *plan should include all such benchmarks.*
8.10.2.9 Describing procedures necessary to maintain the building.

8.10.2.10 Ongoing training of *O&M* personnel and occupants on the current *CFR* and the current systems/assemblies.
8.10.2.11 Defining the process and procedures necessary for satisfying the *measurement and verification (M&V)* requirements.

Informative: Guidance appropriate to single-family homes can be found in the Healthy Homes Maintenance Checklist from the National Center for Healthy Housing.

It has the following sections:

- *Yard and Exterior*
- *Garage*
- *Exterior Roof, Walls, and Windows*
- *Basement and Crawlspace*
- *Attic*
- *Interior Walls, Ceilings, Windows, and Doors*
- *HVAC Equipment filters*
- *Plumbing and Fixtures*
- *Appliances*
- *Electrical Equipment*

8.10.3 Assemble *Systems Manual*

Comply with Section 14 of ASHRAE Standard 202, as amended below:

8.10.3.1 Introduction. The *Systems Manual* documentation shall be provided to the Owner for use in building operation and the training of personnel.
8.10.3.2 Requirements
8.10.3.2.1 The *Systems Manual* shall provide the information needed to understand, operate, and maintain the building's systems and assemblies.
8.10.3.2.2 The *Systems Manual* is the repository of design, construction, and testing information, including updates and corrections to systems and assemblies as they occur during construction. The *Project Team* shall be responsible for updating the *Systems Manual* during Cx, including design, construction, and operation as required in the OPR, Cx Plan, and contract documents.
8.10.3.2.3 The following shall be included in the *Systems Manual*: see Normative Appendix T-4.
8.10.3.3 Acceptance
8.10.3.3.1 The contents of the preliminary *Systems Manual*, Sections 2 through 4 of Appendix T-4, shall be reviewed and evaluated by the *CxP* prior to training of *O&M* personnel and occupants.
8.10.3.3.2 The Owner shall approve the final *Systems Manual* for use in building operations.

8.10.4 Train Facility Personnel

Comply with Section 15 of ASHRAE Standard 202, as amended below:
8.10.4.1 Introduction. The *operations and maintenance (O&M)* personnel and occupants shall be trained on the systems being commissioned, in accordance with the *CFR*, to operate and maintain the building systems and assemblies. The training plan is considered an essential element in designing, preparing, and delivering the training to the participants.
8.10.4.2 Requirements
8.10.4.2.1 The training plan shall include the following items:

a. Level of training for *O&M* staff, emergency response personnel, and occupants.
b. Outline of instructional topics related to the systems, subsystems, equipment, and assemblies. These topics shall address the design, construction, operation, and maintenance of specific systems, assemblies, and equipment.
c. Learning objectives and training delivery methods for each instructional topic.
d. The planned location of the training sessions (classroom, on site, and off site) and the minimum duration of each training session, in hours, to be completed as required in the OPR, Cx Plan, or contract documents.
e. Instructor's qualifications.
f. Training materials requirements to be employed during the instructional process.
g. Training report, records, and recording requirements.

8.10.4.2.2 Archival of instruction, delivery of instruction, and training materials shall be provided as specified in the contract documents and per the *CFR*. A copy of the training plan, training materials, and records shall be included in the final *Systems Manual* as shown in Section 14 of ASHRAE Standard 202.
8.10.4.3 Acceptance
8.10.4.3.1 The training plan, the execution of the training plan, and the delivery of instruction shall be reviewed for acceptance by the *Cx Provider (CxP)* and Owner. The training plan shall be submitted and accepted prior to the delivery of any instruction. Evaluation or survey of the participants shall be as defined in the *CFR* and contract documents.

8.10.5 Reserved

8.10.6 Conduct Lessons-Learned Workshop

If elected by the Owner per section 8.6.5.6, conduct a lessons-learned workshop after the completion of the training and the update of the *Systems Manual.*

Informative: The lessons-learned workshop typically includes all of the key participants and stakeholders of the Cx Process. The lessons-learned workshop provides a forum for the Cx Team *to discuss issues impacting the* O&M *of the facility and to discuss knowledge gained during the implementation of the measures. The discussion should examine both the execution of the Cx Process and the methods and issues found that affect facility operation. The intent of the discussion is to determine improvements in both the Cx Process and facility operations. Because the meeting includes all key stakeholders, the lessons-learned workshop can also be an opportunity to recognize the contributions of individual* Cx Team *members to*

the success of the Cx Process.

See ASHRAE Guideline 0.2, Informative Annex L6, for suggested list of invitees, agenda, list of documents for distribution before the workshop, and outline of the workshop report.

8.10.6.1 Lessons-Learned Report

Document the results of the lessons-learned workshop in a Lessons-Learned Report, which will help to facilitate the transfer and retention of knowledge gained during the Cx Process. Make recommendations to support the *OCx* efforts of the facility, to update the Cx Program Plan and approach for a multiple-facility effort, and improve all future *commissioning* efforts at the facility.

8.10.7 Finalize Cx Report

8.9.7.1 Update the Cx Report to include the final Lessons-Learned Report (if any) and to reflect any necessary changes to the Cx Program Plan and *OCx* Plan.
8.9.7.2 Update the Cx Report to include the final training documentation and verification.

8.10.8 Provide Project Documents to Owner

8.10.8.1 Transfer the completed Cx Report, the *OCx* Plan, and the *Systems Manual* to the Owner. Request the acceptance by the Owner of: these documents, and the improvements implemented.
8.10.8.2 Provide for distribution of the *M&V* Reports to be submitted for approval. The document shall be reviewed with the Owner and operations staff to ensure that the required instrumentation and data collection remain in place in accordance with the *M&V* Plan.

8.10.9 Hand-Off Phase Deliverables

- Cx Report, including addition of the Lessons-Learned Report, if elected.
- *Systems Manual*.
- *OCx* Plan.

8.10.10 Acceptance and Decision to Proceed

8.10.10.1 The Owner and the *Authority* review the deliverables and any unresolved issues from this phase and either accept them in total or make comments.
8.10.10.2 If the Cx Report, *OCx* Plan, and *Systems Manual* are acceptable, then the process will continue as described in Section 8.10.
8.10.10.3 If the Cx Report, *OCx* Plan, or *Systems Manual* are unacceptable, assemble the Hand-Off Phase team to discuss and, if possible, resolve the issues raised and resubmit the plan for review by the Owner and the *Authority*.
8.10.10.4 If neither the Owner nor the *Authority* require proceeding with the *OCx* Phase for the specific facility just commissioned, the Cx Report with all phase reports shall be filed for future reference and the process stopped for this facility.

8.10.10.5 For multiple facilities, refer to the Cx Program Plan to determine the next facility to be assessed and begin the Assessment Phase on that facility.

8.11 *Ongoing Commissioning* Phase

8.11.1 Introduction

The *Ongoing Commissioning* (*OCx*) Phase consists of Cx Process activities that repeat continuously throughout the life of the facility subsequent to the Hand-Off Phase.

The overall objective of the *OCx* is to ensure that the benefits obtained from the Cx and any other building improvements are sustained over time. *OCx* involves performing critical elements of the process repeatedly over a series of cycles with periods typically lasting from months to years.

Informative:
For each facility, the capabilities of the internal facility staff, service contractors, and the nature of the relationship with external professionals, commissioning *contractors, and Cx Process providers are unique. Further, over time, people move in and out of positions, and the structure of the organization changes.*

8.11.2 Assemble the *OCx Team*

8.11.2.1 Reserved

8.11.2.2 Assign responsibility for *OCx* activities in the initial *OCx* Plan. Establish a high-level executive responsible for overall management of the *OCx*. Include staff responsibility assignments for the initial cycle as well as when the organization's structure changes or as staff members' responsibilities change.

8.11.2.3 *OCx* is led by a *Commissioning Provider (OCxP)*. This phase shall be carried out by personnel acceptable to the *Authority*.

Informative: The OCxP *may be a different person than the* CxP *for the previous phases of the Cx.*

8.11.2.4 The *OCx Team* shall include, at a minimum, an Owner’s Representative and an *OCxP*.

Informative: Consider including stakeholders from a variety of levels of responsibility in the organization or leased-property occupants. Increased participation increases the accuracy and scope of the guidance for the OCx*.*

8.11.3 Update the *OCx* Plan

The *OCx Team* shall

- Review The scope of activities in the *OCx* Plan to determine whether assigned resources have the time and skills needed for each activity.
- Review and update the frequency of activities in the *OCx* Plan.

The *OCx* Plan shall clearly define the measures that remain to be implemented in later phases of the retrofit project.

8.11.4 Verify Achievement of *CFR*

8.11.4.1 Reserved.

8.11.4.2 Monitor the actual condition or performance of the defined parameters during the *OCx* to provide feedback to the *OCx Team* of any deviations that may require action.

8.11.4.3 The tracked information shall be consistent with the requirements of the chosen or required *M&V* Plan.

8.11.4.4 Review the *M&V* Plan at regular intervals. If it is determined that certain key parameters necessary to properly monitor the condition or performance of the facility are missing from the *M&V* Plan, revise the *M&V* Plan accordingly.

8.11.5 Investigate Unacceptable Performance or Outcome

8.11.5.1 Whenever there are significant deviations from the *CFR* baseline or parameters, identify the root cause of the unacceptable performance. Section 8.7 of this standard addresses the investigation methodology.

8.11.5.2 Reserved.

8.11.5.3 Maintain the Issues and Resolution Log to track and record issues.
Informative: The Issues and Resolution Log used during this phase can be similar to the Issues and Resolution Log used in previous phases.

8.11.5.4 Once findings and recommendations are identified, they are listed on the Issues and Resolution Log, including any estimated costs and associated benefits that the action will provide. Recommendations shall include methods to maintain the benefits of the performance and improvements made during the Cx.

Informative: In cases where the corrective action is simple, the action should be taken immediately on clearance from responsible operations staff. For other, more complex issues, the nature of the problem and the recommendation may need to be reported to the Owner for approval.

8.11.6 Implement Recommendations

8.11.6.1 Establish a plan for implementing the recommendations, including schedules and responsible parties. Implement the recommendations in accordance with that plan. Verify the action and its effect on the facility.

Informative: It is important that the recommendations are implemented carefully, understanding that actions can often interact with one another. If multiple recommendations are implemented at one time or in a close timeframe of one another, it may become difficult to distinguish the interrelation and interaction of one action and another.

8.11.6.2 Develop relevant documentation for the *OCx* Report once the recommendations have been implemented and verified. Include any lessons-learned discussion that may prevent a recurrence of the issue. This documentation shall include quantitative comparisons of the benefits tracked in comparison with those predicted and in comparison with the acceptable performance. Note any excess or shortfalls in benefits measured.

8.11.6.3 With the facility personnel, develop a plan for maintaining the persistence of benefits related to the implemented recommendations.

8.11.7 Update *Systems Manual*

8.11.7.1 Review the facility *Systems Manual* at least annually to ensure all information is current.

Informative: The Facility Guide *section of the* Systems Manual *should be updated with key performance parameters and facility operating procedures whenever they are changed.*

8.11.7.2 Changes to the *CFR* will eventually arise due to changes in occupancy, use, or remodeling. Document the impact of these changes in the *Systems Manual* and *Facility Guide*.

8.11.8 Update Facility Personnel Training

Informative: Facility personnel training requirements will continue to evolve due to facility changes, operational changes, staff turnover, changes to regulatory factors, facility equipment, or overall facility function.

8.11.8.1 Make regular updates to any formal training program, and conduct training and retraining throughout the *OCx* Process, as needed to allow the *CFR* to be achieved.

8.11.8.2 Discuss with *O&M* Staff all operator-error items identified during fault correction, as lessons learned.

8.11.9 Write/Deliver *OCx* Report

8.11.9.1 Introduction

The *OCx* Report is used to document at regular intervals the performance of the facility and success of the OCx Program. The report shall include the following:

a. Any recommendations that will assist the *O&M* staff to maintain the persistence of building performance, particularly for improvements implemented during the *OCx* Process.
b. Measured verification results over the current *OCx* period.
c. Corrective actions taken and lessons learned.
d. Updates to facility training programs and training conducted based on changes to the facility, staff turnover, or lessons learned.
e. Any updated acceptable performance parameters from the *Authority*.
f. Any improvement recommendations accompanied by estimated costs.
g. The level to which the elective *CFR* items have been achieved.

8.11.9.2 The *OCx* Report shall include the current results of the *M&V* Plan. If the *OCx* requires compliance with an elective *M&V* protocol, the material in the *OCx* Report shall be consistent with the requirements of the *M&V* Plan and be produced and submitted under separate cover.

8.11.9.3 The report shall be submitted at least annually, accompanied by appropriate updates to the *OCx* Plan, *CFR*, *Systems Manual*, and Issues and Resolution Log. Present any issues and recommendations requiring evaluation and selection by the Owner for implementation in the form of a list of findings and recommendations, as discussed in Section 8.7.

8.11.10 *OCx* Phase Deliverables

- Updated *OCx* Plan
- Updated *Systems Manual*
- *OCx* Report (made periodically)

8.11.11 Acceptance

Submit the deliverables to the Owner, and to the *Authority* if so required. If the *OCx* Report is acceptable to the Owner and the *Authority*, then the team shall continue the process into the next cycle.

If the *OCx* Report is unacceptable, determine what the issues are and take corrective action before resubmitting the *OCx* Report.

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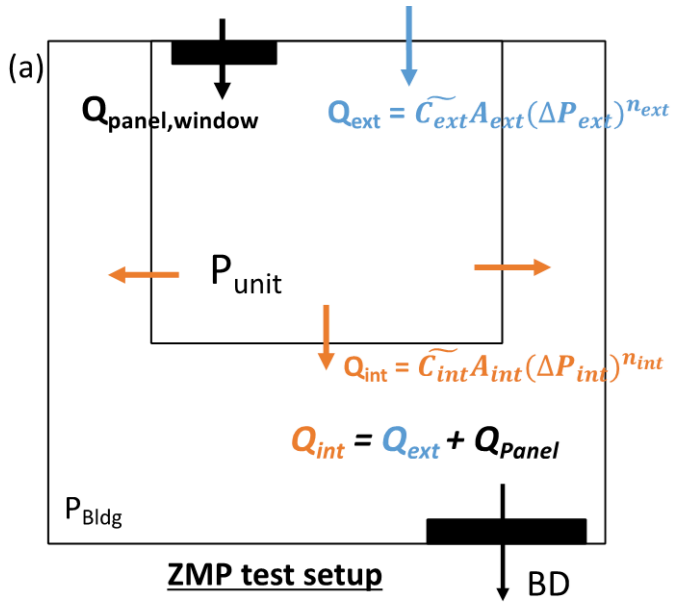
Figure errata:

$$f_i(\vec{x}) = \widetilde{C_{ext}} A_{ext} (\Delta P_{ext,i})^{n_{ext}} + Q_{p,window,i} - \widetilde{C_{int}} A_{int} (\Delta P_{int,i})^{n_{int}} = 0 \quad (1)$$

$$f_i(\vec{x_j})_k + \left[\frac{\partial f_i}{\partial x_j}\right]_k \overrightarrow{\delta x_j} = \vec{b} + J\overrightarrow{\delta x} = 0 \quad (2)$$



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Normative Appendix A – *ADORB Cost* Calculation Method

Informative note: The convention in this appendix is that equals signs "=" indicate calculation formulas and the words "is / are" indicate definitions of the symbols in the formulas.

ADORB = PV/N, where
N is the analysis period [years]. # Per section 6.4.1.1. See also ytt below.
PV is the overall present value [$].

PV = sum over i of PV_i,
where the cost_component i is one of
{dirEnr, # direct energy cost
opCarb, # cost of carbon (operating)
dirMR, # direct maintenance / refit cost
emCarb, # cost of carbon (embodied)
eTran} # cost of energy transition

PV_i = sum over y from 1 to N of C_i_y / (1+k_i)^y , where
C_i is the cost, of cost_component i [$].
k_i is the discount rate for cost_component i [fraction 0 to 1].
k_dirEnr = 0.02
k_opCarb = 0
k_dirMR = 0.02
k_emCarb = 0
k_sysTran = 0.02
y is the year, counting from the current year = 1, that is, the future calendar year minus the previous calendar year.

And, for yearly time resolution:

C_dirEnr_y = Eg_y * Pg_y + Ee_y * Pe_y, where

Eg_y is the Annual gas energy use [therm/yr] in year y.
Ee_y is the Annual site electrical energy use [kWh/yr] in year y.
Pg_y is the Gas price [$/therm] in year y
Pe_y is the Electricity price [$/kWh] in year y

C_opCarb_y = Pc * M_op_y, where

Pc is the Carbon price [$/kg].
Pc = $0.25/kg # Direct air capture

M_op_y is the Annual operating emissions [kg] in year y.
M_op_y = Mg_op_y + Me_op_y
Mg_op_y is the gas emission [kg] in year y.
Me_op_y is the elec emission [kg] in year y.

Mg_op_y = Eg_y * Fg
Me_op_y = Ee_y * Fe_y
Eg_y is the gas energy consumption [therms] in year y.
Ee_y is the electrical energy consumption [kWh] in year y.

Fg is the gas emission factor, taken to be constant
Fg = 12.7 kg/therm # Energy Star Portfolio Manager Technical Reference

Fe_y is the electrical emission factor [kg/kWh] in year y.
For national average electrical emission factor:
if y=1 then
    Fe_1 = 0.433 kg/kWh # Energy Star Portfolio Manager Technical Reference
else # y>1
    Fe_y = max(0,Fe_(y-1) - Fe_1/(grid decarb year - this year)) # Linear glide path

For hourly time resolution:

Me_op_y = sum over the hour from 1 to 8760 of Ee_hour * Fe_hour_region_y

hour is the hour of the year.
region is the NREL Cambium GEA region in which the building is located.
Ee_hour is the electrical energy consumption for the hour [kWh].

Fe_hour_region_y is a long-run marginal emission factor from the NREL Cambium workbook (LRMER) for GEA regions (Gagnon et al 2022), with the following settings:

- Emission - CO2e
- Emission stage - Combined
- Start year - 2023+y
- Evaluation period - 1 years
- Discount rate (real) - 0
- Scenario - 95% decarb by 2050
- Global Warming Potentials - 100-year (AR5)
- Location - End-use

(See Levelized LRMER tab, row 350+, check units and convert to kg/kWh if necessary.)

C_dirMR_y is the cost of all the maintenance or retrofit items occurring in year y.
C_dirMR_y = sum over individual cost items in these categories:

C_dirMR_y =

+ ENV_y # Envelope
+ HVAC_y # HVAC
+ DHW_y # Hot water
+ APL_y # Major appliances, builder-installed.
+ LITE_y # Lighting
+ … continues below

Alternate: It is recommended that the more detailed breakdown of the five hard costs above follows the structure of NREL's Residential Efficiency Measures Database. Its high-level categories are as follows:

AirLeakage
MechanicalVentilation
AppliancesFixtures
CeilingsRoofs
FoundationFloors
Lighting
SpaceConditioning
Walls
WaterHeating
WindowsDoorsSkylights

+ …
+ GEN_y # PV/Battery/Generation

+ CX_y # *Commissioning*, Testing, Inspection
+ PERF_y # Other performance-related
+ IAQ_y # Indoor air quality related
+ HAZ_y # Hazard mitigation related
+ IN_y # Other in-scope
+ OUT_y # Other out-of-scope

+ INC_y # Incentives
+ TAX_y # Tax credits

For items that do not have a replacement interval,

C_dirMR_item_y = Cinitial_item
Cinitial_item is the initial cost of the item [$].

For items that have a replacement interval,
C_dirMR_item_y = Cinitial_item*Flag, where
If (y + repIntv_item - remLife_item) modulo repIntv_item < 1 then
Flag = 1 else Flag = 0

repIntv_item is the replacement interval of the item [years].
remLife_item is the presently remaining life of the item [years].

Note: setting remLife_item to 1 (not zero) in this formula will make the cost happen in year 1.

For Level 1 embodied carbon calc (national emissions intensity based):

Right now there is no decarbonization glide path applied to embodied emissions (i.e. of recurring equipment replacements).

C_emCarb_y = (emMat_y + emLbr_y)*Pc
emMat_y is the embodied emissions due to the material items in year y [kg]
emLbr_y is the embodied emissions due to domestic / installation labor of the items in year y [kg]

emMat_y = sum, over the project retrofit and maintenance items, of emMat_item_y
emMat_item_y is the embodied emissions of the material item [kg].

emMat_item_y = C_dirMR_item_y * (1-LF_item_y) * EF(CoO_item_y)
LF_item_y is the fraction of install labor in C_dirMR_item_y [fraction 0 to 1].
EF(country) is the national emission factor of a country [kg/$].
CoO_item_y is the country of origin for the item occurring in year y.

EF(country) = CO2_country / GDP_country * 1000
CO2_country is the annual CO2e emissions from the country [Megatons].
GDP_country is the annual gross domestic product of the country [USD millions].

EF, CO2 and GDP data for the top 15 US trading partners is shown in Table 1.

emLbr_y = sum, over the project retrofit and maintenance items, of emLbr_item_y
emLbr_item_y is the embodied emissions due to labor, of the item occurring in year y.

emLbr_item_y = C_dirMR_item_y * LF_item_y * EF(COPL)
COPL is the country of the project location / building site.

Table 1. Annual CO2 emissions and GDP of US and top trading partners.

Country	US trading rank	GDP [USD millions]	CO2 [MT]	EF [kg/$]
USA	-	20,936,600.00	4900	0.234
Canada	3	1,643,407.98	565.2	0.344

Country	US trading rank	GDP [USD millions]	CO2 [MT]	EF [kg/$]
China	1	14,722,730.70	9500	0.645
France	15	2,603,004.40	303.5	0.117
Germany	5	3,806,060.14	696.1	0.183
India	10	2,622,983.73	2300	0.877
Ireland	8	418,621.82	35.3	0.084
Italy	12	1,886,445.27	317.1	0.168
Japan	4	5,064,872.88	1100	0.217
Korea, South	7	1,630,525.01	605.8	0.372
Malaysia	13	336,664.44	228	0.677
Mexico	2	1,076,163.32	448.5	0.417
Switzerland	11	747,968.64	35.7	0.048
Taiwan	9	668,510.00	276.7	0.414
United Kingdom	14	2,707,743.78	352.4	0.130
Vietnam	6	271,158.44	226.5	0.835

For level 2 embodied carbon calc (itemized carbon reduction credits)

The formula for C_emCarb changes to:
C_emCarb_y = (emMat_y + emLbr_y - L2mC_y)*Pc,
where L2mC_y is the Level 2 embodied carbon credits for year y [kg]. That is, the Level 2 calc is an adjustment to the Level 1 calc rather than a replacement for it.

L2mC_y = L2mCbizMat_y + L2mCperson_y
L2mCbizMat_y is the embodied carbon credit from Business Process and Materials choices in year y. [kg]
L2mCperson_y is the embodied carbon credit from Personal choices in year y. [kg]

L2mCbizMat_y = sum over g of the carbon credit items L2mCbizMat_g_y
L2mCperson_y = sum over persons p of the carbon credit items L2mCperson_p_y

L2mCbizmat_g_y is an embodied carbon credit item g in year y. [kg]
L2mCperson_p_y is an embodied carbon credit from person p in year y. [kg]

L2mCbizmat_g_y = BAUintens_g_y * BAUqty_g_y - PROJintens_g_y * PROJqty_g_y

BAUintens_g_y and PROJintens_g_y are the business-as-usual and project-chosen carbon intensities respectively, for item g. [units vary but are of the form kg per quantity].
BAUqty_g_y and PROJqty_g_y are the corresponding quantities. [units vary among the items g].

L2mCperson_p_y = IncomeFrac_p_y * Tons_p_y * 1000 * %better_p_y

IncomeFrac_p_y is the fraction of person p's annual income that comes from the project in year y.
Tons_p_y is the tons of CO2e per year, and %better_p_y is the percent better than average, for person p, according to the Berkeley CoolClimate calculator.

C_eTran_y = TCF_y * PkPwr_y * 1000, where
TCF_y is the transition cost factor for year y. [$/Watt.yr]
PkPwr_y is the peak electrical power used by the building in year y. [kVA]

```
if y > ytt, then
        TCF_y = 0
else
        TCF_y = NTCF / ytt    #linear transition
```

ytt is the number of years to transition. Use 2050 minus the current year.
NTCF is the national transition cost factor [$/W]

NTCF = NTC / (NNCI * 1e9)

NTC is the national transition cost [$].
NNCI is the required national nameplate capacity increase (of carbon-free generation) [GW].

For the US,
NTC = $4.5e12
NNCI = 1600 GW

pkPwr_y is calculated by detailed hourly simulation, or by the following simplified method:

Simplified method for baseline cases:

basePkPwr_y = Pavg * PAM_tmy3

Pavg is the current average power consumption [kW].

PAM_tmy3 is a peak over average multiplier for the TMY3 location appropriate for the project location, according to the Open Energy Data Initiative (OEDI).

Simplified method for post retrofit cases:

postPkPwr_y = basePkPwr_y * Elif
Elif is an electrification multiplier [dimensionless]

Elif = (oldCkts + newCkts)/oldCkts
oldCkts is a power rating based on the existing electrical circuits in the building with diversity factors applied. [kVA]
newCkts is a power rating for new electrical circuits with diversity factors applied. [kVA]

oldCkts = sum over k of ckt_k
k is the number of existing circuits.
ckt_k = Voltage_k * Amperage_k * div_k / 1000
Voltage_k is the nominal circuit voltage e.g. 120, 240 [V].
Amperage_k is the circuit breaker / fuse rating of the circuit, e.g. 15, 30 [A].

div_k is the diversity factor according to circuit function, see Table 2. Set the factor to zero for any existing circuits that will be removed.

Table 2. Suggested load diversity factors by circuit function.

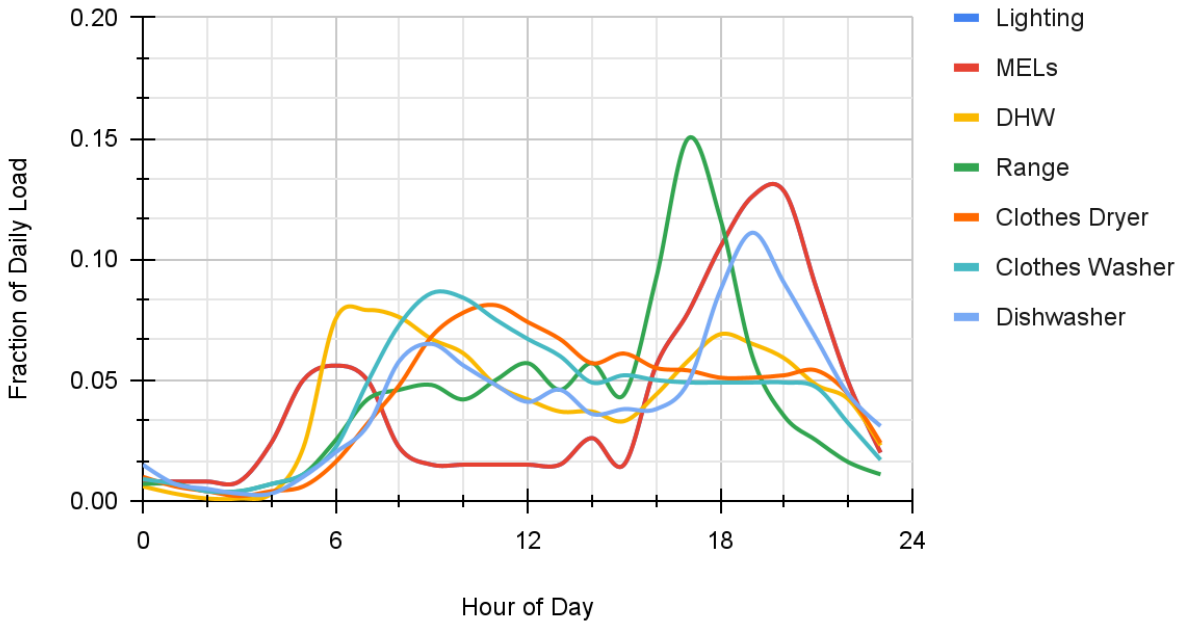
Circuit function	Diversity factor
Range	1
Dryer	1
Furnace	0, because removed
Kitchen	0.2
Lights	0.9
Plugs	0.2
Bath	0.2
Storage	0.01
Heat pump	0.8
Heat pump water heater	0.8

Normative Appendix SC – Schedules

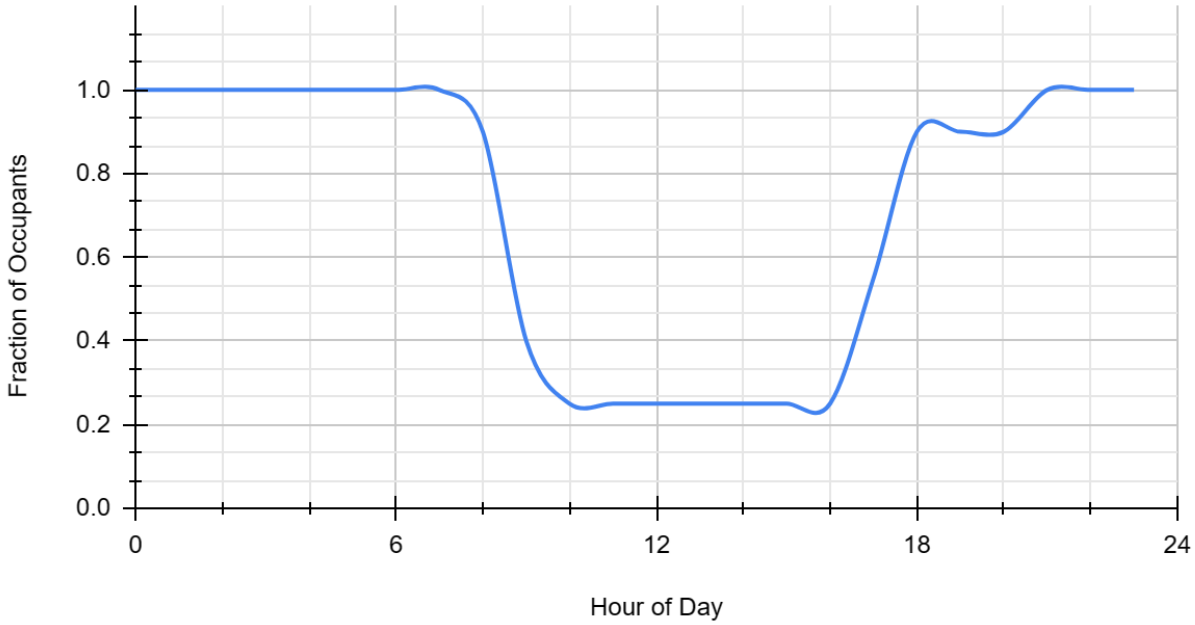
Informative: The schedules used in this section are from the Building America House Simulation Protocol, but simplified into a daily schedule rather than using a seasonal adjustment.

Hour of Day	Lighting Schedule	*MEL*s Schedule	Whole House DHW Schedule	Range Schedule	Clothes Dryer Schedule	Clothes Washer Schedule	Dishwasher Schedule	Occupant Schedule
1	0.008	0.008	0.006	0.007	0.01	0.009	0.015	1
2	0.008	0.008	0.003	0.007	0.006	0.007	0.007	1
3	0.008	0.008	0.001	0.004	0.004	0.004	0.005	1
4	0.008	0.008	0.001	0.004	0.002	0.004	0.003	1
5	0.024	0.024	0.003	0.007	0.004	0.007	0.003	1
6	0.05	0.05	0.022	0.011	0.006	0.011	0.01	1
7	0.056	0.056	0.075	0.025	0.016	0.022	0.02	1
8	0.05	0.05	0.079	0.042	0.032	0.049	0.031	1
9	0.022	0.022	0.076	0.046	0.048	0.073	0.058	0.9
10	0.015	0.015	0.067	0.048	0.068	0.086	0.065	0.4
11	0.015	0.015	0.061	0.042	0.078	0.084	0.056	0.25
12	0.015	0.015	0.048	0.05	0.081	0.075	0.048	0.25
13	0.015	0.015	0.042	0.057	0.074	0.067	0.041	0.25
14	0.015	0.015	0.037	0.046	0.067	0.06	0.046	0.25
15	0.026	0.026	0.037	0.057	0.057	0.049	0.036	0.25
16	0.015	0.015	0.033	0.044	0.061	0.052	0.038	0.25
17	0.056	0.056	0.044	0.092	0.055	0.05	0.038	0.25
18	0.078	0.078	0.058	0.15	0.054	0.049	0.049	0.55
19	0.105	0.105	0.069	0.117	0.051	0.049	0.087	0.9
20	0.126	0.126	0.065	0.06	0.051	0.049	0.111	0.9
21	0.128	0.128	0.059	0.035	0.052	0.049	0.09	0.9
22	0.088	0.088	0.048	0.025	0.054	0.047	0.067	1
23	0.049	0.049	0.042	0.016	0.044	0.032	0.044	1
24	0.02	0.02	0.023	0.011	0.024	0.017	0.031	1

Hourly Load Schedules



Occupant Schedule



Normative Appendix T-0 – Program Plan Outline

In the case of multiple facilities, assemble a Program Plan document containing the following:

a. Facility identification
b. Ranking metrics
c. Prioritized list of facilities
d. Phase plan or execution schedule
e. Program planning team (names, affiliation, and title)

For each building, collect narrative answers to the questions posed in sections 4.5.1.1-3 into a rationale to retrofit.

Normative Appendix T-1 – *CFR* Outline

Facility Summary

A narrative describing facility location, size, occupancy type, construction, systems, and facility usage.

General Requirements

“The retrofitted building shall meet the requirements of Phius REVIVE 2024.”

The retrofitted building shall also meet the Owner’s Facility Requirements, Indoor Air Quality Electives, and Hazard Mitigation Electives listed in the next sections below.

Facility Requirements

Facility requirements per section 8.6.4.1.

- Regulatory
- Financial
- Functional uses
  - Space needs
- Indoor Environment
- Preferred vendors

Nonresidential critical electrical and process loads
Nonresidential outage occupancy schedule
Nonresidential heat exposure criteria for unoccupied zones

Indoor Air Quality Electives

See section 5.1.

1 Asbestos
2 Below ground contaminants (except radon)
3 Building products
4 Carbon Monoxide
5 Environmental tobacco smoke
6 Garage air pollutants
7 Lead
8 Moisture / mold
9 Pests
10 PCBs
11 Radon
12 Wood smoke
13 HVAC equipment
14 Vented combustion appliances
15 Unvented combustion appliances
16 Local exhaust ventilation
17 Whole dwelling ventilation
18 Safety
19 Protecting IAQ during construction
20 Jobsite safety

Defer discussion - not a *CFR* issue but a Cx Plan issue.

Hazard Mitigation Electives

See section 5.2.
Seismic
Flood, Tsunami
Hail
Wind
Snow load
Wildfire

Life Cycle Analysis Period

Life cycle analysis period per section 6.4.1.1.

Decarbonization Pathways 4.2.1

Operational decarbonization pathway chosen per section 6.4.2.1.
Embodied decarbonization pathway chosen per section 6.4.2.2.

Monitoring / *Measurement and Verification* electives

See sections 7 and 8.6.4.2.

Minimum monitoring period required by the *Authority* (per section 7.1.3)

Normative Appendix T-2 – Cx Plan Outline

Assessment Plan

Facility Requirements Assessment Plan

Occupant Concerns Related Assessment Plan

List of concerns from the occupant survey to be assessed in the walkthrough.

IAQ Assessment Site Visit Plan

Per section 8.6.5.1

With respect to the EPA Energy Savings Plus Health documents, list the assessment protocol items that could be accomplished in a walkthrough.

Informative: A suggested list is as follows:

2 Below ground contaminants (except radon)
- *AP 2.1 Evaluate Sources*
  - *-Take note of any odors on site/indoors*
  - *-Visually inspect any drain/waste/vent piping if easily accessible*

3 Building products
- *AP 3.2-3.3 - Building Products/Material Emissions*
  - *-Discuss importance of safe product choices and avoiding VOCs*
  - *-Identify carpet prone to moisture/wetting problems*
  - *-Assess existing ventilation strategies*

4 Carbon Monoxide
- *AP 4.1 Assessment of CO Sources*
  - *-Document all existing combustion equipment*

5 Environmental tobacco smoke
- *AP 5.1 Look for Signs of Smoking Indoors*

6 Garage air pollutants
- *AP 6.1-6.5 Garage Air Pollutants*
  - *-Assess existing garage configuration and characteristics*

7 Lead
- *AP 7.1 Assess Paint Conditions*
  - *-Document peeling, bubbled, or worn paint that may contain lead*

8 Moisture / mold
- *AP 8.1-8.4 - Mold/Moisture Assessment*

-Document all areas where moisture/mold issues are currently present or suspected
-Discuss containment of mold and remediation plan/strategies

Note: ANSI IICRC S520-2015 Standard for Professional Mold Remediation, Section 10.4, addresses building inspection. It suggests looking for water intrusion or condensation, water stains, odors, structural defects and damage, previous repairs and remodeling, among other things, as well as attempting to identify pathways of water intrusion so as to predict where there might be hidden mold.

Intrusive inspections should be deferred to the Investigation Phase, and are preferably conducted and documented according to ANSI/IICRC S500, Standard and Reference Guide for Professional Water Damage Restoration.

9 Pests
AP 9.1-9.2 Pests
-Check for evidence of pests/rodents
10 PCBs
AP 10.1 Assess Light Ballasts
-Document any fluorescent light fixtures
11 Radon
AP 11.3 Determine if Active or Passive Radon Mitigation System
-Document current mitigation system, if applicable
13 HVAC equipment
AP 13.1-13.2 HVAC Equipment
-Document existing equipment functionality
-Document existing equipment information (make, model #, etc.) if easily accessible
-Note specific areas of occupant discomfort/concern
16 Local exhaust ventilation
AP 16.1-16.2 Source/Local Exhaust Ventilation
-Document existing ventilation strategies for kitchen/baths
-Document existing dryer exhaust
18 Safety
AP 18.1 Assess Conditions
-Check if existing wood stove vent is sealed (stove not used)
-Replace batteries/supply CO and smoke alarms
-Identify harmful chemicals on-site
-Inspect existing fire extinguisher, if any
-Check DHW temp. Adjust to align with state/local code if needed
-Document any and all additional hazards/occupant concerns

List of locations to be inspected on site.

Initial Retrofit Phase Plan for Performance-Related Measures

Initial *M&V* Approach

Initial Approach to Maintenance and Persistence of Benefits

Investigation Plan

Facility Requirements Related Investigation

Occupant Concerns Related Investigation

IAQ and Moisture Risk Related Investigation

1 Asbestos
2 Below ground contaminants (except radon)
3 Building products
4 Carbon Monoxide
5 Environmental tobacco smoke
6 Garage air pollutants
7 Lead
    How to identify a Lead Water Water Service Line
8 Moisture / mold
9 Pests
10 PCBs
11 Radon
12 Wood smoke
13 HVAC equipment
14 Vented combustion appliances
15 Unvented combustion appliances
16 Local exhaust ventilation
17 Whole dwelling ventilation -> refers in turn to ASHRAE 62.2, See section 8.7.6.1.
18 Safety
19 IAQ during construction
20 Jobsite safety

Site hazards investigation

Seismic
Flood, Tsunami
Hail
Wind
    FORTIFIED Roof requirements summary:

3.1 roof sheathing thickness
3.2 sealing and strengthening under roof deck
3.3 attic vents and covers (hurricane only)
3.4 engineered attachments for roof PV

Snow Load
Ice dams
Wildfire

Winter Resilience Related Investigation

Summer Resilience Related Investigation

ADORB Cost Reduction Related Investigation

Additional Decarbonization Related Investigation

M&V Related Investigation

Schedule of Investigation Activities

Any system testing that may require interruptions of facility operations.

Pre-Site Visit Tests, Potential Disruptions

Per section 8.7.5.2

Stakeholder Interviews

Per section 8.7.5.3

Test Procedures

Per section 8.7.5.6
Informative Appendix T-2.1 has forms for documenting the condition of equipment, and for writing test procedures.

Lighting

Space Conditioning Equipment

Hot Water Heating (DHW, SWH)

Sampling Strategies for Cx Design Review

(per section 8.8.4)

Sampling Review Process for Submittals

(per section 4.8.7)

Hand-Off Plan

Training Plan

Lessons-Learned Workshop Plan

Per section 8.6.5.6, will a lessons-learned workshop be conducted?

Informative: See ASHRAE Guideline 0.2, Informative Annex L6, for suggested list of invitees, agenda, list of documents for distribution before the workshop, and outline of the workshop report.

Normative Appendix T-4 – *Systems Manual* Outline

Use the outline in ASHRAE 202-2018 section 14.2.3 to develop the *Systems Manual*.

Normative Appendix T-6 – Cx Report Outline

Assessment Report

Facility Information

Facility Summary. A narrative describing facility location, size, occupancy type, construction, systems, and facility usage. Reiterate the summary in the *CFR*.

General Facility Information

Project Name

Occupancy type

- ☐ single-family detached,
- ☐ single-family attached,
- ☐ multifamily,
- ☐ nonresidential, or
- ☐ mixed use.

For nonresidential and mixed-use, specify facility usage.

Contact information for *Cx Team* members.

- Owner
- *CxP Team*
- *V&T providers*
- Design Professionals

Project Address
City with most similar climate to the project location
Year(s) built
Number of occupants by age

- 0 to 5 years
- 6 to 13 years
- 14 to 64 years
- 65 years and older

Energy Prices - Utility names and rate plans for applicable fuels, meter and submeter locations, data availability (hard copy or electronic)

- Electricity [$/kilowatt-hour]
- Piped Natural Gas [$/therm or $/100 cubic feet]
- Liquid Propane Gas (LPG) [$/gallon]
- Fuel Oil [$/gallon]

List of Additional Documents

Per section 8.6.1

Occupant Survey Results

Per section 8.6.2

Additional Facility Information

per section 8.6.1

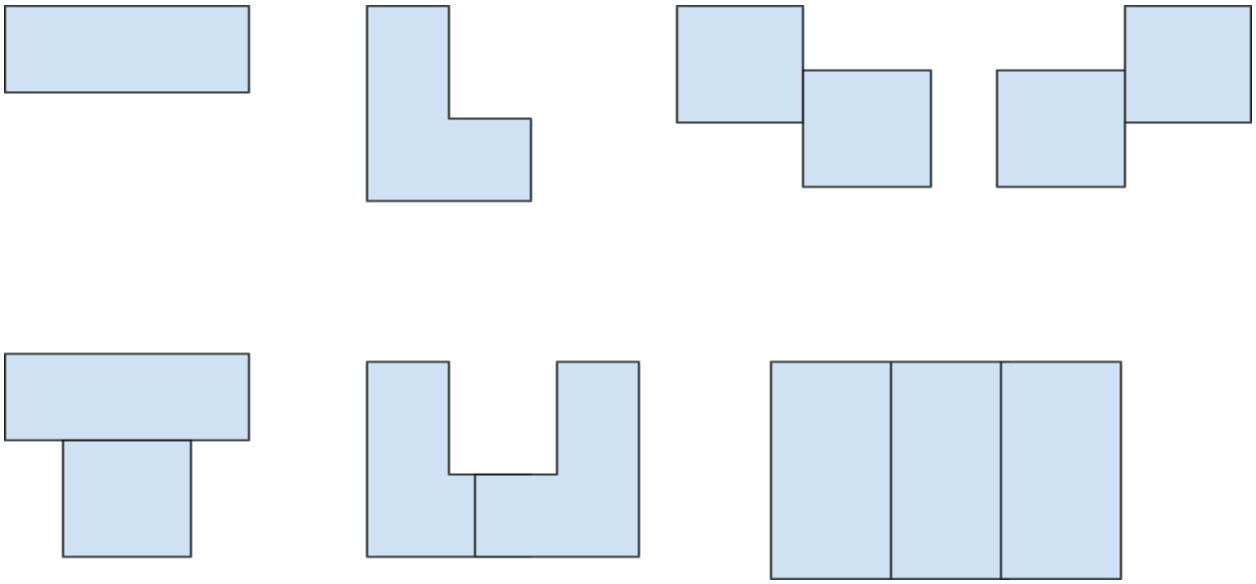
For Single-Family Residential

Direction faced by front door
Stories above ground level
Interior floor-to-ceiling height

Shape / Size / Orientation

Determine the shape below that most closely matches the shape of the house, and record the exterior dimensions of that simplified shape.

- ☐ Rectangle
- ☐ L-Shape
- ☐ Front S-Shape
- ☐ Back S-Shape
- ☐ T-Shape
- ☐ U-Shape
- ☐ Townhouse



Floor area info

- Above grade
- Below grade
- Unconditioned attached spaces (garage etc.)

For Multifamily Residential

Per section 8.6.1, attach MBEST workbook.

For Nonresidential and Mixed-Use

Narrative or graphics describing size and shape, including floor area and number of stories.

List of Immediate Improvements Made

Facility Requirements Related Assessment

List of equipment not in service.
Findings related to occupant concerns.

IAQ and Moisture Risk Assessment

1 Asbestos

2 Below Ground Contaminants (Except Radon)

3 Building Products

Informative re: AP 3.1 new materials - See minimum action MA 3.3 - that actually covers requirements on new materials.

4 Carbon Monoxide

5 Environmental Tobacco Smoke

6 Garage Air Pollutants

7 Lead

8 Moisture / Mold

9 Pests

10 PCBs

11 Radon

12 Wood Smoke

13 HVAC Equipment

14 Vented Combustion Appliances

15 Unvented Combustion Appliances

16 Local Exhaust Ventilation

17 Whole Dwelling Ventilation

18 Safety

19 IAQ During Construction

20 Jobsite Safety

Informative: This is mostly a Cx Plan issue.

Site Hazards Assessment

Seismic

Seismic design category

Flood, Tsunami

Hail

Wind

Ice Dams / Snow load

Wildfire

Initial Performance Modeling Report

Baseline Case

Outage resilience performance
Normal-operation energy end-use breakdown
ADORB cost breakdown
Direct cost breakdown for performance-related upgrades

Post-Retrofit Cases

Outage resilience performance
Normal-operation energy end-use breakdown
ADORB cost breakdown
Direct cost breakdown for performance-related upgrades

Budget categories for performance-related upgrades

Envelope

Air leakage / sealing / tightness
Windows / doors / skylights
Ceilings, Roofs
Walls
Foundation, Floors

HVAC

Mechanical ventilation
Space Conditioning

Hot Water Heating (DHW, SHW)

Major appliances

Lighting

PV / Battery / Generation

Other Performance-Related

More Budget Categories

Commissioning, Testing, Inspection

Indoor Air Quality Related

Hazard Mitigation Related

Incentives / Tax Credits

Other In-Scope

Other Out-of-Scope

Additional Decarbonization Assessment

Investigation Report

Executive Summary

Documentation of changes implemented during the Assessment and Investigation Phases

List of Findings and Recommendations

Calculations and Supporting Documentation for Resilience Performance and *ADORB cost*

Rationale for the Selection or Rejection of Approaches

Documentation of Observations and Data Gathered in the Field

Informative: This information demonstrates the findings that led to development of the related recommendations.

List of Immediate Improvements Made

Facility Requirements Related Investigation

IAQ and Moisture Risk Investigation

Site Hazards and Structural Investigation

Winter Resilience Related Investigation

Summer Resilience Related Investigation

ADORB Cost Reduction Related Investigation

Additional Decarbonization Related Investigation

M&V Related Investigation

List of Deferred Testing, If Any

Implementation Progress Reports

Training Documentation

Lessons Learned Report

Informative: See ASHRAE Guideline 0.2, Informative Annex L6, for suggested list of invitees, agenda, list of documents for distribution before the workshop, and outline of the workshop report.

Informative Appendix E – EPA Indoor Air Quality

According to the US EPA: “EPA's Energy Savings Plus Health: Indoor Air Quality Guidelines documents focus primarily on the health and safety of building occupants. The document identifies priority indoor environmental issues and includes

- Assessment Protocols to evaluate existing conditions,
- Minimum Actions to be taken during home energy upgrade activities, and
- Expanded Actions that provide opportunities to promote improved occupant health through home energy upgrades…”

The tables of contents reproduced below indicate the issues addressed.

Single-Family

Multi-family

Informative Appendix P – Retrofit Package Tiers

Modeling for the selection of the final post-retrofit state of the building could begin with the evaluation of the following upgrade packages a la Munankarmi et al (2023).

All Equipment Swap-outs
+ Lite Envelope (includes H/ERV in some cases)
+ IECC Envelope
+ Phius New Construction Envelope (prescriptive)

Package 1: *All Equipment Swap-outs*

The *All Equipment Swap-outs* package includes upgrades that replace all major fossil fuel-using equipment with high-efficiency electric equipment counterparts, including equipment for space heating, water heating, cooking, and clothes drying. It also upgrades all lighting to 100% LED and upgrades all major appliances to ENERGY STAR® or ENERGY STAR Most Efficient® performance levels. The components of this package are listed in Table 1. Miscellaneous gas end uses such as pool heaters and gas fireplaces are not changed. Exception: miscellaneous gas end uses should be eliminated in studies for Tier A per section 6.4.

In this package, all water heaters are replaced with an 80-gallon heat pump water heater, or a heat pump water heater sized to building demand For HVAC, homes with existing ducts receive a ducted air-source heat pump (ASHP) whereas homes without ducts receive an air-source mini-split heat pump (MSHP). All lighting is upgraded to 83 lumens/watt LED lamps. Ducts in *unconditioned space* are upgraded to 10% leakage, R-8 insulation.

Table 1. Details of *All Equipment Swap-outs* package

Package upgrades	Upgrade details	Upgrade condition
Heat pump water heater	80 gal; UEF around 2.4	All homes
Heat pump HVAC	ASHP, SEER 22, 10 HSPF	Homes with ducts
	MSHP, SEER 29.3, 14 HSPF	Homes without ducts
Duct sealing/insulation	All ducts in *unconditioned space* sealed to 10% leakage and insulated to R-8	All homes
Lighting	100% LED (83 lumens/watt)	All homes
Dryer	ENERGY STAR Most Efficient, Heat Pump, Ventless (CEF=5.2)	All homes

Refrigerator	ENERGY STAR (EF 21.9, 348 rated kWh/yr)	All homes
Clothes Washer	ENERGY STAR Most Efficient (IMEF=2.92)	All homes
Dishwasher	ENERGY STAR (144 Rated kWh/yr)	All homes
Cooking Range	Induction cooktop and electric resistance oven (Cooktop_ef = 0.84, Oven_ef = 0.11)	All homes

Package 2: *Lite Envelope*

This package includes all the upgrades in the *All Equipment Swap-outs* package plus additional envelope upgrades listed in Table 2. These *Lite Envelope* upgrades include attic air-sealing and attic insulation, R-6.5 wall insulation, and low-e storm windows. Each of the upgrades have necessary existing conditions in order to be applied, and thus not all the upgrades are necessarily applied in every home.

Table 2. Details of *Lite Envelope* package

Package upgrades	Upgrade details	Upgrade condition
Attic floor air-sealing and insulation	R-values follow 2021 IECC	Homes with vented attic and attic R-value less than 2021 IECC
R-6.5 wall insulation with re-siding	R-6.5 of continuous wall insulation, e.g., 1” of rigid polyisocyanurate board installed under new siding	Homes older than 1990 with less than R-19 wall insulation
Low-e storm window	Exterior low-e storm windows	Homes with single and double pane windows

Homes with vented attics and attic floor R-values less than those specified in 2021 IECC code receive the attic air sealing and insulation upgrade. Because attic floor insulation often cannot be applied at full thickness near eaves, as shown in Figure 1 [6], a derate is applied to determine the effective attic insulation level used in modeling the packages for each climate zone (see Table 3). The derate was calculated using attic perimeter insulation calculations in BEopt [7] based on average attic perimeters from ResStock.

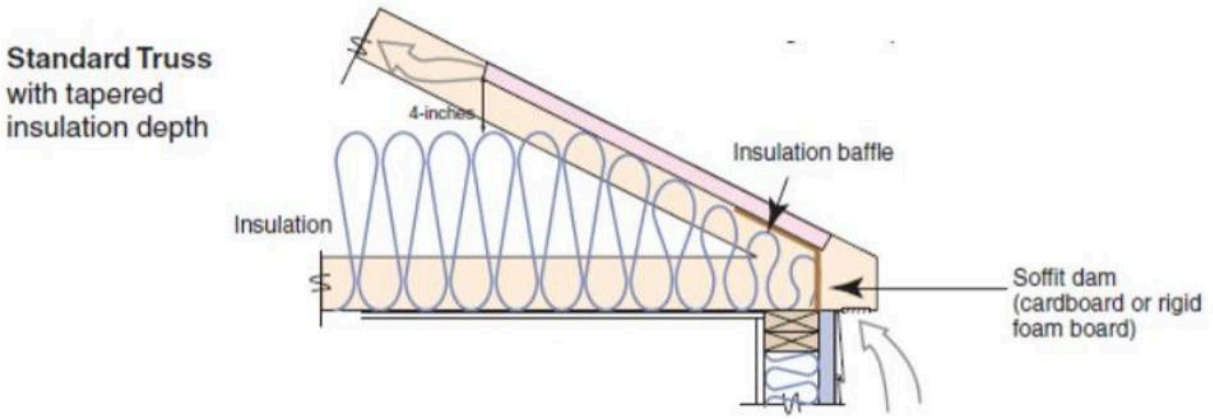


Figure 1. Standard roof trusses are narrow at the eaves, preventing full insulation thickness over the top plate of the exterior walls. Image source: Building America Solution Center [6]

The attic insulation level for each climate zone is specified in Table 3.

Table 3. Attic insulation for *Lite Envelope* upgrade

Climate Zone	Attic Floor R-value, Nominal	Attic Floor R-value, Effective
1	30	29
2-3	49	44
4-7	60	51

Similarly, exterior low-emissivity (low-e) storm windows are added to the homes with pre-existing single and double pane windows. These exterior storm windows can reduce the air infiltration and conductive heat transfer associated with the window. The U-value and SHGC value for windows with and without low-e storm window is shown in Table 4.

Table 4 Window Properties with and without addition of low-e windows

Primary Window Type	Without Storm Window		With Low-E Storm Window	
	U-Value	SHGC	U-Value	SHGC

Single-Pane, Clear, Metal Frame	1.16	0.76	0.69	0.59
Single-Pane, Clear, Non-Metal Frame	0.84	0.63	0.40	0.48
Double-Pane, Clear, Metal Frame	0.76	0.67	0.38	0.51
Double-Pane, Clear, Non-Metal Frame	0.49	0.56	0.29	0.42

R-6.5 continuous wall insulation with re-siding is added in homes meeting two conditions. First, the vintage of the homes should be earlier than 1990 so that the siding is at least 30 years old and, second, the wall insulation of the home should be less than R-19. This upgrade is a generic performance level that can be achieved with currently available or emerging insulation materials, but agnostic of the specific technology used. Rigid polyisocyanurate insulation board (1” thickness) would be a typical example of a product achieving this performance level.

All three upgrades in the *Lite Envelope* package have associated reductions in air infiltration. The air leakage reduction from each upgrade of *Lite Envelope* is provided in Table 5 [8] [9]. The whole-home air leakage reduction due to the upgrades is calculated using Equation 1:

$$(1 - (1 - r1)*(1 - r2)*(1 - r3)) \quad (1)$$

Where r1, r2, r3 represent the air leakage reduction from each package upgrade.

For instance, let us consider a home with single pane windows and no storm windows and a vented crawlspace where all three of these upgrades apply. In this case, the air leakage reduction from attic air sealing is 8%, R-6.5 wall insulation upgrade is 13%, and low-e storm window upgrade is 21%. Thus, the whole-home air leakage reduction is calculated to be 37%.

Table 5. Air Leakage Reduction

Package upgrades	Vented crawlspace	Other than Vented crawlspace
Attic air-sealing and insulation	8%	13%
R-6.5 wall insulation with re-siding	13%	19%

Window upgrade for single pane without storm window	21%	30%
Window upgrade for double pane or single pane with storm window	7%	10%

Energy recovery ventilators (ERV) or heat recovery ventilators (HRV) are provided in homes with post-retrofit air infiltration rates less than 7 ACH_{50}. The efficiency of ERV and HRV upgrades are provided in Table 6.

Table 6 Efficiency of ventilation system by climate zone

Climate Zone	Ventilation System	Sensible Recovery Effectiveness	Total Recovery Effectiveness
1A	ERV	NR	60%
2A	ERV	60%	60%
2B	ERV	50%	60%
3A	ERV	70%	60%
3B	HRV	70%	NR
3C	HRV	60%	NR
4A	ERV	80%	50%
4B	HRV	75%	NR
4C	HRV	70%	NR
5A	HRV	85%	NR
5B	HRV	80%	NR
6 (6A and 6B)	HRV	85%	NR
7 (7A and 7B)	HRV	85%	NR

NR = not reported (total recovery efficiency is not reported for HRVs). Values are based on calculation of the recovery efficiency needed to deliver 60 ºF air with outside air at the coldest average month temperature. Using

calculations from 1,000 climate locations, the table values are halfway between the maximum and the mean value for locations in each zone, rounded to the nearest 5%.

Package 3: *IECC Envelope*

This package includes all the upgrades in *All Equipment Swap-outs* plus envelope upgrades achieving performance levels consistent with the 2021 IECC Residential prescriptive path [10], [11], including the insulation of wall, floor, foundation wall, and window U-values and SHGCs (Table 7). *IECC Envelope* upgrades are applied to all the residential buildings with lower efficiency envelopes than *IECC Envelope* specifications, and are also applied to mobile homes and multifamily buildings with more than three stories. We recognize that there may not yet exist easy or practical methods to achieve these performance levels via retrofit at scale; the purpose of this analysis is to explore the hypothetical savings that could be achieved from a package such as this.

Table 7 Details of *IECC Envelope* package upgrade, based on 2021 IECC prescriptive path specifications

Climate Zone	Window U-factor	Window SHGC	Ceiling R-value	Wall R-value	Floor R-value	Foundation Wall R-value	Slab Edge R-value
1	0.40	0.25	30	13	13	0	0
2	0.40	0.25	49	13	13	0	0
3	0.30	0.25	49	20	19	5	2 ft R-10
4 except Marine	0.30	0.40	60	20	19	10	4 ft R-10
5 and Marine 4	0.30	0.40	60	20	30	15	4 ft R-10
6	0.30	0.40	60	30	30	15	4 ft R-10
7 and 8	0.30	0.40	60	30	30	15	4 ft R-10

In this package, envelope air leakage is reduced to 3 ACH_{50} for homes with a leakage rate greater than 3 ACH_{50}. ERV and HRV upgrades are included as detailed in the *Lite Envelope* upgrade package.

Package 4: *Phius New Construction Envelope*

This package includes all the upgrades in package 1 (*All Equipment Swap-outs*) with the addition of the *Phius Envelope* upgrades (Table 8). The building envelope in this package is aligned with the 2021 Phius prescriptive specification [12]. This package is applied to all residential buildings with lower efficiency envelopes than what is specified in Phius, includes mid- and high-rise residential buildings. The air leakage rate is reduced to 1 ACH_{50}, and it is assumed that there are no duct losses in crawlspaces or attics as these spaces are fully brought within the thermal envelope. As with the *IECC Envelope* package, we recognize that there may not yet exist easy or practical methods to achieve these performance levels via retrofit at scale; the purpose of this analysis is to explore the hypothetical savings that could be achieved from a package such as this.

Table 8. Details of *Phius New Construction Envelope* package

Climate Zone	Window U-factor	Window SGHC	Ceiling R-value	Wall and Floor R-value	Foundation Wall R-value	Slab Edge R-value
1A	0.5	0.25	R-51	R-22	R-7	2ft R-7
2A	0.28	0.25	R-56	R-27	R-10	2ft R-10
2B	0.29	0.25	R-56	R-27	R-13	2ft R-13
3A	0.23	0.25	R-61	R-31	R-13	2ft R-13
3B	0.28	0.25	R-60	R-30	R-14	2ft R-14
3C	0.32	0.25	R-59	R-30	R-10	2ft R-10
4A	0.19	0.25	R-66	R-36	R-17	2ft R-17
4B	0.18	0.25	R-67	R-37	R-17	2ft R-17
4C	0.24	0.4	R-65	R-35	R-16	2ft R-16
5A	0.16	0.4	R-72	R-42	R-21	2ft R-21
5B	0.17	0.4	R-69	R-39	R-19	2ft R-19
6A	0.13	0.4	R-77	R-46	R-24	2ft R-24
6B	0.14	0.4	R-75	R-44	R-23	2ft R-23
7A	0.12	0.4	R-82	R-51	R-30	2ft R-30
7B	0.12	0.4	R-82	R-51	R-30	2ft R-30

Informative Appendix S – Seismic Assessment & Evaluation Resources

Investigation Phase Resources from FEMA P-154:

“ASCE/SEI 41-13 provides both procedures to evaluate the seismic force-resisting capacity of buildings and recommended procedures for the seismic retrofitting of buildings with inadequate seismic capacity. The ASCE/SEI 41-13 procedure includes three tiers of evaluation and is ideal for those buildings that require a Detailed Structural Evaluation.[2]

FEMA P-58-1, Seismic Performance Assessment of Buildings, Volume 1 – The Methodology (FEMA, 2012d), is the initial volume in a series of publications that document a sophisticated “methodology for seismic performance assessment of individual buildings that properly accounts for uncertainty in accurately predicting response, and communicates performance in ways that better relate to the decision-making needs of stakeholders. The procedures are probabilistic, uncertainties are explicitly considered, and performance is expressed as the probable consequences, in terms of human losses (deaths and serious injuries), direct economic losses (building repair or replacement costs), and indirect losses (repair time and unsafe placarding) resulting from building damage due to earthquake shaking.”

HAZUS-MH is FEMA’s nationally applicable software program that estimates potential building and infrastructure losses from earthquakes, riverine and coastal floods, and hurricane winds using methodology documented in the Multi-Hazard Loss Estimation Methodology, Earthquake Model, HAZUS-MH MR4 Technical Manual (FEMA, 2009a). HAZUS can be used to inform decision-making at all levels of government by providing a reasonable basis for developing mitigation, emergency preparedness, and response and recovery plans and policies.

FEMA 547 report, Techniques for the Seismic Rehabilitation of Existing Buildings (FEMA, 2006), provides a comprehensive discussion of common techniques for seismic retrofitting, with extensive figures and advice on detailing.

FEMA P-807 report, Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings with Weak First Stories (FEMA, 2012c), provides guidance for evaluation and cost-effective retrofit procedures for wood buildings with weak ground stories.

FEMA E-74 explains the sources of nonstructural earthquake damage in simple terms and provides methods for reducing potential risks. FEMA E-74 is ideal where a Detailed Nonstructural Evaluation is recommended based on the results of the rapid visual screening.”

[2] Previously, evaluation was covered by ASCE/SEI 31-03, Seismic Evaluation of Existing Buildings (ASCE, 2003), and recommended retrofitting procedures, along with more in-depth evaluation procedures were contained in the separate ASCE/SEI 41-06 standard, Seismic Evaluation and Retrofit of Existing Buildings (ASCE, 2007). ASCE/SEI 31 was an updated version of FEMA 310, Handbook for Seismic Evaluation of Buildings - A Prestandard (FEMA, 1998), which in turn was an update of the original FEMA 178 report, NEHRP Handbook for the Seismic Evaluation of Existing Buildings (FEMA, 1992). ASCE/SEI 41 began as an updated version of FEMA 356, Prestandard and Commentary for the Seismic Retrofit of Buildings (FEMA, 2000b), which was in turn an update of FEMA 273, NEHRP Guidelines for the Seismic Rehabilitation of Buildings (FEMA, 1997a).

Informative Appendix T-2.1 – Cx Plan Outline ideas

Additional ideas about the content of Cx Plans can be found in the references listed below:

ASHRAE Standard 230 Section 6.2.1.2.3.1

Note there is no Implementation section in this outline.

ASHRAE Guideline 0.2 Informative Annex G

ASHRAE Guideline 0.2 Section 6.5.1

Note there is no Implementation section in this outline, but Guideline 0.2 Section 8.6.2 and 8.6.3 do cover Implementation Plan and Implementation Verification Plan respectively.

ASHRAE SSPC 300 Informative Annex 05 - Commissioning Process Plan

ASHRAE Guideline 0.2 Section 7.5.1.6.3 and 7.5.1.6.4 contain the following templates for Investigation-Phase test procedures for equipment, and recording the condition of equipment.

Document test procedures in forms that include the following:
a. Purpose of the test
b. Participants required for the test
c. Schedule for testing
d. Precautions, including potential risks and disruptions
e. List of tools and/or equipment (ladders, test meters, gauges, sensors) required, means of access (keys, security codes), safety procedures (asbestos, specialty gases), and site protocols (sign-in, gowning, ID checks)
f. Accuracy and calibration of instrumentation
g. Prerequisites for the test
h. Step-by-step instructions for conducting the test. For each step of the test, include the following:

1. Parameters and physical quantities to be measured
2. Baseline information and measurements that need to be recorded for the *M&V* approach
3. Expected performance and range of acceptable results
4. Observed performance and if it is acceptable or not (pass/fail). (This information is recorded during the test.)
5. Back-out and return to normal procedures

Make forms for documenting the installed characteristics and condition of equipment (heating, ventilation, air conditioning, refrigeration, service hot water, laundry, dishwashers, and cooking appliances) including the following:

a. Make and model
b. Location
c. Quantity
d. Age
e. Size
f. Capacity
g. Condition

Informative Appendix T-3 – Basis of Design Outline

When design work is required, e.g. for additions or major renovation, ASHRAE SSPC 300 Informative Annex 06 might be useful in developing the Basis of Design document.

Informative Appendix T-5 – *Facility Guide* Outline

ASHRAE Guideline 0.2, Informative Annex M1 (reproduced below) might be useful in developing the *Facility Guide*.

Executive Summary
The executive summary contains an explanation of the source and use of the guide and an overview of the building design, construction, and operational requirements. The information is intended to provide general guidance on the intended operation of the building in conformance with the *Current Facility Requirements (CFR)*.

Facility Operations Instructions

a. **Operating Plan**. Insert a copy of the completed facility operating plan with explanations of the intended use and operation of the facility.
b. **Building and Equipment Operating Schedules, Setpoints, and Ranges**. Insert a copy of setpoints of all equipment with normal operational adjustments. Include the setpoint normal intended ranges and limitations.
c. **Sequences of Operation and Limitations**. Insert a copy of the sequences of operation for appropriate operating equipment in language and a format that is understandable to the property managers or to other groups using the guide. This would not be the controls submittal drawings but a written description of the sequences and the intent of each sequence. It should include relevant sequence/system interaction as well as graphics or schematics.
d. **Start-Up and Shutdown Actions**. Insert a copy of routine system start-up and shutdown procedures and locations of applicable controls and shutoffs.

***Ongoing Commissioning* (*OCx*) Operational and Maintenance Record Keeping**
Include *OCx* and optimization procedures and documentation to monitor and improve the performance of facility systems. These instructions should also be used as the basis for periodic Cx of operations or for contracts for this process.

The following sections can be added to the *FG* and *Systems Manual* when required … or when these items are available.

Maintenance Procedures, Checklists, and Records
Insert procedures, forms, and checklists for facility operation and their maintenance functions. Include updating requirements. Describe inspections and testing required on a routine basis and standard forms required.

a. **Maintenance Schedules**. Include recommended maintenance schedules for systems and equipment along with update requirements. The intent here is to provide guidance for the facility manager on when to order routine heavy maintenance functions such as annual testing.

Utility Measurement and Reporting
Include a description of utility metering and monitoring systems. If included in the property management functions, provide document formats and procedures for tracking utility use and reporting this information to meet the Owner's and jurisdictional requirements.

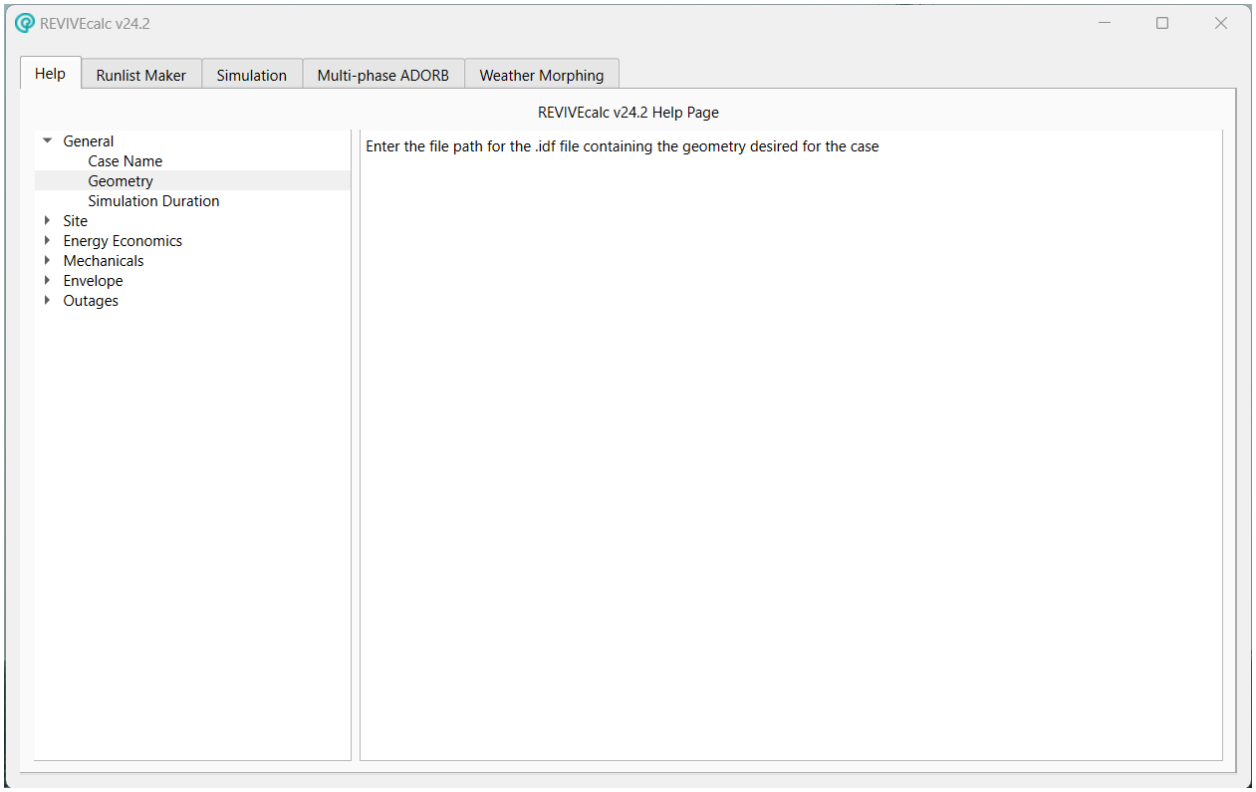
Janitorial and Cleaning Plans and Procedures
Insert a copy of facility cleaning and janitorial plan with procedures and intended chemicals and equipment if this is a function of the building property management. These janitorial plans could also be used to contract for those services.

Informative Appendix U – Calculation Engine User Manual

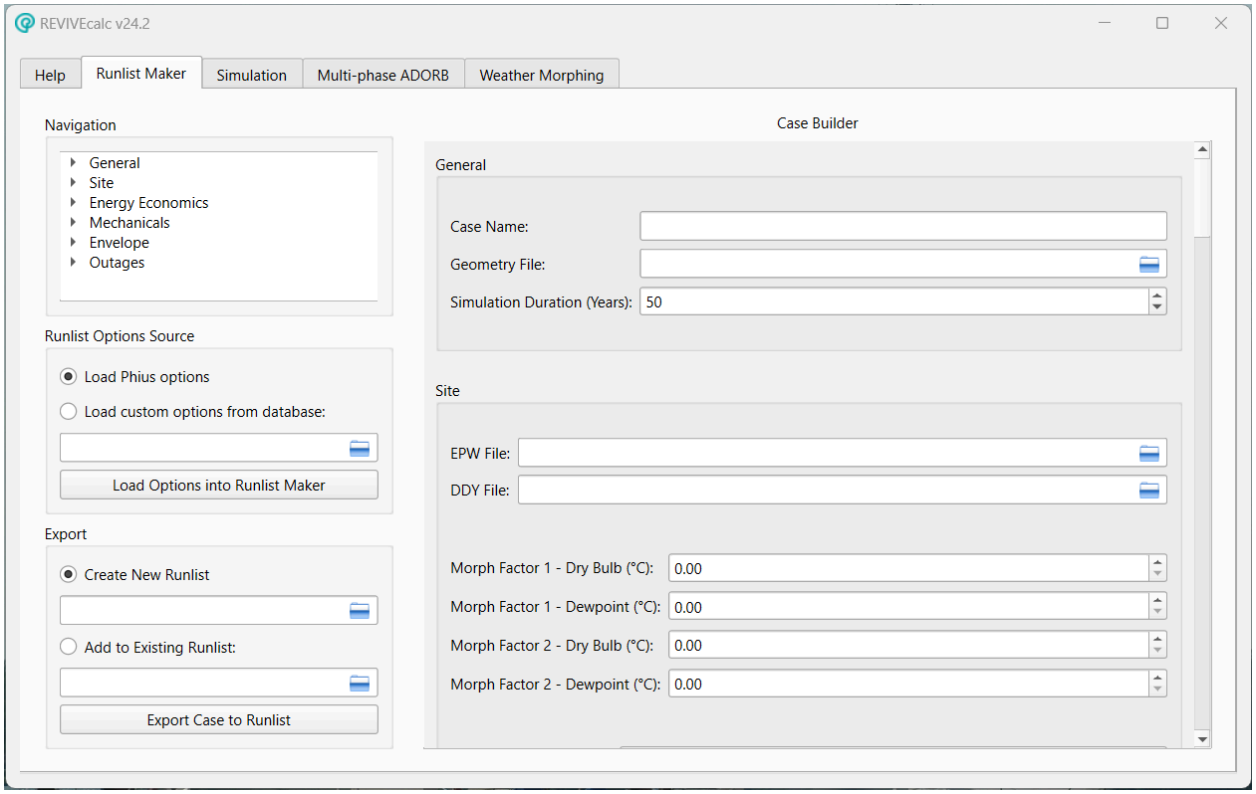
This appendix describes the inputs, outputs and function of the software tool that was developed to comply with the performative aspects of this standard. The tool is open source and based on the EnergyPlus simulation engine. Additional training videos as well as software download may be found on the Github Repository here.

U.1 - Workflow Description

The tool is a graphical user interface that serves as a simulation launcher platform. The first tab of the tool provides a help menu for the user. At the top are the tabs that separate the tool's functions into different inputs for each step of the analysis.

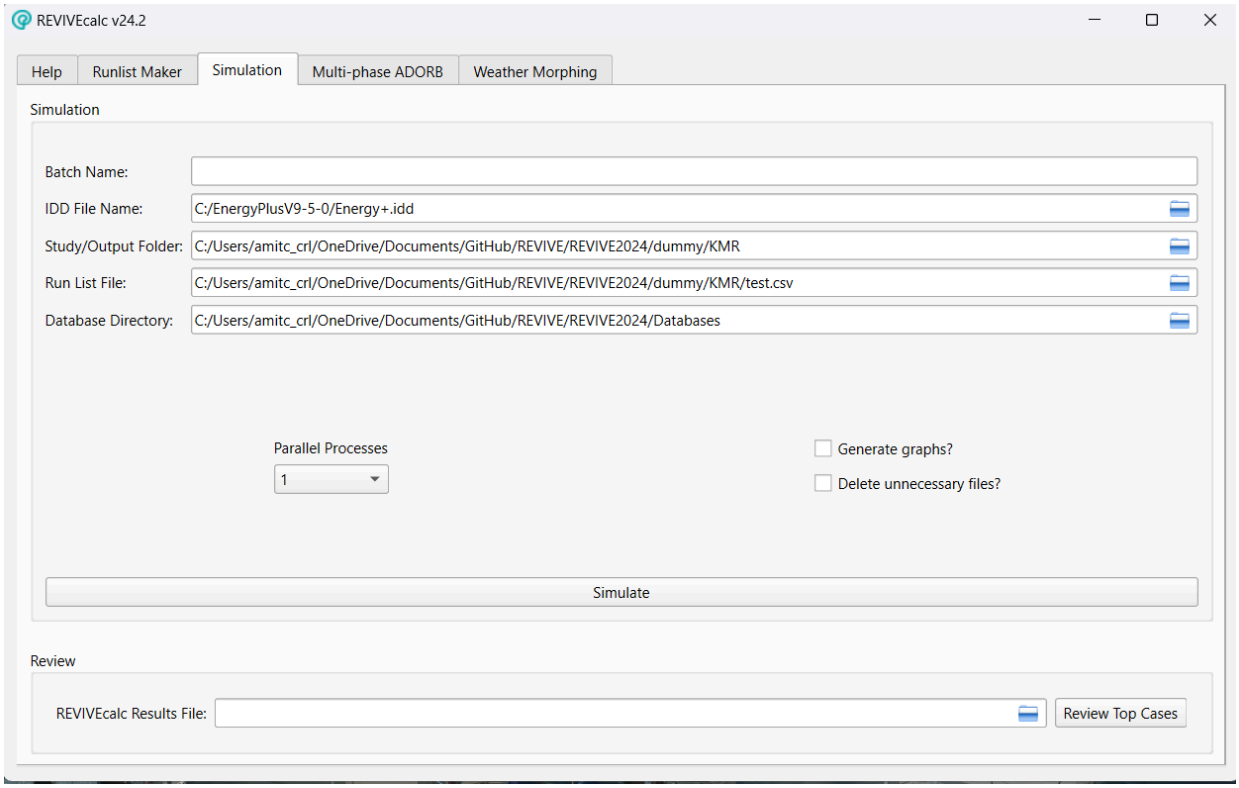


The **Runlist Maker** tab contains the GUI interface to make a run list. First, options must be loaded into the software, using the **Runlist Options Source** button on the lower left of the tool. Beneath that is the export function to save the completed runlist to a csv, or to append the case to an existing runlist. See section U-2 and the internal help menu for a definition of the inputs into the runlist maker.



The **Simulation** tab has most of the normally used settings for the usage of the tool. Aside from the **Batch File Name**, all of the inputs are file paths to the files that are needed for simulation. Fill out this entire tab of the tool in order to run an analysis. When ready to perform the analysis, press the **Simulate** button at the bottom of the screen. When fully complete the popup window will appear.

Use the **Review** section at the bottom of the tab to open a results table and quickly sort through possible retrofit paths forward.

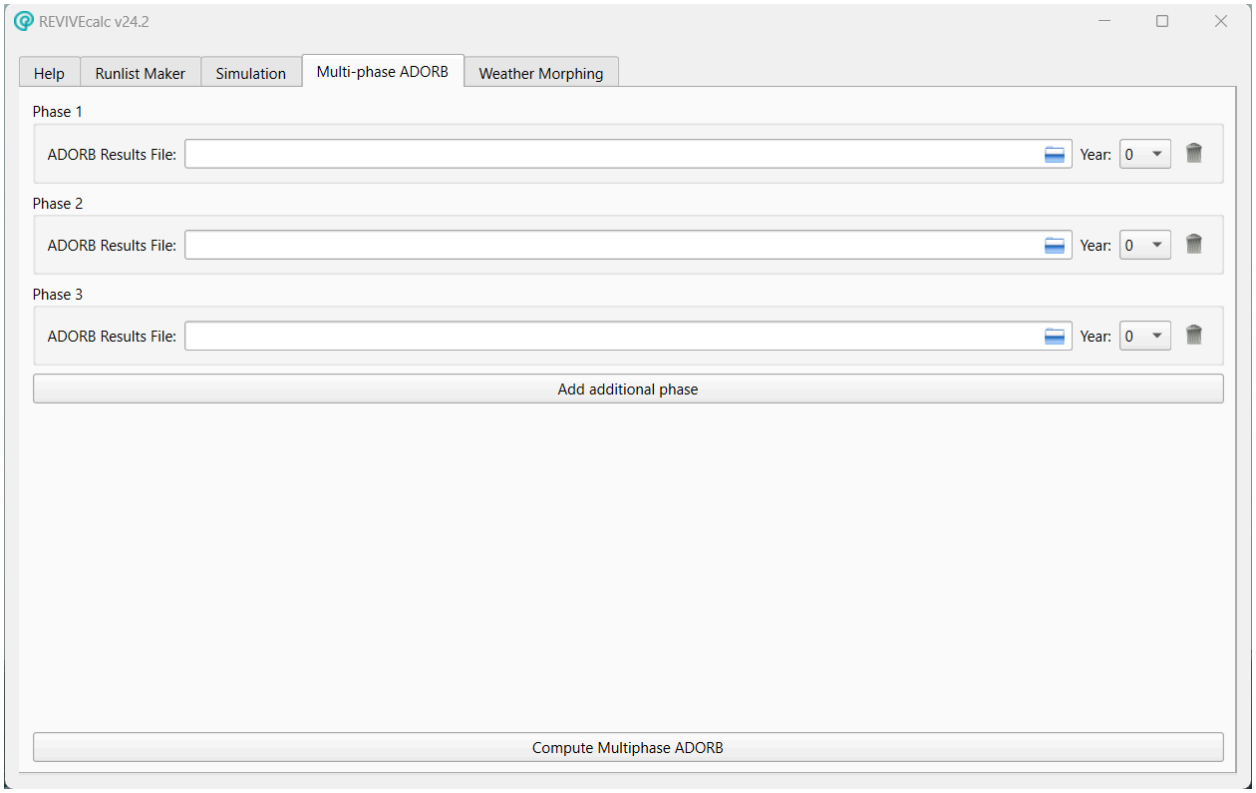


Definitions of inputs:

- **Batch Name:** This text input will apply the batch name to all of the files created from the current run. This will make the files identifiable when running multiple scenarios.
- **IDD File Location:** This input is the path to the EnergyPlus Input Data Dictionary (IDD) file. This is needed to run write and run the energy simulation files. Please note that v23.1.0 of the tool runs on EnergyPlus 9.5.0 only.
- **Study Folder:** Provide a path to a folder where all of the output files and energy models should be saved. Each case can create multiple files while running, so ensure that there is adequate space in this folder.
- **Run List Location:** This path is to the **Run List,** the .csv file that contains all of the inputs for the building other than the geometry.
- **Database Folder Location:** This path input is to the database folder which can be downloaded from the Github Repository. The database files contained within this folder are all user editable, and will be described in U.3.
- **Generate PDF?:** This beta feature will develop a PDF output with the graphs for the case included, as well as some additional information. This setting requires a Latex compiler to be installed, please see the Github Release for more information about this dependency. The default input is unchecked.
- **Delete Unnecessary Files:** Check this box to remove the files associated with EnergyPlus and the Latex PDF processing that are not needed for the end user. Default is checked.

- **Parallel Processes:** Select the number of parallel simulations to run. Most computers can handle 4, while a more powerful computer can do more. Use no more than the number of cores available on the computer.
- **REVIVEcalc Results File:** Provide the path to a results table output from a batch simulation to sort through the options quickly and find the five cases with the lowest ADORB cost that meet the thermal resilience criteria.

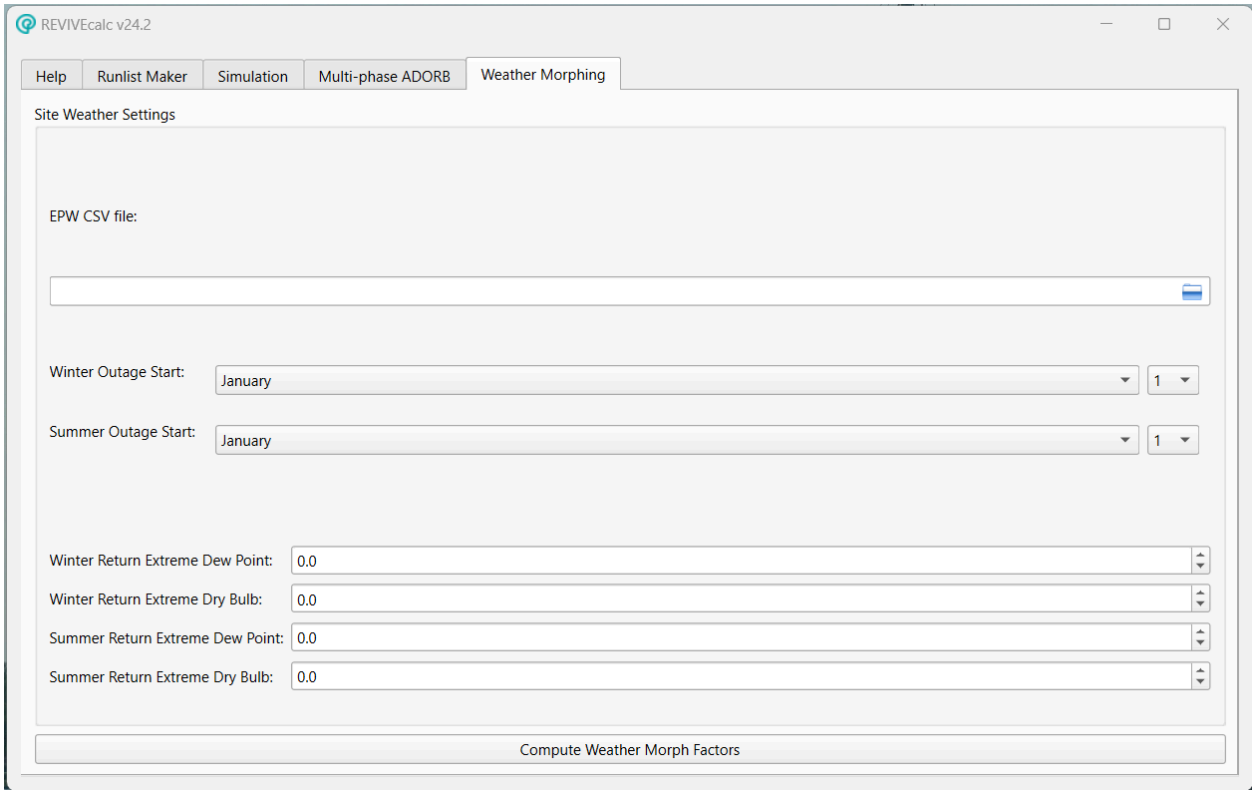
The **Multi-phase ADORB** tab is designed to support a phased project, where there are different states of completion the project will reach over the years. This tab will stitch together the yearly ADORB calculation results from the simulation and calculate an *ADORB Cost* for a 2-5 phase retrofit. A popup window will appear with the final result.



Definition of inputs:

- **Year X ADORB Results Fle:** Path to the **XXXX_ADORBresults.csv** output of the tool. Select them in sequential order for the retrofit phases.
- **Year X ADORB Start:** Input the year in which the case starts. The first input should be 1, and the other two in sequential order, for example 5 and 10 for a retrofit that causes a second phase in year 5 and third phase in year 10.

The **Weather Morphing** tab takes a epw weather file in a csv format and calculates the morphing factors for the outage period. After providing the dates, path to weather file, and the extreme return temperatures, click the **Compute Weather Morph Factors** and a popup window with the results will appear.



Definitions of inputs:

- **EPW CSV File:** Provide the path for an epw in csv format.
- **Winter Outage Start:** Provide the outage start date as referenced in U.2.
- **Summer Outage Start:** Provide the outage start date as referenced in U.2.
- **Winter Return Extreme Dewpoint:** Enter the dewpoint temperature to use in the winter morph.
- **Winter Return Extreme Dry Bulb:** Enter the dry bulb temperature to use in the winter morph.
- **Summer Return Extreme Dewpoint:** Enter the dewpoint temperature to use in the summer morph.
- **Summer Return Extreme Dry Bulb:** Enter the dry bulb temperature to use in the summer morph.

U.2 - Run List Input Description

The primary input for the tool is the **Run List.** This .csv file contains all of the information needed to apply the design parameters to the geometry model and run the analysis, aside from the information contained in the databases. That being said, there are many inputs in the **Run List** that reference the database inputs, and congruence in naming conventions and formatting is critical. It is best practice to keep a copy of these inputs in a standard Excel workbook and copy those into the .csv version of the **Run List** as needed. This way colors, formatting and any formulas are saved in a working version, and the inputs can be easily copied into a .csv file for the software to read. All inputs are case and format sensitive.

Definition of inputs:
CASE_NAME: Enter a unique case name. Using "BASE" in the name of the case will assign this as the base case for comparison.
GEOMETRY_IDF: Enter the file path for the .idf file containing the geometry desired for the case.
ANALYSIS_DURATION: Enter the duration for the of the lifecycle cost analysis

EPW: Enter the exact name or path of the .epw file to be used for this case. Ensure that the file is located in the "Weather Data" folder of the databases.

DDY: Enter the exact name or path of the .ddy file to be used for this case. Ensure that the file is located in the "Weather Data" folder.

MorphFactorDB1: Dry Bulb [°C]: Enter the dry bulb morphing factor for the first outage of the year

MorphFactorDP1: Dewpoint [°C]: Enter the dewpoint morphing factor for the first outage of the year

MorphFactorDB2: Dry Bulb [°C]: Enter the dry bulb morphing factor for the second outage of the year

MorphFactorDP2: Dewpoint [°C]: Enter the dewpoint morphing factor for the second outage of the year

ENVELOPE_COUNTRY: Select the country in which the project is going to be built from the dropdown.

GRID_REGION: This selects the grid region for the Cambium factors. If working outside the 48 contiguous states, select the option that most closely matches the grid mix of the project site.

ELEC_PRICE_[$/kWh] :: Enter the marginal electric rate for the location. Do not include fixed charges (static utility fees).

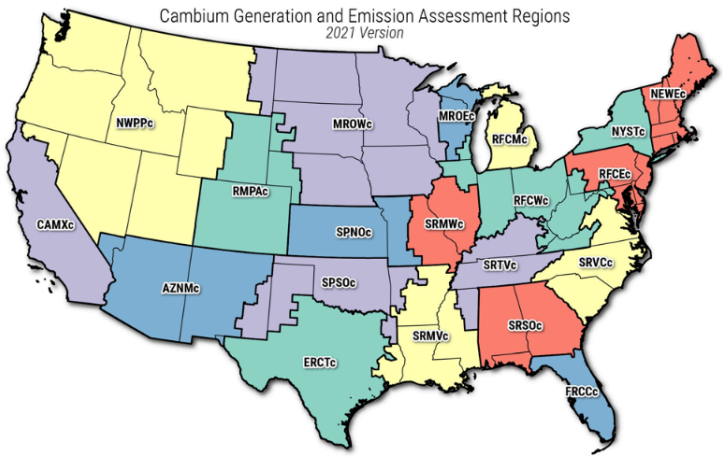


Figure 6. Cambium's generation and emission assessment (GEA) regions

SELLBACK_PRICE_[$/kWh] : Enter the price which the utility purchases electricity that is sold back from the grid.

NATURAL_GAS: This boolean determines whether or not there is natural gas present in the project.

GAS_PRICE_[$/THERM]: Enter the marginal natural gas price for the location. Do not include fixed charges (static utility fees).

Annual Electricity Fixed Charge [$]: Enter the annual fixed electrical charge for the location.

ANNUAL_GAS_CHARGE: Enter the annual fixed natural gas charge for location.

INFILTRATION_RATE: Enter the infiltration rate for the project. Use the test flow in cfm/sf of envelope area at 50 pa test pressure.

CHI_VALUE: Input the average chi value of the zones in the model. This will be applied as a thermal bridge in the model.

EXT_WINDOW_1: Applies to all three inputs. These inputs reference the window type assemblies from the construction database. Use this for all windows and doors with greater than 25% glazing. Enter the specific name of the window in the database.

EXT_WALL_1_NAME: Similar for all other numbered inputs. This input references the construction database for the opaque wall assemblies.

EXT_ROOF_1_NAME: Similar for all other numbered inputs. This input references the construction database for the opaque roof assemblies. **EXT_FLOOR_1_NAME:**Similar for all other numbered inputs. This input references the construction database for the opaque floor assemblies. Use this input for floors that face the ambient or foundation conditions

EXT_DOOR_1_NAME: Similar for all other numbered inputs. This input references the construction database for the opaque door assemblies.

INT_FLOOR_1_NAME: Similar for all other numbered inputs. This input references the construction database for the opaque floor assemblies. Use this for interstitial floors that do not face the exterior.

FOUNDATION_INTERFACE_1: Select the foundation interface referenced in the model you want to define additional parameters for. The current options are Crawlspace, Basement, and Slab.

FOUNDATION_INSULATION_1: Select a vertical insulation for the foundation interface, this must reference a material from the material database.

FOUNDATION_PERIMETER_1: Enter the exposed perimeter length of the foundation in feet.

FOUNDATION_INSULATION_DEPTH_1: Enter the depth of the insulation from the top of the foundation wall in feet.

Operable_Area_N: This applies to W,S,E inputs as well. Input the average operable area per unit facing each out the directions to be used in the natural ventilation calculations during the outage.

VENT_SYSTEM_TYPE: Select the ventilation system type from the drop down menu. Balanced assumes an ERV or HRV installation while exhaust only will add 50 cfm out the bathrooms, half an hour runtime per bathroom at 6 am and pm.

WATER_HEATER_FUEL: Select the water heater fuel type. In v24.2.0 of REVIVEcalc, you can select between an electric resistance tank and a gas fired tank water heater

MECH_SYSTEM_TYPE: Select the mechanical system type from the dropdown menu provided. The current system options are PTHP with electric backup, mini split heat pump, and a gas furnace with DX cooling.

COOLING_COP, HEATING_COP: Input the coefficient of performance (COP) for the heating and cooling systems applied to the project. For furnaces, enter the efficiency as a decimal, for example an 80% AFUE furnace would have a COP of 0.80.

SENSIBLE_RECOVERY_EFF, LATENT_RECOVERY_EFF: Enter the sensible and latent recovery efficiency for the ERV or HRV model. The upper limit is 1.0. Enter 0.0 or a HRV.

PV_SIZE_[W]: Enter the size of the PV array on the project. Use 0.1 W for the sizing for a model with no PV installed

PV_TILT: Enter the angle of the PV array, 0° for a system that is flat on the roof, 90° for a vertical system.

PV_AZIMUTH: Enter the azimuth angle of the PV array, 180° for a system that faces south, 0° for a system that faces north

APPLIANCE_LIST: Enter the names of the appliances and lighting efficiency in the project, referencing those input in the construction database. Separate the names by a comma. Only one type of each appliance is permitted.

1ST_OUTAGE: Define whether the first outage in the calendar year is a COOLING or HEATING outage

OUTAGE_1_START: Enter the last day power is available for the first outage and the outage will start at midnight. Use the format dd-mmm, ie 17-Jan. This is the default date format for csv files.

OUTAGE_1_END: Enter the last day power is not available for the first outage and the outage will start at midnight. Use the format dd-mmm, ie 17-Jan. This is the default date format for csv files.

OUTAGE_2_START: Enter the last day power is available for the second outage and the outage will start at midnight. Use the format dd-mmm, ie 17-Jan. This is the default date format for csv files.

OUTAGE_2_END: Enter the last day power is not available for the second outage and the outage will start at midnight. Use the format dd-mmm, ie 17-Jan. This is the default date format for csv files.

NAT_VENT_TYPE: Select between the following two types of natural ventilation for the outage: *NatVent* - This control sequence uses a delta dry bulb temperature control. Whenever the outdoor air temperature is 1.8°F cooler than the indoor air, the windows will be opened. *SchNatVent* - This control sequence uses a delta dry bulb temperature control and an astronomical clock to determine if the sun is up. Whenever the outdoor air temperature is 1.8°F cooler than the indoor air and the sun is not up, the windows will be opened.

NAT_VENT_AVAIL: Set boolean to 1 if natural ventilation is used in the building during an outage

SHADING_AVAIL: Set boolean to 1 if using exterior retractable shading, the shading will be activated by the solar gain on the surface of the window.

DEMAND_COOLING_AVAIL: Set boolean to 1 if demand limited cooling is available for the project. The model will maintain a setback temperature of 80.6°F. When cooling is called for, but no onsite PV is provided, the model will draw from the battery, and this unmet demand is calculated in the battery sizing outputs. When extra PV production is available, the control sequence will overcool the building below the setback temperature.

PERF_CARBON_MEASURES: Enter the names of the performance related carbon measures from the database to be included in the ADORB cost.

NON_PERF_CARBON_MEASURES: Enter the names of the non-performance related carbon measures from the database to be included in the ADORB cost.

ENVELOPE_COUNTRY: Enter the country of the project site.

ENVELOPE_LABOR_FRACTION: Enter the percentage of the envelope cost that is labor cost versus material costs.

U.3 - Results Table Definitions

The **Results Table** is the primary output to be reviewed when designing a retrofit project. This csv file contains a summary of the results of all of the cases and can be reviewed by the design team to select optimal retrofit packages.

Output Definitions:
Run Name: The Case name that was used for this simulation.

SET < 12.2°C Hours (F): The number of SET Hours for the worst case zone below 12.2°C. For compliance purposes, the limit is 216.

Hours < 2°C [hr]: The total hours in the building below 2°C, to limit freezing. The limit for compliance is 0.

Total Deadly Days: This metric is looking at overheating in the space, and calculated per the Mora deadly day criterion. The limit is 0 deadly days for compliance.

Min outdoor DB [°C]: The lowest dry bulb temperature outdoors experienced during the winter outage.

Min outdoor DP [°C]: The lowest outdoor dew point temperature experienced during the winter outage.

Max outdoor DB [°C]: The highest outdoor dry bulb experienced during the summer outage.

Max outdoor DP [°C]: The highest outdoor dew point temperature experienced during the

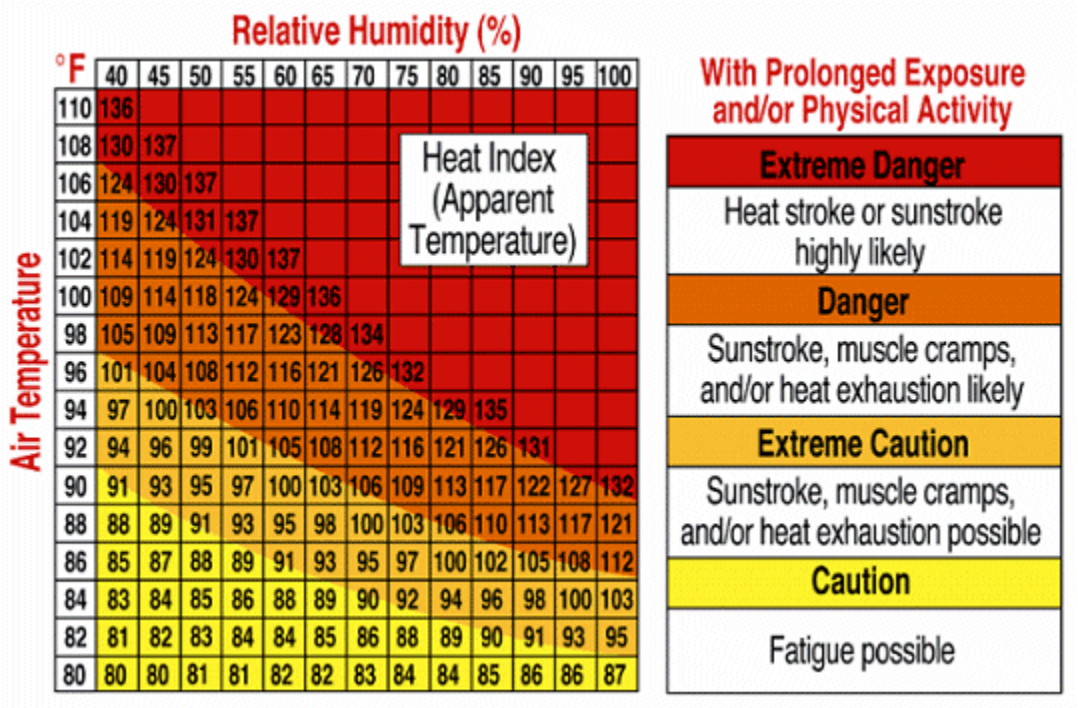
summer outage.

Caution (> 26.7°C < 32.2°C) [hr]: The number of hours from the 168 hour outage in the heat index of caution.

Extreme Caution (> 32.2°C < 39.4°C) [hr]: The number of hours from the 168 hour outage in the heat index of extreme caution.

Danger (> 39.4°C < 51.7°C) [hr]: The number of hours from the 168 hour outage in the heat index of danger.

Extreme Danger (> 51.7°C) [hr]: The number of hours from the 168 hour outage in the heat index of extreme Danger



EUI: The energy use intensity of the project in kBtu/ sf yr.

Peak Electric Demand [W: The peak electrical load on the grid.

Heating Battery Size [kWh]: This output sums the unmet electricity demand during the winter outage, and can be used to approximate initial battery sizing.

Cooling Battery Size [kWh]: This output sums the unmet electricity demand during the summer outage, and can be used to approximate initial battery sizing.

First Year Electric Cost [$]: This is the total annual cost of electricity in the first year of the simulation, representing what the owner would pay for energy the first year with the project.

First Year Gas Cost [$]: This is the total annual cost of natural gas in the first year of the simulation, representing what the owner would pay for energy the first year with the project.

First Cost [$]: This cost represents the total cost of the retrofit for the project, including mechanical and envelope upgrades.

Wall Cost [$]: This cost is the wall component of the first cost.

Roof Cost [$]: This cost is the roof component of the first cost.

Floor Cost [$]: This cost is the floor component of the first cost.

Window Cost [$]: This cost is the fenestration component of the first cost.

Door Cost [$]: This cost is the opaque door component of the first cost.

Air Sealing Cost [$]: This cost is the air sealing component of the first cost.

Mechanical Cost [$]: This cost is the mechanical component of the first cost.

Water Heater Cost [$]: This cost is the water heater component of the first cost.

Appliances Cost [$]: This cost is the sum of the appliances component of the first cost.

PV Cost [$]: This cost is the photovoltaic component of the first cost.

Battery Cost [$]: This cost is the battery component of the first cost.

Total ADORB Cost [$]: This is the total lifecycle cost in net present value of the project for the life cycle duration of the building.

pv_dirEn_tot: This is the net present value of the direct energy costs for the lifecycle of the building, and is a component of the total ADORB cost.

pv_dirMR_tot: This is the net present value of the direct maintenance and retrofit costs, including the first cost and system, appliance and window replacement costs for the lifecycle of the building, and is a component of the total ADORB cost.

pv_opCO2_tot: This is the net present value of the fictitious social cost of carbon for the operational carbon for the lifecycle of the building, and is a component of the total ADORB cost.

pv_emCO2_tot: This is the net present value of the fictitious social cost of carbon for the embodied carbon costs for the lifecycle of the building, and is a component of the total ADORB cost.

pv_eTrans_tot: This is the net present value of the grid energy transition costs for the lifecycle of the building, and is a component of the total ADORB cost.

Informative Appendix V – *V&T Provider* Credentials

Any of the following credentials might suffice for *V&T providers* (aligns with Energy Star credentials list).

Licensed Professional Mechanical Engineer

Representative of the Original Equipment Manufacturer

EPA Energy Star Credentialed HVAC Contractor

AABC Commissioning Group (ACG)
- Certified Commissioning Authority (CxA)
- Certified Commissioning Technician (CxT)

ASHRAE
- Building Commissioning Professional (BCxP, formerly the Commissioning Process Management Professional (CPMP))

Association of Energy Engineers (AEE)
- Certified Building Commissioning Professional (CBCP)
- Existing Building Commissioning Professional

Building Commissioning Certification Board
- Certified Commissioning Professional

National Comfort Institute (NCI)
- Refrigerant Side Performance and: an Air-Side Certification or National Balancing Council Large Commercial Balancing Certification

National Environmental Balancing Bureau (NEBB)
- Building System Commissioning Certified Professional (BSC BP)
- Building System Commissioning Certified Technician (BSC CxCT)
- Commissioning Process Professional (CxPP)

University of Wisconsin (UW)
- Qualified Commissioning Process Provider (QCxP)
- Commissioning Process Authority Professional (CxAP)
- Commissioning Process Manager (CxM)
- Commissioning Process Technical Service Provider (CxTS)
- Green Commissioning Process Provider (GCxP)

Informative Appendix W – Wind retrofit structural code compliance checks

FEMA P-804, Second Edition, Table 7: Building Code Compliance Checks

Note: SI means Substantial Improvement, SD means Substantial Damage, as defined by the I-codes and the National Flood Insurance Program (NFIP).

Code Check	2021 IEBC[1]	7th Edition 2020 FBC: Existing[2]	Comments
Flood Hazard Areas	104.2.1, 401.3, 405.2.6, 502.3, 503.2, 701.3, 1103.3, 1301.3.3: Where work constitutes SI/SD, the building shall comply with flood-resistant requirements for new construction.	401.3, 406.2.4, 502.2,503.2, 701.3, 1103.5, 1401.3.3: Where work constitutes SI/SD, the building shall comply with flood-resistant requirements for new construction	SI/SD is a minimum requirement of floodplain management ordinances in communities that participate in the NFIP, regardless of whether a building code is adopted. All Mitigation Packages: Applicable if done simultaneously with SI/SD and located in a flood hazard area.
Existing Structural Elements Carrying Gravity Load	503.3: Any existing gravity load-carrying structural element, for which an alteration causes an increase in design load of more than 5%, shall be strengthened, supplemented, replaced, or otherwise altered to carry the increased load.	807.4: “Alterations shall not reduce the capacity of existing gravity load-carrying structural elements unless the elements demonstrate the capacity to carry the applicable design gravity loads required by the Florida Building Code, Building. Existing structural elements supporting any additional gravity loads as a result of the alterations, including the effects of snow drift, shall comply with the Florida Building Code, Building. Exceptions: 1. Structural elements whose stress is not increased by more than 5 percent. 2. Buildings of Group R occupancy with not more than five dwelling or sleeping units used solely for residential purposes where the existing building and its alteration comply with the conventional light-frame construction methods of the Florida Building Code, Building or the provisions of the Florida Building Code, Residential.”	Basic Mitigation Package: New roof covering may weigh more than the previous roof covering (or greater than 5% of the previous in the case of the FBC). IEBC: Existing load-carrying structural elements should not require strengthening to carry increased gravity loads from retrofits. FBC: Selection of a roof covering product less than 5% heavier than the existing roof covering is recommended.

Code Check	2021 IEBC[1]	7th Edition 2020 FBC: Existing[2]	Comments
Wall Anchors for Concrete and Masonry Buildings	706.3.1: If re-roofing more than 25% of the roof area of an unreinforced masonry building in seismic design category D, E, or F, work shall include installation of wall anchors to resist IBC seismic forces.		Basic Mitigation Package: Applicable if re-roofing in an area that is both hurricane- and earthquake-prone (e.g., Charleston, SC) with concrete and masonry construction.
Voluntary Lateral-Force Resisting System Alterations	503.13: Structural alterations of existing and new structural elements intended to increase the lateral force-resisting strength need not be designed for the IBC forces if all the following conditions apply: the capacity of the existing system isn't reduced, new or relocated elements are detailed and connected to existing or new structural elements according to IBC for new construction, and the alteration doesn't create a structural irregularity per ASCE 7 or make a structural irregularity more severe.	807.6: "Structural alterations that are intended exclusively to improve the lateral force-resisting system and are not required by other sections of this code shall not be required to meet the requirements of Section 1609 or Section 1613 of the Florida Building Code, Building, provided that all of the following apply: 1. The capacity of existing structural systems to resist forces is not reduced. 2. New structural elements are detailed and connected to the existing or new structural elements as required by the Florida Building Code, Building for new construction. 3. New or relocated nonstructural elements are detailed and connected to existing or new structural elements as required by the Florida Building Code, Building for new construction. 4. The alterations do not create a structural irregularity as defined in ASCE 7 or make an existing structural irregularity more severe."	All Mitigation Packages: Applicable if wind retrofit project qualifies as a Level 2 alteration;[3] an engineer may be needed to conduct an analysis. Wind retrofit projects should not qualify as a Level 2 alteration unless additional work is being done to the house.

Code Check	2021 IEBC[1]	7th Edition 2020 FBC: Existing[2]	Comments
Structural Alterations	906.1: If a Level 3 alteration results, all structural elements of the lateral force-resisting system in the building shall comply with 906.2 (next row of this table). Additional structural provisions may apply to buildings based on seismic provisions of Section 906.		All Mitigation Packages: Applicable if the wind retrofit project results in a Level 3 alteration. Wind retrofit projects should not qualify as a Level 3 alteration unless additional work is being done to the house.
Level 3, Substantial Structural Alterations	906.2: For a Level 3 alteration where more than 30% of the total floor and roof areas of the building have been proposed to be involved in a structural alteration in a 1-year period, an analysis must show the altered building complies with the IBC for wind loading and reduced seismic forces.		All Mitigation Packages: Applicable if the wind retrofit project results in Level 3 alterations. Wind retrofit projects should not qualify as a Level 3 alteration unless additional work is being done to the house. NOTE: 30% of the total floor and roof area includes tributary areas to vertical load-carrying components.

Code Check	2021 IEBC[1]	7th Edition 2020 FBC: Existing[2]	Comments
Roof Diaphragm	706.3.2: Where roofing materials are removed from more than 50% of the roof diaphragm or if the building is located where the ultimate wind speed is greater than 130 mph, the integrity of the roof diaphragm shall be evaluated, and connections must be provided or replaced to meet IBC requirements. There is an exception for buildings that comply with the wind load provisions of ASCE 7-88 or later editions.	707.3.2: “Where the structural roof deck is removed from more than 30 percent of the structural diaphragm of a building or section of a building located where the ultimate design wind speed, Vult, determined in accordance with Figure 1609.3(1) of the Florida Building Code, Building, is greater than 115 mph (51 m/s), as defined in Section 1609 (the High-Velocity Hurricane Zone shall comply with Section 1620) of the Florida Building Code, Building, roof diaphragms, connections of the roof diaphragm to roof framing members, and roof-to-wall connections shall be evaluated for the wind loads specified in the Florida Building Code, Building, including wind uplift. If the diaphragms and connections in their current condition are not capable of resisting at least 75 percent of those wind loads, they shall be replaced or strengthened in accordance with the loads specified in the Florida Building Code, Building. Exception: This section does not apply to buildings permitted subject to the Florida Building Code.”	Basic Mitigation Package: Applicable only if the house has “defective” roof sheathing, and, therefore, is not generally considered a good candidate for a retrofit project. Wind speed triggers differ for the IEBC and the FBC. IEBC: Provision applies only if roof structure and not roof covering is at least 50% replaced. This condition should not occur for eligible candidates. FBC: Provision applies when the roof deck is removed from more than 30% of the roof diaphragm. An exception may apply to some buildings based on permitting dates and applicable codes

Code Check	2021 IEBC[1]	7th Edition 2020 FBC: Existing[2]	Comments
Roof Covering		706.1.1: “Not more than 25 percent of the total roof area or roof section of any existing building or structure shall be repaired, replaced or recovered in any 12-month period unless the entire existing roofing system or roof section is replaced to conform to requirements of this code. Exception: If an existing roofing system or roof section was built, repaired, or replaced in compliance with the requirements of the 2007 Florida Building Code, or any subsequent editions of the Florida Building Code, and 25 percent or more of such roofing system or roof section is being repaired, replaced, or recovered, only the repaired, replaced, or recovered portion is required to be constructed in accordance with the Florida Building Code in effect, as applicable. Pursuant to s. 553.844(5), Florida Statutes, a local government may not adopt by ordinance an administrative or technical amendment to this exception.”	Basic Mitigation Package: Applicable when reroofing. The entire roof system and section must conform to the FBC when more than 25% of the roof covering is replaced within a 12-month period. Some exceptions apply to roof systems built to the 2007 or later editions of the FBC.

Code Check	2021 IEBC[1]	7th Edition 2020 FBC: Existing[2]	Comments
Roof-to-Wall Connections		706.8: “When a roof covering on an existing structure with a sawn lumber, wood plank or wood structural panel roof deck is removed and replaced on a building that is located in the wind-borne debris region as defined in the Florida Building Code, Building and that has an insured value of $300,000 or more or, if the building is uninsured or for which documentation of insured value is not presented, has a just valuation for the structure for purposes of ad valorem taxation of $300,000 or more: Roof to wall connections shall be improved as required by Section 706.8.1. Mandated retrofits of the roof-to-wall connection shall not be required beyond a 15 percent increase in the cost of reroofing. Exception: Structures permitted subject to the Florida Building Code are not required to comply with this	Basic Mitigation Package: These provisions are applicable when reroofing a house unless the gable-end work costs less than 15% of the roof replacement work. There may be an exception applicable to the building based on the permitting date and the applicable code adoption date. If these provisions are triggered, some roof-towall

		section." 706.8.1: "Where required by Section 706.8, the intersection of roof framing with the wall below shall provide sufficient resistance to meet the uplift loads specified in Table 706.8.1 either because of existing conditions or through retrofit measures. As an alternative to an engineered design, the prescriptive retrofit solutions provided in Sections 706.8.1.1 through 706.8.1.7 shall be accepted as meeting the mandated roof-to-wall retrofit requirements. Exceptions: Where it can be demonstrated (by code adoption date documentation and permit issuance date) that roof-to-wall connections and/or roof-to-foundation continuous load path requirements were required at the time of original construction. Roof-to-wall connections shall not be required unless evaluation and installation of connections at gable ends or all corners can be completed for 15 percent of the cost of roof replacement."	connections may have to be installed, even for the Basic Mitigation Package

[1] The IBC states that there is an alternative compliance with the IEBC in place of the IBC for existing structures (any retrofit projects would fall into this category). Most of the provisions of the IBC are similar to the IEBC, but the IBC is not as stringent in its requirements.
[2] 7th Edition 2020 FBC: Existing Building – Additionally, Chapter 17 – Retrofitting should also be consulted during wind retrofits.
[3] Levels of alteration correspond to the three levels defined in the IEBC, IBC, and FBC: Existing Building