PHIUS+

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CERTIFICATION GUIDE BOOK

PHIUS+ 2015 Passive Building Standard – North America

Certification Guidebook

Version 1.01
9 June 2016

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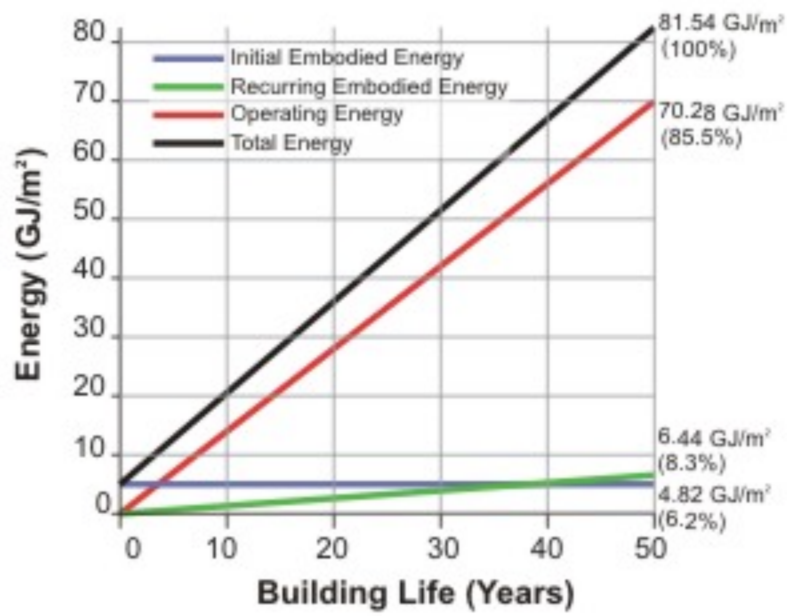
1. About PHIUS+ 2015

1.1 Introduction

Thank you for your interest in the PHIUS+ 2015 Passive Building Standard: North America.

While some "green building" standards focus on the environmental impacts or energy intensity of the building materials and construction process itself, PHIUS+ 2015 is a "high-performance building standard" – it challenges the building industry to do its part for sustainability with buildings that can maintain a comfortable indoor environment with very low *operating* energy. A priority on reducing operating energy is consistent with the idea that for buildings of typical construction, the operating energy far exceeds the embodied energy over the life of the building. An illustrative example is shown below in Figure 1.1. PHIUS+ puts a priority on reducing operating energy, but is compatible with other green building programs and broader sustainability concepts.



Components of Energy Use During 50-Year Life Cycle of Typical Office Building with Underground Parking, Averaged Over Wood, Steel and Concrete Structures in Vancouver and Toronto [Cole and Kernan, 1996].

Figure 1.1. Example comparing operating energy and embodied energy of a building. [1]

PHIUS+ 2015 is a pass-fail standard for building energy performance, with additional requirements for quality assurance inspections, and for low-moisture-risk design.

The energy performance is assessed based on calculation, a.k.a. mathematical modeling, using standardized climate conditions and occupant behavior. As such, it is a certification of a building design, independent of the household or business using the building.

The particular focus of PHIUS+ is on reducing heating and cooling energy using passive measures. In addition to an overall limit on energy use for all purposes, it features limits on heating and cooling energy, in both the annual-total and peak-power sense. The targets for these heating and cooling "loads" are climate-specific and have been set based on consideration of the best that can be achieved "cost-competitively".

For typical sized residences, compared to IECC 2009 code, it represents an 86% reduction in heating energy demand, 46% reduction in cooling (on average over all climates), with overall site energy use intensities (EUI) in the range of 10-20 kBtu per gross square foot and year.

There are also two add-on badges available, for buildings with even higher performance.

The PHIUS+ 2015 Climate-Specific Passive Building Standards were developed in cooperation with Building Science Corporation, under a U.S. Department of Energy Building America Program grant. Click here to download the report. [2]

PHIUS+ emphasizes quality assurance. It demands more than calculating out to the energy standards in the model and passing a blower door test. PHIUS+ requires additional reasonable assurances that projects are going to perform as designed, have healthy indoor environments, and be durable. To that end, PHIUS+ requires both pre-certification review as well as third-party on-site quality assurance checks. Pre-certification is done by PHIUS staff, and final certification involves also the participation of PHIUS-certified independent Raters or Verifiers who carry out on-site quality inspections (see Section 3.6).

Certification proceeds through two stages – in essence:

- Pre-certification verifies that the *energy model* matches the plans and specifications, and
- Final certification verifies that the *finished building* matches the plans and specifications.

1.2 Why certify?

Certification represents a third-party verification that the building is designed to meet the high performance standards for energy use, is constructed with quality assurance, and that critical systems are commissioned into proper operation. (Third-party verification is typically required by the incentive programs of utilities and governments.) Certification also shares knowledge – it builds the public online database of projects. Also, as more situations come up, more solutions and guidance are developed. Certification staff can pass that knowledge on to other project teams directly and via ongoing updates to this guidebook.

PHIUS Certification staff also provides guidance and support for project submitters, especially when working on their first PHIUS+ project.

1.3 About this guide

The list of certification requirements and protocol in this Guidebook may seem lengthy. But all of it is intended to help – to help your project team design and execute high-performance, high-quality buildings and avoid as many pitfalls as possible. ∗

This guidebook contains the following kinds of information, roughly in the order for which they are relevant in the building delivery process.

- General hints and tips for success.
- Design-phase requirements, both performance and prescriptive.
- Construction-phase requirements.
- The certification process, pricing, and roles of the parties involved.
- Energy modeling protocol.

1.4 The project team

Delivering a high performance building requires very good cooperation between the design professionals and the building professionals. "Design-build" or "integrated-project-delivery" organization is more common in passive building and often mentioned as a success factor.

It is very preferable that a Certified Passive House Consultant (CPHC), PHIUS Certified Builder, and PHIUS+ Rater are all involved.

The Rater is an integral part of the project team and should be hired early in the process. PHIUS asks that you hire a Rater when you submit a contract at the start of the Certification process.

1.5 Types of Projects

As in RESNET, "residential" includes single-family detached, single-family attached, and multifamily buildings, excepting hotels and motels.

1.5.1 Single-family residential Projects

Herein, "single-family" refers to single-family detached. What may elsewhere be called "single-family attached" housing is here considered to be "multifamily." Single family projects should complete the PHIUS+ Single Family Quality Assurance Workbook.

1.5.2 Multifamily residential Projects

Multi-family projects should follow the PHIUS+ Multifamily Quality Assurance Protocol for quality assurance, prescriptive design requirements, and commissioning. All performance-based certification criteria remain the same as for single-family.

Modeling protocol for multifamily projects differs slightly from single-family because of the addition of common space lighting loads, elevators, shared spaces, etc, as noted in Section 6.6 below.

∗ Simplicity is a popular idea in the abstract, but in practice a simple rule often meets objections that it is lacking some desired nuance in certain cases; as a result, certification protocol tends to become more elaborate over time.

1.5.3 Campus/Community Certification

For campus/community certification, where there are multiple residential buildings being certified that share a common building or space, a primary energy limit applies for the campus/community as a whole. For example laundry rooms and kitchens may be in a common shared space.

Space conditioning: Each individual enclosure must be modeled separately, allocating the correct internal loads to each enclosure for accuracy of the internal heat calculation (ex: if all of the laundry is done in one building, the gains from this laundry should only be counted in that enclosure). The space conditioning targets (heating demand, heating load, cooling demand, cooling load) must be met for each enclosure in the separate energy models, and the air-tightness requirements also apply for each enclosure individually.

Primary Energy allowance: If the campus/community is strongly/mainly residential in character the primary energy allowance is proportional to the design occupancy. The allowance for each person is 6200 kWh/yr, per Section 3.3.2.
For nonresidential day schools, commuter campuses and the like, the primary energy allowance is 38 kBTU/yr per square foot of interior conditioned floor area (iCFA) (or 11.1 kWh/ft^2.yr), per Section 3.3.1 and 4.4.1.4.

1.5.4 Commercial/Non-Residential Projects

The Criteria for Non-Residential Projects are the same as for residential projects, apart from the Primary Energy requirement. The Primary Energy limit for commercial buildings is proportional to floor area, rather than occupancy. There may be additional differences that require additional documentation for PHIUS+.

Compared to residential projects, the energy models for Non-Residential projects need more detailed information on lighting systems, usage patterns, plug loads, and custom internal heat gains. For commercial buildings with process loads, PHIUS will determine the Primary Energy allowance on a case-by-case basis.

Nonresidential certification protocol will be updated as more information becomes available on these types of projects.

1.5.5 Retrofit Projects

The criteria for retrofit projects are the same as for new construction, except that a case-by-case energy allowance may be made for a foundation perimeter thermal bridge or other such hard-to-fix structural thermal bridges - provided that the design is also "damage-free," that is, low risk from a moisture point of view.

As with new construction projects, there is a moisture criterion that basically requires less than 80% RH on interior surfaces. Any critical areas that need surface temperature calculation will be noted in pre-certification. The calculation will be performed in accordance with ISO 13788.

Air-tightness requirements are the same as for new construction (see Section 3.2).

2. General Notes/Guidance

2.1 General challenges associated with energy efficient buildings

Please be aware of these general issues with "super-insulated," "low-load" buildings:

- Better insulation leads to colder exterior surfaces and less heat available to evaporate water in the assemblies.[3] See also Section 3.4.3.
- The "sensible heat ratio problem", that is, HVAC dehumidification capacity at part load conditions. Sensible cooling demands and loads are reduced, while dehumidification demands and loads may still exist. [4] [5]

2.2 "Yellow flag" items

Please contact us early for more information if the project entails any of these items:

- Retrofit projects with foundation thermal bridges.
- Nonresidential projects with "process loads" or unusual heating/cooling set point temperatures.
- Site altitude very different from the nearest climate data set location.
- Thermal bridge calculations – contact certification staff or study the THERM training package.
- No Rater within 100 miles of the project location.

Please study the referenced information soon, if the project entails any of these items:

- Spray foam, Flash-and-fill assemblies – see Section 3.4.3.1 and Appendix B.
- Floors with air-permeable insulation – see Section 3.4.3.2.
- Thermal mass – anything more than "light construction" – see Section 6.4.
- Gas exhaust dryers, exhausting range hoods – use Makeup Air calculator if using PHPP.
- Heat pumps of any kind – Download Heat Pump COP protocol kit.

2.3 Tips to design a low-cost passive building

- Keep thermal envelope simple (add "architectural interest" outside of it).
- Keep window area down (10-15% of wall area for single-family houses).
- For small buildings, design a compact shape. For large buildings, bump-ins for daylighting may be more important.
- Limit "open to below" areas in the floor.
- Not too "tiny" and detached – design attached housing with small units instead.
- Use good details that don't require excessive labor to air-seal (avoid "conceptual retrofitting".)

2.4 Tips on assemblies

Air barrier

- Mid-wall is the best place for the air barrier, exterior or interior placement is more vulnerable.

Two wall types

- Keep in mind the "perfect wall" concept - structure to the inside, insulation to the outside. Diffusion open or exterior rigid foam, both versions can work moisture-wise and super-insulated. [6] [7]

Avoid

Exterior load-bearing double-stud walls are discouraged in climate zones 3 and higher. These will generally incur additional certification cost for hygrothermal analysis (WUFI), need a spray foam global warming potential (GWP) impact calculation, or both. They tend to be too vapor-closed on the outside for those climates and also put the air barrier on the exterior where it will be less durable than a mid-wall air barrier.

In heating dominated climates, double stud walls should be of the interior load-bearing type, either Larsen truss (standoff truss) or the kind described in [8], [9].

Slab

- Moisture barrier and air barrier are typically placed between foam layer and slab.
- Polyisocyanurate insulation is typically not to be used below grade. [10] Thoroughly follow the application guidance of the manufacturer's warranty and any ICC Evaluation Service report that pertains.

3. Certification Requirements

3.1 Overview / Space Conditioning

All of the requirements in Section 3.1.1 and 3.1.2 need to be met to achieve PHIUS+ Certification. The specific heating and cooling energy targets for the project will be determined by the location of the project. See this clickable map to determine criteria for the project location.

3.1.1 Main Performance Criteria for Certification

- Annual Heating Demand[2] ≤ A (kBTU/ft^2.yr)
- Annual Cooling Demand[2,3] ≤ B (kBTU/ft^2.yr)
- Peak Heating Load[2] ≤ C (BTU/ft^2.hr)
- Peak Cooling Load[2] ≤ D (BTU/ft^2.hr)
- Air-tightness[4] ≤0.05 cfm/sf envelope @50Pa
- Primary Energy Demand[5,6] ≤ 6200kWh/yr.person

3.1.2 Summary of Other Requirements

- Moisture design criteria for assemblies and details (see Section 3.4 and Appendix B)
- Quality-related prescriptive design elements (see Section 3.5)
- Field quality assurance inspections (see Section 3.6)
- Contractor declaration (see Section 3.9)

3.1.3 Optional Additional Certification Badges

- Supply air heating and cooling sufficient
- Source net zero

2 The space conditioning criteria are all per square foot of interior Conditioned Floor Area (iCFA). (See Section 4.4.1.4.) The heating and cooling criteria are determined from formulas based mainly on local climate factors including degree-days, outdoor design temperatures, design humidity, and annual solar radiation. The formulas were developed from life-cycle cost optimization studies as described in the development report. [2] (See also Appendix C.) As a result, the heating criteria also depend secondarily on energy prices (on a state-by-state average basis), because higher electricity prices justified more investment in heat-saving upgrades. The energy price effect was not statistically significant for cooling, thus the cooling criteria depend only on climate factors. The annual heating and cooling demands, and the peak heating load, are to be calculated by WUFI Passive or PHPP, which generally follow the monthly-method path of ISO 13790 for the annual demands and EN 12831 for the peak heating load. [11] [12] See Section 6.1.1 for accepted software versions. For the peak *cooling* load, for the time being there is an option to calculate either by WUFI Passive/PHPP, or by ACCA Manual J, for residential projects. [13] The peak cooling load target varies depending on the calculation method – Manual J includes latent but WUFI Passive/PHPP is currently only sensible. (A future version of WUFI Passive will be compliant with Manual J calculation for residential and ASHRAE 183 for nonresidential.) [14]
3 Annual Cooling Demand is total cooling, latent plus sensible.
4 See detailed explanation in Section 3.2 below.

5 Occupancy is determined by the # of bedrooms + 1, per unit. The plan is to reduce the limit to 4200 kWh/person.yr over a few short years.
6 The primary energy limit for non-residential buildings is 38 kBTU/ft^2.yr. See additional details in Section 3.3 below.

3.1.4 Window Recommendations

As noted in Section 3.4 below, there is a "hard requirement" on window performance to avoid condensation risk. However, the space conditioning criteria are predicated on using windows better than that - with a low enough U-value to maintain at least 60 F interior surface temperature at the 12-hour mean minimum winter temperature. This design temperature is available for individual climate locations upon request, but it is generally recommended to follow the zone-by-zone guidelines on the PHIUS window program page.

3.2 Air-tightness Criterion

Normative:

A whole-building test for air tightness must be performed. See Section 3.8 for further details. If testing at 75 Pa, report the flow coefficient and exponent from the blower door tests.

The certification requirement is as follows:

For buildings of five stories and above that are also of noncombustible construction:

q50 <= 0.080 CFM$_{50}$/ft^2 or q75<= 0.100 CFM$_{75}$/ft^2 of gross envelope area

For all other buildings:

q50 <= 0.050 CFM$_{50}$/ft^2 or q75<= 0.080 CFM$_{75}$/ft^2 of gross envelope area

Gross envelope area is measured at the exterior of the thermal boundary, the same as for the energy model, and includes surfaces in contact with the ground.

Exception, for non-threatening air leakage: If the air-tightness criterion is missed, and the extra leakage can be proven to be due to a non-assembly-threatening leakage element, certification staff may allow that element to be taped off for the purpose of passing the air-tightness criterion. The un-taped test result must be used for the energy model. Further details are subject to staff interpretation as detailed below.

Informative:

Exception

Non-threatening leakage elements which may be taped upon PHIUS approval:

- Fire Rated Entry Doors - leakage through operable components
- Entry Doors with Panic hardware requirements - leakage through operable components
- Entry door thresholds with universal accessibility requirements - leakage at threshold/sweep
- Elevator Doors - leakage through operable components into shaft
- Dampers - leakage at seal

- Trash chutes and compactor systems, code required dampened openings like elevator shaft vents, gas meter room vents, coiling doors
- Direct Vent Gas Fireplace – leakage through firebox
- Window mounted space conditioning unit – leakage through unit itself or through gasket inset in window glazing or window frame (some frames present durability risk and certifier has discretion to decline request for taping)

Non-threatening leakage elements already accounted for in the cfm/ft^2 gross envelope limit. May not be taped.

- Standard Casement/TT/Awning Windows - leakage through operable components
- Standard Lift and Slide Doors - leakage through operable components Standard Balcony/French Doors – leakage through operable components
- Duct/vent leakage if fully exposed and in conditioned space

Threatening leakage sources. May not be taped.

- Window or door installation - leakage at rough opening
- Duct/vent/wiring - leakage at penetration of exterior wall
- Duct or vent - leakage inside assembly
- Exterior wall mounted space conditioning unit installation– leakage through rough opening

The "crossover" for comparison to 0.6ACH50 is at roughly 10,000 square feet of envelope area. Projects larger than this will be slightly tightened from the 0.6ACH50 metric and projects smaller than this will be slightly loosened from the 0.6ACH50 metric.

The higher limit for tall buildings should be considered temporary – more research is needed and the criterion might be tightened in the future.

Background

The PHIUS Technical Committee goal was a clear standardized building enclosure metric for <u>all</u> buildings, large and small. ACH_{50} is not an equitable metric since the volume of a building does not scale at the same rate as surface area. PHIUS views the primary purpose of the air-tightness threshold as the reduction the risk of building assembly damage due to air-leakage driven moisture in super insulated assemblies with minimized mechanical systems, and energy efficiency as the secondary purpose.

Establishing a maximum durability leakage rate recognizes that in many smaller buildings, while the conversion of a 0.05 cfm/ft^2 leakage limit to ACH_{50} results in a threshold higher than 0.6 ACH_{50}, the driver behind a project team's leakage target for these structures will be achievement of energy performance thresholds, rather than durability.

Testing at 75 Pa aligns with commercial code (IBC, IECC) and U.S. Army Corps of Engineers (as well as U.S. General Services Administration Facilities Standards, ASTM E779, ASHRAE 90.1, and the National Building Code of Canada.)

Related Documents

1. Acceptable Air Tightness of Walls in Passive Houses – Salonvaara and Karagiozis 2015
2. PHIUS Technical Committee Airtightness Comparison

3.3 Primary Energy Criterion

As mentioned in the standard-adaptation development report, there is a certification limit on primary (a.k.a. source) energy use because that is a good measure of the impact that the building's operation has on society. [15] That impact consists mostly of CO_2 emissions but the source energy metric differs from carbon-scoring in that it includes the impact of nuclear power as well.

3.3.1 Non-residential buildings

The annual primary energy limit for non-residential buildings is 11.1 kWh per square foot of interior conditioned floor area (iCFA), equivalent to 38 kBTU/ft^2.yr or 120 kWh/m^2.yr. See Section 4.4.1.4 for the iCFA calculation rules.

For commercial buildings with process loads, PHIUS will determine the primary energy allowance on a case-by-case basis.

3.3.2 Residential buildings – low rise and high rise

Buildings considered residential include single-family detached housing, single-family attached housing, multifamily buildings, excepting hotels and motels.

The primary energy (PE) limit for both low and high-rise residential buildings is 6200 kWh/person.yr. (The plan is to reduce the limit to 4200 kWh/person/yr over a few short years.)

For purposes of the PE limit, the number of persons, the design occupancy, is taken to be the number of bedrooms+1, on a per unit or unit-by-unit basis (e.g., four two-bedroom units have a design occupancy of twelve, not nine.)

- Note that when the floor area per person is greater than about 500 square feet, the primary energy criterion becomes very hard to meet.

3.3.3 Mixed-use buildings

The residential limit also applies if the building has common spaces and conditioned spaces that are not dwelling units, but that primarily serve the residents. Nonresident occupants of such common spaces (staff) are not included in the occupant count for determining the primary energy allowance. (Nor do they determine lighting and miscellaneous energy use of the common spaces, as explained in Section 6.6.1.1.)

If there are non-residential spaces designed to mainly serve non-resident customers/clientele, an additional PE allowance may be calculated based on the iCFA of those spaces. The nonresident occupants of such spaces, the staff and customers, are not included in the occupant count for determining the per-person portion of the primary energy allowance.

Certification staff may require separate modeling of the residential and nonresidential parts of a mixed-use building.

3.3.4 Renewables credits

Solar thermal:

An active solar thermal system is regarded as reducing the source energy demand associated with water heating and, if so configured, space heating as well. The system is not regarded as reducing the space heat demand itself.

Solar PV and other renewable electricity:

An estimate of coincident production-and-use of energy from renewable energy systems (such as PV) may be included in the calculation similarly to the way solar thermal systems are treated, that is, the limit applies to primary energy consumption net of that generation.

NREL's PVwatts calculator may be used to calculate PV array output. [16]

The amount of source energy that may be offset by a renewable electricity source depends on the utilization factor. This can be calculated by determining the coincident production-and-use fraction of the generation. If only using PV without battery storage, PHIUS' pre-defined utilization curves may be used to determine the utilization factor. These curves can be found in the PHIUS+ 2015 Calculator, (OR, download here). If using more than one renewable electricity generation technology on-site, electrical battery storage, or for off-grid buildings, see Appendix A.

Process for determining Primary Energy reduction **in WUFI Passive** from grid-tied PV without battery storage:

1. Run the PV Watts calculator for the location and note the annual output in kWh. http://pvwatts.nrel.gov
2. Take the annual output of the system from PV Watts and divide it by the Annual kWh Demand of the site *electricity* for the building (this is less than the site energy if there are other fuels.)
3. Find the fraction on the horizontal axis in the corresponding climate specific utilization curve to get a % utilization.
4. In WUFI Passive, under 'Systems', add a photovoltaic device, input the value found in Step 1 as the 'Photovoltaic/renewable energy'.
5. Add the value found in Step 3 as the 'Onsite Utilization'.

Process for determining Primary Energy reduction **in PHPP** from grid-tied PV without battery storage:

1. Run the PV Watts calculator for the location, note the annual output in kWh. http://pvwatts.nrel.gov
2. Take the annual output of the system from PV Watts and divide it by the Annual kWh Demand of the site *electricity* for the building (this is less than the site energy if there are other fuels.)

3. Find the fraction on the horizontal axis in the corresponding climate specific utilization curve to get a % utilization.
4. Multiply the utilization % by the annual output of the system from PV Watts.
5. Take the result from 4 and multiply by 3.412 (kBTU/1 kWh) to determine the kBTU of site energy offset.
6. Multiply the result from 5 by the 3.16 (kWh/kWh) PE factor for electricity to determine the primary energy offset.
7. Divide by the iCFA to get kBTU/ft^2yr.
8. Subtract result from number 7 from the calculated primary energy demand shown on the Verification page in the energy model.

See Section 6.11 for example calculations.

3.3.5 Tip: Determining Equivalent Primary Energy Allowance, in PHPP

For a residential project modeled in the IP version of PHPP, the final output for Primary Energy in the energy model will be kBTU/ft^2.yr.

To determine the PHIUS+ 2015 primary energy target, calculate the design occupancy as the number of bedrooms plus one (unit-by-unit), multiply by 6200 kWh, multiply by (3.412 kBTU/1 kWh), and divide by the iCFA.

Example: 4-bedroom house, 2000sf iCFA

(5 persons * 6200 kWh/person/yr * 3.412 kBTU/kWh)/2000 ft^2 =

PE Limit: 52.9 kBTU/ft^2.yr

Primary Energy Factor for Electricity Mix: Increases from 2.6 (or 2.7) to 3.16

*Note: Please revise the 'Data' sheet of the PHPP to reflect the higher PE factor if submitting for PHIUS+ 2015 certification.

3.3.6 Co-generation

There are two ways to operate a combined-heat-and-power (CHP) unit – on electrical demand or on heating demand.

On the "E-priority" path, the CHP is run independently of the heating load, with the intent of producing electricity, and the heat production is a byproduct, which may or may not be usable.

On the "H-priority" path, the CHP is run to match the heating demand (hot water and/or space heat), and the electricity produced while the CHP operates is regarded as a byproduct, that is either used on site or sold to the grid.

The H-priority path in turn has two variants depending on whether the backup heat is supplied by electricity or fuel combustion. See Appendix A for more details. The calculation protocol is implemented in the PHIUS Cogen PE Factor Calculator.

3.4 Moisture design criteria for assemblies and details

3.4.1 Minimum interior surface temperature for thermally-bridged construction details

Sometimes, if thermal bridge is significant enough, PHIUS may ask that an interior surface mold risk analysis be completed according to ISO 13788. The calculator can be downloaded here.

One of the "hard requirements" for certification pertains to avoiding mold growth on interior surfaces caused by thermal bridges. Even if a thermal bridge is tolerable in terms its impact on the space conditioning loads and demands, it is not tolerable if it can lead to mold growth on the inside. The protocol follows ISO 13788, and one of our calculator tools follows its methods. Just as in calculating the *energy* impact of a thermal bridge, the detail is modeled in THERM. But instead of calculating the extra energy loss, the critical result is the point of lowest temperature on the inside surface, and the criterion is that at that point, the interior air, when chilled down to that temperature, should be at less than 80% relative humidity.

ISO 13788 addresses how to determine the appropriate boundary conditions – the outside temperature and the indoor relative humidity. This is based on consideration of the monthly average outside temperature and humidity for the climate. The outdoor humidity is added to an indoor source that depends on one of five building humidity classes from low to high.

For each month, a psychometric calculation is then done to determine a minimum inside surface temperature needed to keep the RH at the surface below 80%.

The critical month is the one in which that minimum surface temperature is farthest from the outside temperature and closest to the inside temperature, because that requires the detail to be the most "insulating." This "surface temperature factor" (fRsi) of the building element is defined mathematically as

fRsi = (inside surface temp – outside temp)/(inside temp – outside temp),

with a surface resistance at the inside surface of Rsi.

(Usually the critical month is also the coldest month but not always – depending on the climate it might be in October, for example.)

3.4.2 Window condensation resistance

ISO 13788 also addresses assessment of condensation on "low thermal inertia" elements such as windows and doors, using a similar procedure, but with some differences: instead of keeping the RH below 80%, the goal is to avoid outright condensation (RH=100%), because windows and doors have impermeable surfaces that aren't as subject to mold, but vulnerable to rot and corrosion if outright wet. But the outside design temperature is more severe – instead of a monthly average, it calls for the lowest daily mean temperature of the whole year.

In October 2015 the PHIUS Technical Committee reached consensus on the general matter of setting a definite requirement to avoid condensation on windows, and directed Certification staff to develop protocol.

Currently, it is recommended to do a window condensation check when any of these risk factors are present:

- Window U-value significantly above the comfort requirement.
- Frame U-value significantly above the glass U-value.
- Presence of aluminum spacers.
- Lo-e coating on the inside surface of the glass.

The current passing criterion is that 1-D calculations on the surface temperatures or fRsi of the frame and the glass, or an AAMA CRF rating, should meet the ISO 13788 minimums at the ASHRAE 99.6% design temperature for the climate, with some safety margin, or that a CSA I-value meets it without a safety margin.

PHIUS has developed this calculator to determine if a window is at risk of condensation, based on the ISO 13788 protocol for "low thermal inertia" elements.

For example, with an interior RH of 48% in the coldest month, the dew point of the interior air is 47.7 F, so the inside surface must be warmer than that.

The calculator does a one-dimensional calculation with the frame U-value, for example 0.28, to determine if this is the case. Instead of the lowest daily mean temperature, use (for convenience) the ASHRAE 99.6% design temperature, as AAMA does for their Condensation Resistance Factor. Suppose this is 13.8 F.

With an interior temperature of 68 F, and an inside film resistance of 0.74 h.ft^2.F/Btu, the inside surface temperature then is 68-(0.29*0.74)*(68-13.8) = 56.7 F, that is, 9 degrees above the dew point.

Of course, this does ignore the fact that the surface temperature could be lower right in the corner where the frame meets the glass, because of the conductivity of the spacer, but 9 F provides a comfortable margin. ISO 13788 does caution that one-dimensional calculations aren't generally good enough, but it is a place to start.

Other Condensation Resistance Ratings

We have been asked whether we can specify an NFRC Condensation Resistance rating (CR). The AAMA recently published a good summary paper (AAMA CRS-15) that explains the differences between NFRC's Condensation Resistance (CR), AAMA's Condensation Resistance Factor (CRF), and the Canadian temperature Index or I-value, per CSA A440.2. All of these are 0-100% higher-is-better ratings, but they are not directly comparable to each other. [17]

From that paper it is clear that the CRF and the I-value are similar to what ISO 13788 calls fRsi – ratios that indicate how far some critical inside surface temperature is towards the inside air temperature. Therefore, if that data is available for a window of interest, those ratings could be compared directly to the required fRsi from a 13788 calculation for "low thermal inertia elements" for an indication as to whether a window is good enough in the climate location of interest.

The AAMA white paper indicates that the I-value is generally more conservative/stringent than the CRF due to differences in the temperature sensor placements. Both of these are physical tests.

AAMA provides an online calculator that takes a given outdoor temperature, indoor temperature, and relative humidity, and computes the dew point and the required CRF, so it is making the same kind of calculation as called for in ISO 13788. (The disclaimer for it makes many valid points.) [18]

The NFRC Condensation Resistance rating is more complicated and harder to interpret, except as a relative ranking. It is basically the percentage of the window frame, glass, or edge-of-glass area (whichever is worst) that is below dew point under the standard test condition temperatures, averaged over interior RH levels of 30, 50, and 70%. It is based on modeling rather than a physical test.

3.4.3 Limiting moisture risk in assemblies

3.4.3.1 Climate-appropriate wall and roof assemblies

It's important to avoid risks related to mold and moisture. Following the prescriptive guidelines in Appendix B will generally allow us to accept or "green light" an assembly in certification. Assemblies that do not comply are given a "yellow light". The next step is usually a request for revision of the assembly to follow the prescriptive guidelines. If revision is not possible or desired, next is a WUFI analysis. Sometimes a WUFI analysis will turn a yellow light green, but sometimes it will turn it red, in which case, we would require a letter from a qualified, licensed professional engineer, to the effect that the mold / moisture risk to the assembly is acceptably low.

- In general, we recommend against using wet spray cellulose.

3.4.3.2 Masonry walls and freeze-thaw

Interior insulation retrofits of masonry walls in cold climates can cause durability problems. Please review the information in these articles: [19] [20] [21] Certification staff may require a "hold harmless" agreement.

3.4.3.3 Floor/Slab Components

Fluffy Floors

- Floors are subject to "bulk water events" from above, and have trouble drying out.
- Framed floors with fluffy insulation and rigid on the bottom are riskier than all-fluff or all-rigid.
- For fluffy floors without rigid on the bottom, over crawlspace, hydrophobic insulation such as fiberglass or most preferably mineral wool, is preferable to cellulose (drain-down strategy instead of buffering.)
- Don't do: slab, with rigid on top, and then a framed floor with fluffy insulation on top of that. Such floors should be almost all rigid insulation with only a little fluffy insulation on top for sound deadening.

Framed floors with rigid & fluffy insulation

- Floors are preferably insulated with all rigid insulation, except for at most a thin layer of fluffy insulation near the inside for acoustic reasons.
- <u>Not certifiable</u>: mostly-fluffy floors directly on slabs, or with a thin layer of rigid on the bottom and slab or ground directly below. The risk of never drying out from a bulk water event is too high - repair would be very expensive, could entail removal of interior walls.
- <u>Certifiable</u>: partly fluffy floors over crawlspace or unheated basement, with 50% or more insulation value from rigid on the bottom. The floor structure is protected from humid

conditions below, is accessible from below for repair in the event of water from above, and the cold side of the fluffy insulation stays warm enough to be out of trouble with mold under normal conditions.

- Conditionally certifiable: partly-fluffy floors over crawlspace or unheated basement with less than 50% insulation value from outboard rigid, are acceptable if WUFI Bio analysis, assuming outside climate without rain or sun (stress case for cold-season moisture accumulation), shows green light at the outboard side of the fluffy insulation in the years after the initial dry-out.

3.5 Quality-related prescriptive design requirements (QA/QC Checklist Items for CPHC/Designer)

Most of the items on the PHIUS+ quality assurance checklist worksheets are the responsibility of the builder, but there are some that concern the designer as well. Those items are collected in this section for emphasis, along with some other prescribed items. For additional details on some items see the PHIUS+ Single Family Quality Assurance Workbook, and follow the Workbook in case of discrepancy with this document. (Please bring discrepancies to our attention.)

Fireplaces

A passive house can have a woodstove, woodstove fireplace insert or sealed combustion gas fireplace vented to the outside, but the stove or fireplace box needs to be airtight. In an airtight house there is great danger of back drafting or for the fireplace/stove using the interior air for combustion. Therefore the combustion intake air must be directly from the outdoors and independent of the interior air supply. Warning systems should be considered such as carbon monoxide detectors or depressurization sensors. If the building gets depressurized for some reason (one of the ventilator fans fails and the defect goes unnoticed) then, despite of all the precaution of airtight fire box and dedicated combustion air, back drafting could still occur and draw potentially life threatening gases into the interior of the building. Open and/or unvented fireplaces are prohibited in PHIUS+ projects.

Building Envelope

6.1: Fenestration shall meet or exceed **ENERGY STAR** requirements. Where triple glazed window assemblies with thermal breaks/spacers between the panes are used, such windows are deemed to meet this requirement even in the absence of an ENERGY STAR certification.

6.2: Ceiling, wall, floor and slab insulation shall **meet or exceed 2012 IECC insulation levels**. A total UA calculation may also be used to demonstrate compliance in lieu of individual component U-factors.

Insulation levels in a home shall meet or exceed the component insulation requirements in the 2012 International Energy Conservation Code (IECC).

The following exceptions apply:

Steel-frame ceilings, walls, and floors shall meet the insulation requirements of the 2012 IECC – Table 402.2.6.

1. For ceilings with attic spaces, R-30 shall satisfy the requirement for R-38 and R-38 shall satisfy the requirement for R-49 wherever the full height of uncompressed insulation at the lower R-value extends over the wall top plate at the eaves. This exemption shall not apply if the alternative calculations in d) are used;
2. For ceilings without attic spaces, R-30 shall satisfy the requirement for any required value above R-30 if the design of the roof / ceiling assembly does not provide sufficient space for the required insulation value. This exemption shall be limited to 500 sq. ft. or 20% of the total insulated ceiling area, whichever is less. This exemption shall not apply if the alternative calculations in d) are used;
3. An alternative equivalent U-factor or total UA calculation may also be used to demonstrate compliance, as follows: An assembly with a U-factor equal or less than specified in 2012 IECC Table 402.1.3 complies. A total building thermal envelope UA that is less than or equal to the total UA resulting from the U-factors in Table 402.1.3 also complies. The insulation levels of all non-fenestration components (i.e., ceilings, walls, floors, and slabs) can be traded off using the UA approach under both the Prescriptive and the Performance Path. Note that fenestration products (i.e., windows, skylights, doors) shall not be included in this calculation. Also, note that while ceiling and slab insulation can be included in trade-off calculations, Items 4.1 through 4.3 of the ENERGY STAR for Homes V3 Thermal Enclosure System Rater Checklist shall be met regardless of the UA tradeoffs calculated. The UA calculation shall be done using a method consistent with the ASHRAE Handbook of Fundamentals and shall include the thermal bridging effects of framing materials. The calculation for a steel-frame envelope assembly shall use the ASHRAE zone method or a method providing equivalent results, and not a series-parallel path calculation method.

6.3: All ceiling, wall, floor, and slab insulation shall achieve RESNET-defined Grade I installation or, alternatively, Grade II for surfaces that contain a layer of continuous, air impermeable insulation ≥ R-3 in Climate Zones 1-4, ≥ R-5 in Climates Zones 5 to 8.

See the RESNET Standards, Appendix A, page A11 to A16. [22]

Where ceiling, wall, or floor assembly insulation is installed "blind" between layers of sheathing and therefore cannot be visually inspected, such assemblies are deemed equivalent to a RESNET-defined Grade 1 installation if the assembly insulation level is at least 50% greater than the specified value for the DOE Challenge Home Target Home, based on nominal R-value.

6.4: For insulated ceilings with attic space above (i.e., non-cathedralized), Grade I insulation extends to the inside face of the exterior wall below at these levels: CZ 1-5: ≥ R-21; CZ 6-8 ≥R-30

6.5: For slabs on grade in CZ 4 and higher, 100% of slab edge insulated to ≥R-5 at the depth specified by the 2009 IECC and aligned with thermal boundary of the walls.

6.6: Insulation beneath attic platforms (e.g., HVAC platforms, walkways) ≥R-21 in CZ 1-5; ≥R-30 in CZ 6-8.

6.7: Reduced thermal bridging at above-grade walls separating conditioned from unconditioned space (rim / band joists exempted) using one of the following options: A) Continuous rigid insulation, insulated siding, or combination of the two; ≥R-3 in Climate Zones 1 to 4, ≥R-5 in Climate

Zones 5 to 8 or; B) Structural Insulated Panels (SIPS), or; C) Insulated Concrete Forms (ICFs), or; D) Double-wall framing (for example: double-stud wall or Larsen Truss wall) or; E) Advanced framing, including all five items listed in the PHIUS Plus Checklist Workbook.

Ventilation

The ventilation system must be capable of at least 0.3 ACH (based on the net volume) on its maximum setting.

1.9: On the outside of the building the supply and exhaust diffusers should be located at least 10 feet apart to keep from short circuiting exhaust air back into the house. All ventilation air inlets located at least 10 feet ("stretched-string distance") from known contamination sources.

Examples of contamination sources include: plumbing vents, exhaust vents, combustion exhaust, and vehicle exhaust. Exception: ventilation air inlets in the wall at least 3 feet from clothes dryer exhaust or contamination sources exiting through the roof.

Taking the supply air from above the roof is generally not recommended, because of the possibility of excessive heat and hot-roof odor.

1.11: Ventilation air inlets are at least 2 feet above grade in climate zones 1-3 and at least 4 feet above grade in climate zones 4-8, and are not obstructed by snow, plantings, outdoor equipment, or other material at the time of inspection.

Exception: 2 feet allowed in North Carolina CZ 4 and 2.5 feet in North Carolina CZ 5.

1.13: Ventilation air comes directly from outdoors, not from adjacent dwelling units, garages, crawlspaces or attics.

1.17: Outside air filter is located to facilitate regular service by the occupant/owner.

Ventilation requirements for nonresidential buildings have not been established. In many places compliance with the International Mechanical Code (Chapter 4) would be required. ASHRAE Standard 62.1-2016 also addresses ventilation for nonresidential spaces.

HRV filtering:

A minimum of MERV 8 filtration is required for all ventilation systems, as well as ducted heating/cooling systems.

MERV 12 or higher is recommended for filtration of the ventilation air.

Heating and Cooling

2.12: Cooling equipment latent capacity is at least 100% of latent load.

2.13: Cooling equipment sensible capacity is at least 100% of sensible load.

2.14: If latent cooling capacity is less than 100% of latent cooling load, then an Energy Star qualified dehumidifier must be installed.

2.15: Cooling equipment total capacity is 95%-125% of load for heat pumps, 95%-115% of load for air conditioners, or next nominal size.

2.28: Furnace capacity is 100-140% of load, unless a larger size is necessary for cooling equipment selection.

3.2: Duct layout and branch design airflow values are included in documentation folder.

3.3-F: Building cavities not used as supply or return ducts.

3.3-G: No ducts are installed in exterior assemblies or in unconditioned space.

Domestic Hot Water + Lights + Appliances

1: Project team has provided DHW drawings with lengths, diameter and insulation specs.

4: DHW system passes hot water distribution performance test.

For more information, see the EPA Watersense Guide for Efficient Hot Water Delivery Systems. [23] The associated design-aid calculator is posted here.

Indoor Air Quality

2.1: Approved radon-resistant features installed in Radon Zone 1 homes.

4.1: Equipment selected to keep relative humidity <60% in "Warm-Humid" climates (Exception: see spec).

4.2: Duct systems protected from construction debris and no building cavities used as air supplies or returns.

4.3: No air-handling equipment or ductwork installed in garage and continuous air barrier in adjacent assemblies.

5.1: Emissions standards met for fuel-burning and space-heating appliances (Exceptions: see spec).

6.1: Certified low-formaldehyde composite wood materials and structural plywood AND OSB PS1 or PS2 compliant.

6.2: Certified low-VOC or no-VOC interior paints and finishes used.

6.3: Carpet, carpet adhesives CRI Green Label Plus AND carpet cushion CRI Green Label.

Water Management System

Water-Managed Site and Foundation

1.1: Patio slabs, porch slabs, walks, and driveways sloped ≥ 0.25 inches per ft. away from home to edge of surface or 10 ft., whichever is less.

1.3: Capillary break beneath all slabs (e.g., slab on grade, basement slab) except crawlspace slabs using either: ≥ 6 mil polyethylene sheeting, lapped 6-12 in., or ≥ 1 in. extruded polystyrene insulation with taped joints.

1.4: Capillary break at all crawlspace floors using ≥ 6 mil polyethylene sheeting, lapped 6-12 in., & installed using one of the following options.

> **1.4.1:** Placed beneath a concrete slab; OR,
>
> **1.4.2**: Lapped up each wall or pier and fastened with furring strips or equivalent; OR,

1.4.3: Secured in the ground at the perimeter using stakes.

1.5: Exterior surface of below-grade walls of basements & unvented crawlspaces finished as follows:

For poured concrete, masonry, & insulated concrete forms, finish with damp-proofing coating.

For wood framed walls, finish with polyethylene and adhesive or other equivalent waterproofing.

1.6: Class 1 vapor retarder not installed on interior side of air permeable insulation in ext. below-grade walls.

1.8: Drain tile installed at the exterior side of footings of basement and crawlspace walls, with the top of the drain tile pipe below the bottom of the concrete slab or crawlspace floor. Drain tile surrounded with ≥ 6 in. of ½ to ¾ in. washed or clean gravel with gravel layer fully wrapped with fabric cloth. Drain tile level or sloped to discharge to outside grade (daylight) or to a sump pump.

Water-Managed Wall Assembly

2.1: Flashing at bottom of exterior walls with weep holes included for masonry veneer and weep screed for stucco cladding systems, or equivalent drainage system.

2.2: Fully sealed continuous drainage plane behind exterior cladding that laps over flashing in Item 2.1 and fully sealed at all penetrations. Additional bond-break drainage plane layer provided behind all stucco and non-structural masonry cladding wall assemblies.

2.3: Window and door openings fully flashed.

Water-Managed Roof Assembly

3.1: Step and kick-out flashing at all roof-wall intersections, extending ≥ 4" on wall surface above roof deck and integrated shingle-style with drainage plane above; boot / collar flashing at all roof penetrations.

3.2: For homes that don't have a slab-on-grade foundation and do have expansive or collapsible soils, gutters, and downspouts provided that empty to lateral piping that discharges water on sloping final grade ≥ 5 ft. from foundation or to underground catchment system not connected to the foundation drain system that discharges water ≥ 10 ft. from foundation. See Footnote for alternatives & exemptions.

3.3: Self-heating bituminous membrane or equivalent at all valleys & roof deck penetrations.

3.4: In 2009 IECC Climate Zones 5 & higher, self-sealing bituminous membrane or equivalent over sheathing at eaves from the edge of the roof line to > 2 ft. up roof deck from the interior plane of the exterior wall.

Water-Managed Building Materials

4.3: In Warm-Humid climates, Class 1 vapor retarders not installed on the interior side of air permeable insulation in above-grade walls, except at shower and tub walls.

Renewable Energy Ready

Exemption 1: Daily average solar radiation for the site less than 5 kWh/m2/day. As of April 2016 this exemption *no longer applies*.

Exemption 2: Location does not have significant natural shading (for example, from trees neighboring buildings, mountains, etc.) on the south-facing roof. If you answered "NO", then **STOP**, you do not have to complete the rest of the worksheet.

Exemption 3: Home as designed has adequate free roof area within +/-45° of true south as noted in Table 3.1 below. Note that in some cases a house may have insufficient roof area for the Solar Electric RERH checklist, but it may still have the minimum roof area for the solar thermal RERH Checklist and would therefore have to comply with the Solar Thermal RERH checklist. In other cases, the home may only have adequate south facing roof for the Solar Electric or Solar Thermal RERH Checklist, but not both. In that case the builder can decide which one of those two checklists to apply. If you answered "NO", then **STOP**, you do not have to complete the rest of the worksheet.

Table 3.1. Roof area sizing chart.

Photovoltaic		**Solar Water Heating**	
House Size (sq. ft.)	**Free South Roof Area**	**House Size (sq. ft.)**	**Free South Roof Area**
≤ 2000	110	≤ 2000	40
≤ 4000	220	≤ 4000	60
≤ 6000	330	≤ 6000	80
> 6000	440	> 6000	100

4: Does the house have a PV system? If you answered "YES", then you should only complete the solar thermal section below.

5: Does the house have a solar hot water system? If you answered "YES", then you should only complete the PV section below.

6: Architectural drawings are provided that show:

A proposed array location and square footage of available roof area (sq.ft.)

The orientation (azimuth) of the proposed array/s (180 degrees = true south) (degrees)

Identify the inclination/tilt for the proposed array location (degrees)

7: Provide code-compliant documentation of the maximum allowable dead load and live load ratings of the existing roof; recommended allowable dead load rating can support an additional 6 lbs/sq. ft. for future solar system.

8: Provide architectural drawing and riser diagram of RERH solar PV system components and solar hot water components, **OR**, provide the building owner with each of the following:

a) List of renewable-ready features
b) Available free roof area within +/- 45° of true south
c) Location of panel or blocking for future mounting of PV and SWH components

d) Location of Riser
e) Location of Breaker or slot for future breaker in electrical service panel
f) Copy of the Consolidated RERH Checklist
g) A copy of the RERH Solar PV Specification Guide
h) A copy of the RERH Hot Water Specification Guide

9: Install a 1″ metal conduit for the DC wire run from the designated array location to the designated inverter location (cap and label both ends).

10: Install a 1″ metal conduit from designated inverter location to electrical service panel (cap and label both ends).

11: Install a single 4″ chase or two 2″ chases from utility room to the attic space below designated array location (cap and label both ends).

12: Provide code-compliant documentation of the maximum allowable floor load rating for storage tanks installed on non-concrete floors.

13: Install and label a 4′ x 4′ plywood panel area for mounting an inverter and balance of system components. **Alternative:** Blocking is permitted to be used as an alternative to the 4′ x 4′ panel. The area designated for the future panel to mount PV components shall be clearly noted in the system documentation.

14: Install a 70-amp dual pole circuit breaker in the electrical service panel for use by the PV system (label the service panel). **Alternative:** Provide a labeled slot for a double-pole breaker in the electrical service.

Homes equipped with an ENERGY STAR qualified whole home gas tankless water heater or an ENERGY STAR qualified heat pump water heater are exempt from the remaining provisions of the checklist.

15: Install and label a 3′ x 3′ x 7′ area in the utility room adjacent to the existing water heater for solar hot water tank.

16: Install and label a 3′ x 2′ plywood panel area adjacent to the solar hot water tank for the balance of system components/pumping package. **Alternative:** Blocking is permitted to be used as an alternative to the 3′ x 2′ wood panel area designated for the future panel to mount solar HW components shall be clearly noted in the system documentation.

3.6 Quality Assurance requirements and Rater Information

PHIUS+ uses the Energy Star and DOE Zero Energy Ready Home programs as prerequisites (for all single family projects, and most other residential projects). Therefore, all single-family projects will use the Energy Star, Zero Energy Ready Home and PHIUS+ checklist items for their on-site QA process and will earn Energy Star, Zero Energy Ready Home and PHIUS+ certifications.

The PHIUS+ Single Family Quality Assurance Workbook incorporates all of the checklist items into a single document.

All of the checklists, site visits and tests are managed by the PHIUS+ Rater. The PHIUS+ Rater also handles the actual submissions for Energy Star and DOE Zero Energy Ready Home certification.

The Energy Star for Homes and Zero Energy Ready Home program and checklists are geared toward single-family houses. Multifamily buildings have their own quality assurance protocol. Please download the PHIUS+ Multifamily Quality Assurance Protocol.

Canada and California regulations present different circumstances. Generally, the only cases where a single-family PHIUS+ project may **not** earn Energy Star or ZERH are cases of:

1. Retrofits (some of the time)
2. Projects in California and Alaska
3. Projects in Canada / International Projects

Once all required documents have been provided and the project has passed the Pre-Certification review, the following documents will need to be updated or provided when construction has been concluded:

- Air tightness testing report, both pressurization and depressurization.
- Ventilation system commissioning report.
- Declaration of the construction supervisor (see below in Section 3.9 for example)
- 7 photos: 1 main, 6 additional. At least 3 of the finished project for the PHIUS online database.
- Exterior photos of each façade and surrounding site
- Representative photos of the various insulated assemblies, window and door installs
- Representative infrared photos, inside and outside
- Applicable PHIUS+ Quality Assurance Workbook.
- REM/Rate Model (if applicable).
- HERS Certificate (if applicable).

3.7 Hiring a PHIUS+ Rater/Verifier

We recommend contacting a PHIUS+ Rater as soon as certification becomes a goal for the project, and incorporate them into the project team early on. PHIUS asks that you hire a Rater when you submit a project contract to PHIUS at the start of Certification.

Find a PHIUS+ Rater.

When there is no PHIUS+ Rater within a 2-hour drive of the project location, for one project only, we allow the project team the option to use someone closer who is a RESNET HERS Rater (or CalCerts Rater in California, or EnerGuide Rater in Canada). In this case, the PHIUS Quality Assurance Manager will have to work with the Rater to bring them up to speed on PHIUS+ on-site requirements. After the first project, the project team will need to use someone who is a PHIUS+ Rater - this gives their Rater-of-choice some time to get trained.

PHIUS acknowledges that the addition of this component to our certification does raise fees. However, we also feel strongly that it helps create higher quality buildings.

PHIUS has not set a fee structure for the PHIUS+ Raters to charge for their services. For a single family home, expect 20 hours of work at the PHIUS+ Rater's hourly rate (typically $75-$125 per hour depending on market). This does assume a relatively straightforward process. Significant problems could result in more time needed, but simple homes may expect less time for completion.

Be aware that travel can significantly affect the quote the project team receives from a PHIUS+ Rater.

Typical site visits for the Rater:

1. Sub-slab insulation check.
2. Preliminary blower door test.
3. Insulation quality check.
4. Final blower door, ventilation commissioning, final Quality Assurance Workbook.

Coordination of the site visits and design review by the PHIUS+ Rater should occur between the rater and the project team. The number of site visits is up to the Rater. If they are close by, we encourage them to see the slab insulation in person. However, they can choose just to collect photos. Preliminary blower door testing is, strictly speaking, optional, however, it is strongly encouraged.

3.8 Blower Door Instructions

Personnel:

The PHIUS+ Rater will perform the blower door testing.

Net Air Volume:

First, determine the net air volume for the blower door test. To determine the net air volume, calculate the home's interior volume (drywall to drywall floor to ceiling, wall to wall) minus volume taken up by interior walls and floor systems.

Building preparation:

The building should be prepared for the test according to: RESNET – Mortgage Industry National Home Energy Rating Standards – Chapter 8, quoted below:

"802.2 Protocol for Preparing the Building Enclosure for Testing

> **802.2.1 Doors and windows that are part of the conditioned space boundary shall** be closed and latched.
>
> **802.2.2 Attached garages:** All exterior garage doors and windows shall be closed and latched unless the blower door is installed between the house and the garage, in which case the garage shall be opened to outside by opening at least one exterior garage door.
>
> **802.2.3 Crawlspaces:** If a crawlspace is inside the conditioned space boundary, interior access doors and hatches between the house and the crawlspace shall be opened and exterior crawlspace access doors, vents and hatches shall be closed. If a crawlspace is outside the conditioned space boundary, interior access doors and hatches shall be closed. For compliance testing purposes, crawl-space vents shall be open.
>
> **802.2.4 Attics:** If an attic is inside the conditioned space boundary, interior access doors and hatches between the house and the conditioned attic shall be opened; and attic exterior access

doors and windows shall be closed. If an attic is outside the conditioned space boundary, interior access doors and hatches shall be closed and exterior access doors, dampers or vents shall be left in their as found position and their position during testing shall be recorded on the test report.

802.2.5 Interior Doors: Shall be open within the Conditioned Space Boundary. See the definition of "Conditioned Space Boundary" for clarification.

802.2.6 Chimney dampers and combustion-air inlets on solid fuel appliances:

Dampers shall be closed. Take precautions to prevent ashes or soot from entering the house during testing. Although the general intent of this standard is to test the building in its normal operating condition, it may be necessary to temporarily seal openings to avoid drawing soot or ashes into the house. Any temporary sealing shall be noted in the test report.

802.2.7 Combustion appliance flue gas vents: Shall be left in their normal appliance- off condition.

802.2.8 Fans: Any fan or appliance capable of inducing airflow across the building enclosure shall be turned off including, but not limited to, clothes dryers, attic fans, kitchen and bathroom exhaust fans, outdoor air ventilation fans, air handlers, and crawl space and attic ventilation fans. ***Continuously operating ventilation systems shall be turned off and the air openings sealed, preferably at the exterior terminations.***

802.2.9 Non-motorized dampers which connect the conditioned space to the exterior or to unconditioned spaces: Dampers shall be left as found. If the damper will be forced open or closed by the induced test pressure, that fact shall be reported in the test report. Clothes dryer exhaust openings should not be sealed off even if there is no dryer attached but this fact should be noted in the test report.

802.2.10 Motorized dampers which connect the conditioned space to the exterior (or to unconditioned spaces): The damper shall be placed in its closed position and shall not be further sealed.

802.2.11 Un-dampered or fixed-damper intentional openings between conditioned space and the exterior or unconditioned spaces: Shall be left open or fixed position, however, temporary blocking shall be removed. For example: fixed-damper ducts supplying outdoor air for intermittent ventilation systems (including central-fan- integrated distribution systems) shall be left in their fixed-damper position. *Exception:* Un-dampered supply-air or exhaust-air openings of *continuously operating* mechanical ventilation systems shall be sealed (preferably seal at the exterior of enclosure) and ventilation fans shall be turned off as specified above.

802.2.12 Whole building fan louvers/shutters: Shall be closed. If there is a seasonal cover, install it.

802.2.13 Evaporative coolers: The opening to the exterior shall be placed in its off condition. If there is a seasonal cover, install it.

802.2.14 Operable window trickle-vents and through-the-wall vents: Shall be closed.

802.2.15 Supply registers and return grilles: Shall be left open and uncovered.

802.2.16 Plumbing drains with p-traps: Shall be sealed or filled with water, if empty.

802.2.17 Combustion appliances: Shall remain off during the test."

<u>Test Method:</u>
The blower door testing should be computer-controlled using automated testing software (such as "Tectite" from The Energy Conservatory or "Fantestic" from Retrotec). The PHIUS+ Rater will conduct multi-point testing in both pressurization and depressurization modes. The test method in the automated testing software should be set as "RESNET" or "ASTM E779". The final ACH_{50} for certification purposes is the average of the two results.

<u>Documentation:</u> The project team or PHIUS+ Rater will submit PDF reports from the automated testing software documenting the test results.

3.9 Contractor Declaration

The intent of the Contractor Declaration is to have a written statement of proof that the as built building conforms to the provided documentation. This information will be verified through the site tests as performed by the PHIUS+ rater.

Here are some sample wordings:

I, _______________, as general contractor of the ________________ (project) located at _____________________ (address), confirm that the documents supplied to PHIUS on _____________ (date) are identical to the finished project.

Any discrepancies or changes are listed here: _______________________.

This declaration certifies that the ________________ (project) located at _____________________ (address), has been constructed according to the technical specifications in the ____________ energy model, which has been populated based on the drawings submitted on _______________ (date).

There are no deviances from the file or any of the supporting documentations that have previously been submitted to PHIUS.

These declarations should be placed on an official letterhead and signed by the construction supervisor or general contractor. These wordings can be adjusted, but these are good examples to start from.

3.10 Optional Additional Certification Badges

Additional recognition will be given to project designs that meet the regular requirements and also achieve any of the following performance goals:

3.10.1 Supply air heating and cooling sufficient

The design is supply air heating and cooling sufficient per WUFI Passive / PHPP static calculation, with average design ventilation rate no more 0.4 ACH. This is accomplished with low peak load design.

3.10.2 Source net zero

To meet the Source Net Zero badge, the building must generate as much energy as it uses, on an annual, source-energy basis. (Because total energy is addressed with a source energy criterion, when it comes to adding an extra badge for "zero", it was logical to base that on "source net zero".)

Onsite renewable electricity generation, above any that was already credited as coincident-production-and-use, counts toward source net zero with the same source energy multiplier for electricity, i.e. 3.16. In other words, with the primary energy factor for grid electricity at 3.16, every kWh electric generated on site is considered to neutralize 3.16 kWh at the source. Thus for an all-electric building, the same PV array (for example) that gives site zero also gives source zero.

It is different if the building uses other fuels - for example if the building made heavy use of biomass for heating, the overall source/site ratio of its usage might be only 1.5, while the source/site ratio of the PV is 3.16. Therefore on that building the PV array size for *source* zero would be smaller than the array size for *site* zero, because of the additional source-reduction strategy.

To determine if a project meets this badge, determine if the total estimated annual renewable energy production (with a utilization factor of 1) will offset the annual source energy. That is, the net annual source energy use $PE_{A,net}$ is calculated in the same manner as PE_A in Appendix A, but with $C_{RE} = 1$.

4. Process

- Pre-Process Paperwork
    - Review this PHIUS+ Certification Guidebook and all other information at http://www.phius.org including the clickable process steps outline.
    - Review and sign the PHIUS+ Certification Contract.
        - This contract must be requested by emailing certification@passivehouse.us.
    - Email (or mail) signed contract to certification@passivehouse.us.
    - Register and make payment via PayPal or request invoice for payment by check.

- Create a Project
    - Log on to PHIUS+ Project Database
    - If necessary, PHIUS will create account or give access to submit projects.
        - For CPHCs, this should not be necessary.
    - Create a project by adding at minimum a project name and location. Other information can be added at a later time.
    - Once a project is created, PHIUS certifiers will be informed by the database. At this time, PHIUS will create a DropBox folder for the project, and invite the Submitter to the folder. The Submitter may invite other members of the project team.
    - **When ready for a review, the project team must inform PHIUS that all documents have been prepared and uploaded to the DropBox.**
    - When the contract, payment, energy model, drawings, and specifications have all been submitted or uploaded, the project is added to the PHIUS+ review queue.

- Quality Assurance and Quality Control
    - The QA/QC components of PHIUS+ Certification performed by PHIUS+ Raters are an essential part of the PHIUS+ Process.
    - That PHIUS+ component is covered under a separate contract between the project team and the rater.
    - For more information about the PHIUS+ Rater process, see Section 3.6, 3.7, and 3.8.

- Incentives
    - With the addition of a QA/QC process, PHIUS+ Projects are now able to gain more performance based incentives.
    - Since 2013, PHIUS has partnered with the Zero Energy Ready Home Program as well as Energy Star for Homes. These programs are pre-requisites for PHIUS+ Certification. Your PHIUS+ Rater will complete documentation for all of these programs during their on-site visits, and the project will be awarded recognition from all three.

        - Most projects will automatically receive a RESNET HERS Index score as part of certification. The RESNET HERS Index is the leading industry standard by which a home's energy efficiency is measured. Many local, state, and federal financial incentive programs require a HERS Index to demonstrate compliance.

    - PHIUS+ Certification (Final Stages)
        - Take the verified results from the on-site rating and adjust the documentation accordingly.
        - PHIUS will adjust the final WUFI Passive or PHPP energy model to match the verified results.
        - Upload final drawings, documents, pictures, etc. to the DropBox.
        - PHIUS will review the final documentation and issue the PHIUS+ Certified Passive House Certificate.
        - Purchase PH Certified Project Plaque ($75 additional cost, not required). *Information on this can be found on the Certification page of the PHIUS website. *If project qualifies for PHIUS+ Source Zero, an additional plaque is available for $75.

4.1 General Tips During the Process

- When uploading new information, please also update the feedback form, so that we know what has changed. The feedback form is the primary communication channel. It covers all the bases, that is, it serves also as a checklist. It is a written record and keeps everything in one place so it keeps straight what was said by whom and when on each point.
- Communication by phone or email can be used from time to time, but these outside discussions should be captured in the feedback form.
- Likewise, when uploading new feedback, please give it a final run through to make sure that if you refer to new information, that those documents are in fact uploaded to the DropBox - and, that the noted adjustments to the energy model were implemented.

From time to time we may ask for changes to the energy model even if it looks like the change will probably have a small impact, or in cases where there are two mistakes but net result is a wash. There are two reasons for this: one is educational—on the next project it may make more of a difference and we don't want people to repeat mistakes. The other is to improve the chances that the model will match actual energy use if the comparison is ever made.

4.1.1 Timeline

Generally, projects can expect the follow review timeframes:

- Round 1: 4-8 weeks
- Round 2: 4-6 weeks

- Round 3: 2-4 weeks

The overall certification process timeline is highly variable, and depends on the response time from both the reviewer and the submitter. It also depends on the completeness and accuracy of the first submission.

4.2 PHIUS+ Project Database Access

Go to the PHIUS+ Certified Projects Database

The **Login Link** is at the top right of the page.

A current PHIUS Certified Passive House Consultant can simply log into their CPHC database account. To create a new a project, click on the "New Project" button and following the instructions in Section 4.3. If you have any questions about logging into your account, contact certification@passivehouse.us.

If you are not currently a Certified Passive House Consultant, please request login information to log into the system as a Project Submitter. This will be created once the certification fee is paid and the certification contract is signed.

Once in the system, a Submitter can fill in project information to the PHIUS Projects Database. All uploads should be added into the DropBox folder and PHIUS must be informed that the project is ready for PHIUS' review so the certification team can add the project into the review queue. A project will not be reviewed until the Certification Fee and Contract is on file, and the project reaches the front of the review queue. When all of the required documentation and models have been uploaded, please double check with PHIUS that your project is noted as ready for review.

4.3 Database/DropBox Instructions and Tips

Creating a New Project in the Database

To begin a new project, log into the system then:

Click the "New project" button near the top of the page. A comprehensive form of project detail fields will appear.

***Note**: Most of these fields will be completed later in the process, and many cannot be completed until the project proceeds. (Once the project is ultimately pre-certified or certified, many of these fields will be viewable to the public.)*

To create a new project in the PHIUS Project Database, you initially need only complete the following fields:

- Project Name: (e.g. Dublin Project)
- Project Location

Click the "Add project" button.

*If the information is available, we prefer that you also select the 'building function', input the floor area and number of units.

After your project is created, PHIUS will create a DropBox folder for the project, and invite the Submitter to the folder. The Submitter may invite other members of the project team.

A few important notes:

- We strongly encourage you to click the "Add project" button as soon as you have added the key pieces of project information listed above. That creates the record and puts the project in the system.
- **The database "times out" often, so if you are inputting the project details, be sure to save often or the information will be lost.**
- Uploading can take some time depending on the size of your file(s). **Do not click** "Add project" again or attempt to make any changes during the upload. Doing so can create duplicate projects, in which case you'll need to email certification@passivehouse.us so that we can delete duplicates.
- Upon successful upload, you will see a screen that indicates the project has been created.
- Important: To review or edit your project, click the "Edit" button at the end (right side) of the project listing. Do not use the "Back" button on your browser. In general, use the "Edit" button, or to return to the basic project listing, click "Projects" in the upper right of your screen.

As the project submitter you will be able to add to or modify the project until the project is marked as Certified by the PHIUS certifier.

Notes on Project Details fields

- Projects that reach Pre-Certification status will be accessible by public search of the PHIUS+ Certification Database. Please note that not all information supplied for certification will be visible. In fact, only a subset of the Project Details fields will be listed, as well as photographs.
- The "Units" field in Project Details refers to the number of living quarters (not measurement units).
- Cost fields will only accept digits. Do not include commas or dollar signs.

4.4 Required Submission Documentation

Project Documentation:

For PHIUS to begin a Project Review, the following documents need to be added to the DropBox:

0. Energy Model
1. Drawings

For PHIUS to pre-certify a project, the following documents must be added to the DropBox and approved by the PHIUS+ Certification team:

0. Energy Model
1. Drawings

2. Specifications

All other documentation must be added to the folders before Final Certification can be awarded.

The following does not need to be completed for Pre-Certification (though any additional information available should be uploaded):

- Airtightness Reports
- Ventilation Commissioning
- Contractor Declaration
- Photos
- PHIUS+ Rater Workbook

4.4.0 Energy Model

For Accepted Modeling Software, see section 6.1.1.

The energy model must be:

- Fully complete with all branches/pages filled out.
    - The Pre-Certification review can begin without all final specifications developed for such items as appliance types or mechanical systems – but building envelope components should be specified for the first review.
- Congruent with the rest of the submitted documentation.

4.4.1 Construction Drawings

The construction drawings should be submitted in .PDF format and cover the following list of documents:

Design Drawings:

- Plans
- Sections
- Elevations

Detailed Drawings

- Show all junctions of the thermal envelope
    - Exterior and interior wall junctions to the basement floor or slab
    - Exterior junctions to roof or ceiling
    - Window installation conditions (including reveal dimensions)
    - any exterior anchoring systems for balconies or awnings
- Airtight details
    - Window Installations
    - Building component connections
    - Penetrations
    - The airtight layer must be marked and its details comprehensive at all junctions.

- All details must be fully annotated with dimensions and information regarding materials and thermal conductivity.
- Airtight details must be comprehensible and show a continuous uninterrupted barrier that forms from the different materials and components.

Thermal Envelope

- Must be clearly identified.
- Thermal bridges need to be called out.
- Best accomplished using section or elevation drawings with exterior dimensions.

Mechanical Drawings

Mechanical drawings need to show:

- Ventilation
    - Duct layout and sizes
    - Airflow rates at each diffuser and the diffuser location
    - Soundproofing, filters, pressure overflows
    - Supply and extract air values
    - Outdoor intakes of exhaust and supply
    - Duct insulation
    - Duct length from the inside of the exterior wall to the ventilation unit
- Heating and Cooling
    - Location of elements - both point source and supply air
    - Size of elements
    - For incentives Manual J/D calculations or dynamic simulation may become necessary.
- DHW System
    - Type of tank(s) and system
    - Comprehensive length of the DHW pipe length calculation as described in the energy modeling protocol section of this guidebook (see Section 6.10).
- Additional systems (solar thermal, defroster, ground loop, earth tube, etc)
  *In climates that need a defrost for their ERV/HRV, we require a pre-heater defrost to be installed rather than relying on re-circulation defrost.

4.4.1.1 Ventilation Calculations

- Gross Building Volume
    - Total enclosed volume of the building
    - Uses exterior dimensions, to the edge of the thermal boundary to calculate
- Net Air Volume
    - The real building volume for use with the ACH50 pressurization tests
    - Total volume within the building envelope - drywall to drywall
    - Important to calculate accurately – see Section 3.8.

4.4.1.2 Site Plan

Needs to show:

- The buildings orientation
- Changes in topography (if applicable)
- The location and height of neighboring buildings or structures
- The location and height of trees or ground levels that cast lateral shadows

The site plan and site shading photos together must show the complete shading situation. If necessary, other drawings should be included.

4.4.1.3 Site Shading

PHIUS requires a shading study on the project site. We will need sky-dome or sky-panorama images for each façade, with overlaid measurement grids. Solar PathFinder images are preferred. However, other methods are acceptable. No special programs need to be purchased to analyze the Solar Pathfinder images. A free analyzer is included in the shading protocol package linked below. If this link will not work for you, please contact PHIUS for the Shading Protocol Package.

Download shading protocol package

4.4.1.4 Interior Conditioned Floor Area (iCFA)

Briefly, iCFA is the interior-dimension (drywall-to-drywall) projected floor area of the conditioned spaces with at least seven feet 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′ 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. (The general concept is "walkable").
- Other than open-to-below, the projected floor area of all spaces within this 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′ height rule, some floor area under the stairs on the 1st floor would be excluded. This conflict is resolved by including it).

Naming Conventions

PHIUS has not dictated strict naming conventions. However, naming conventions should be included for all windows and areas. These should be clearly labeled and easily understood by a reviewer unfamiliar with the project. The best way to do this is to label the drawing and have the labels in the drawings match the labels used in the Energy Model. There should be enough overlap in the names such that each window and door can be positively identified. Often, following a logical rotation (such as clockwise) is helpful. A copy of the drawing set that is annotated specifically for PHIUS+ Certification is extremely helpful and preferred. All penetrations should be listed.

Formats and Sizes

PHIUS does not dictate drawing scales though they should be large enough to be comprehensive and readable. PDF is the preferred drawing file format. PHIUS respects the intellectual property right you have for your details and drawings. This concern should not inhibit the sending of drawings, specifications, or other documentation. Remember that comprehension of a project by an outside party (PHIUS) is the goal. The easier it is to understand a project the quicker and less costly the certification will be for all parties involved.

4.4.2 Technical Specifications

- Data Sheets and performance specifications are necessary for all values input into the energy model
- This should include documentation from third party agents including earth tube efficiencies, shading calculations, appliance energy usage, and any other exteriorly derived values
- It is best to have this information available and formatted ahead of the Pre-Certification process

The following Sections: 4.4.3-7 must be submitted for final certification along with any updates to Sections 4.4.1 and 4.4.2.

4.4.3 Pressure Test Verification

- Must be performed by an approved PHIUS+ Rater.
- Must be a multipoint test of both pressurization and depressurization.
- The final result is the average of pressurization and depressurization.
- See Section 3.8 for test protocol details.

4.4.4 Ventilation Commissioning

Will be completed by an approved PHIUS+ Rater/Verifier and should include the following information:

- Description and location of the project.
- Name and address of the Rater.
- Time and date of commissioning.
- Manufacturer and model number of ventilation unit.
- Adjusted volumetric flows per diffuser - both supply and exhaust.
- Flow comparison between supply and exhaust airstreams as measured between the unit and the exterior, or the interior before any branch ducts (imbalance <10%).
- Power draw of the ventilation unit at nominal speed.

4.4.5 Declaration of the Construction Supervisor

- See Section 3.9 for an example.

4.4.6 Photographs

- 1 main photo, 6 additional.
- At least 3 photos of the final project.
- Exterior photos of each façade and surrounding site
- Representative photos of the various insulated assemblies, window and door installs
- Representative infrared photos, inside and outside
- Documentation for the construction is also acceptable.

4.4.7 Additional Documentation

- Examples could be shading studies, extra calculations, system sizing, ground loop calculations, etc.

4.4.8 QA/QC Reports

- Supplied by the PHIUS+ Rater.
- Available to both the submitter and PHIUS.
- Submitter is able to update energy model and documentation based on reports.

4.5 PHIUS+ Feedback Document

The PHIUS+ Feedback Document is one of the main channels of communication between PHIUS and the project submitter. The document is used to track the pre-certification progress and includes feedback on the energy model, the drawings submitted, and specifications submitted. **Please inform your PHIUS reviewer when you have uploaded this document to the database or added it to your project's designated DropBox Folder.** When the submitter makes changes to the PHIUS+ Feedback Document, the updated energy model should also be uploaded.

5. PHIUS+ Certification Fee Schedule

PHIUS quotes a single fee for the full certification process, rather than a separate fee for pre-certification and final certification. Certification fees are based upon the project's calculated square feet of iCFA (interior conditioned floor area).

PHIUS' quoted fees do not include the cost of the QA/QC visits and final on-site testing, which are determined by the PHIUS+ Rater/Verifier of choice, see Section 3.7.

	0-2500 ft^2	**2501-4500 ft^2**	**4501+ ft^2**	**Hourly Rate**
PHIUS Professional (CPHC, Builder) & PHAUS member	$1080	$1480	Custom	$120/hr
PHIUS Professional (CPHC, Builder) & professionals in-training	$1282.50	$1757.50	Custom	$150/hr
Project Owner	$1350	$1850	Custom	$150/hr

Certified Passive House Consultants that are also PHAUS Professional Members receive a 20% discount.

Certified Passive House Consultants and CPHC-in-training (non PHAUS Members) receive a 5% discount.

Non-Profit Organizations such as Habitat for Humanity are eligible for a larger discount.

For projects larger than 4501 square feet, the price will be less per square foot, but will require a quote. To request a quote, please email certification@passivehouse.us

Here are some estimated fees for larger buildings:

iCFA	**10,000 ft^2**	**20,000 ft^2**	**50,000 ft^2**	**100,000 ft^2**	**200,000 ft^2**	**500,000 ft^2**
Base Fee	$3850	$6600	$9350	$12,100	$17,600	$34,100

PHIUS+ Certification Plaque $75
Source Zero Plaque $75

6. Energy Modeling Protocols

6.1 Getting started

6.1.1 Accepted Modeling Software

WUFI Passive: 3.0 or later

WUFI Passive Free: 3.0 or later

PHPP: 06-02-10 IP-overlay of v2007 through PHPP v8.5

Though not required for certification, consider also doing dynamic modeling (WUFI Plus) when:

- Cooling and/or moisture loads are high.
- Heating is discontinuous (during the heating period).
- Occupancy and indoor conditions vary considerably.
- Comfort and overheating have to be assessed.

If dynamic modeling seems called for, PHIUS suggests running a 3-zone dynamic model as a comfort analysis using WUFIplus (WUFI Passive dynamic side), or another dynamic energy model. The 3 zones would be coldest room, warmest room, rest-of-building. There are two possible approaches – one is to set the heating and cooling system capacities very high, and look for the per-square-foot differences in the heating and cooling loads among the zones. The other is to limit the system capacities and look for failure to maintain the desired interior temperature set-points.

6.1.2 Climate data

- Must be approved by PHIUS for each project.
- It is important to choose the correct data set, especially under the PHIUS+ 2015 climate specific program where space conditioning targets vary by location.
- PHIUS has generated 1000+ Climate Data sets for locations around the US. These sets can be found on the PHAUS website under the member resources. Click Here for PHIUS+ Climate Data Sets Please contact PHIUS if you are unable to access these sets.
- PHIUS has created state-by-state XML database import files, and a single XML file for the entire United States. These can also be downloaded from the PHAUS member resources page, and uploaded into your WUFI Passive database for future use.
- Avoid using data for a location more than fifty linear miles from the project location.
- We recommend using a different/custom dataset if the difference in elevation between the project site and station location is greater than 300-400 feet. More on when to request a custom climate data set.
- For some additional advice on selecting the right climate data, see this blog post.

Energy Model Defaults

The accepted software versions agree on default input values for a number of input parameters. Unless otherwise noted below, these values should be used in the energy model for certification. These values (and the way they are calculated) may be updated in the future to coincide with research and best practices.

6.1.4 Energy model inputs requiring additional documentation

- Ground Thermal Resistivity >0.1 hr.ft^2.F/BTU.in.
- Window psi Installation
    - For mid mounted, over-insulated window <0.015 BTU/hr.ft.F.
    - For mid mounted window <0.020 BTU/hr.ft.F.
- Subsoil Heat Exchanger efficiency >60%.
- Framing factors
    - Down to 15% for advanced framing, 24 in. OC.
    - Down to 12% if window psi-installation calculations are done, because some of the framing is accounted for in this calculation.
- Heat recovery Efficiency of CERV (from Newell Instruments / Build Equinox), or other such refrigerant-based heat recovery devices - use 75%.
- Air change rate for window night ventilation is limited; see Section 6.7.
- Solar fraction for hot water – expert/specialist calculation recommended if greater than 65% covered by Solar.

6.2 Localization/Climate

Ground Thermal Resistivity

In heating dominated climates, this value may not exceed 0.1 (hr.ft^2.F/BTU.in), and should usually be left at the default of 0.07 (hr.ft^2.F/BTU.in).

For thermal conductivity, this is equivalent to no less than 1.5 W/mK (0.87 BTU/hr.ft.F).

Download and save a PHIUS+ Climate file or PHIUS+ Climate XML Database

See Section 6.1.2.

To upload a PHIUS+ Climate file into WUFI Passive

Select 'User Defined' from the dropdown list, hit the 'Browse' button, and search for the saved climate file. Change the file type in the bottom right hand corner to 'Excel (.xls)' if need be.

OR, complete a one-time download of the climate database XML file to your WUFI Passive database. This can be done by selecting 'Database' then drop down to 'Import from XML File'. These files are also available on the PHAUS Member resources. After this import, you will be able to browse your WUFI Passive database to select a climate data set for your new project.

*Please note climate data import is not available in WUFI Passive Free. In the free version, the climate data must be input manually.

About the design temperatures in the climate data

A super-insulated structure responds more slowly to outside conditions, so the peak loads are moderated. The static mode calculation does also assume a slightly wider comfort range on the inside, 68-77 F instead of for example the Building America default 71-76 F, and similarly, the reason for this is that the inside surface temperatures should be more stable, so the air temperature can vary a bit more and still be comfortable, because the radiant temperature of the surfaces varies less.

We recommend against taking the passive mode design temperatures and using them in an ACCA manual J calculation, but rather run each method on its own terms and compare the bottom line Btu/h results.

Primary Energy Factor for grid electricity

The primary energy factor for the grid electricity mix in the U.S. is different from that of Europe. Use the U.S. national average value of 3.16 for certification, regardless of regional differences.

This policy forestalls the tendency for "rebound effect" - of building designers taking advantage of locally "cleaner" grids to use more energy, and instead, in effect, shares that benefit with designers in "dirty grid" regions. This is consistent with the idea that, with the current fossil-dominated primary fuel mix, energy impact translates into atmosphere impact, and the atmosphere is a commons.

6.3 PH Case

PH Case - General

The interior temperature thresholds for PHIUS+ Certification are 68F and 77F. Please contact PHIUS if the program of the project requires a different temperature set point.

6.3.1 Occupancy and Internal Heat Gains

For residential projects, model occupancy as the # of bedrooms + 1. This is per unit if there are multiple units.

Model Internal heat gains as 'Calculated' rather than default.

For building types that have unusual occupancy loads and patterns, deviant values may be used with an explanation, and approval of the PHIUS reviewer.

A <u>bedroom</u> is defined as per RESNET: [24]

> *A room or space 70 square feet or greater, with egress window and closet, used or intended to be used for sleeping. A "den." "library," "home office" with a closet, egress window, and 70 square feet or greater or other similar rooms shall count as a bedroom, but living rooms and foyers shall not.*

Number of Units

This is used to calculate the reference quantity for refrigerator and freezer entries, as well as calculating the DHW tap openings per year.

PH Case - Additional Data

Fresh air per person

18 cfm for residential, 9-12 cfm for school and daycare, 35 cfm for sports halls.

Infiltration/ Air-tightness

Per Section 3.2:

For buildings of five stories and above that are also of noncombustible construction:

$q50 <= 0.080\ CFM_{50}/ft^2$ <u>or</u> $q75 <= 0.100\ CFM_{75}/ft^2$ of gross envelope area

For all other buildings:

$q50 <= 0.050\ CFM_{50}/ft^2$ <u>or</u> $q75 <= 0.080\ CFM_{75}/ft^2$ of gross envelope area

Gross envelope is measured at the exterior of the thermal boundary, the same as for the energy model, and includes surfaces in contact with the ground.

<u>Example project conversion from cfm50/ft² to ACH50</u>: Total envelope area 6958 ft^2, net volume 19387 ft^3

$6958\ ft^2 * (0.05\ ft^3/min)/ft^2) * (60\ min/hr) * (1/19387\ ft^3) = 1.08\ ACH50$

Net air volume for pressurization test

To determine the net air volume, calculate the home's interior volume (drywall to drywall floor to ceiling, wall to wall) minus volume taken up by interior walls and floor systems.

Max Humidity Ratio (if dehumidification is planned)

The default value is 0.012 lbw/lba; it is not to be changed. It is the upper limit for humidity levels according to the comfort standard ASHRAE 55-2004. This is essentially a humidity setpoint. At 77 F and a 0.012 humidity ratio, it corresponds to approximately 60% relative humidity.

Domestic Hot Water use per person

- <u>Residential</u>: 6.6 gal/person/day
- <u>Commercial</u>: 3.2 gal/person/day

This input pertains to showers, hand-washing, and shaving. Laundry and dishwashing is separate from that, and calculated with the appliance entries. If there is no dishwasher, consider adding extra gallons to this daily value.

Remember, these are "hot gallons" (140 F). It calculates the energy to raise the water from the incoming water temperature (default 50 F) to 140 F, a 90 F rise. When mixed down to a temperature a person would actually want to shower under, it goes almost twice as far in terms of volume.

Cold Water Supply/Incoming Temperature

- 50 F is the default.
- If this input is left blank in WUFI Passive, it will calculate using an average annual ground temperature.

Adjusting the incoming cold water temperature dependent on climate

The default temperature (50F) for cold water may be adjusted if supporting documentation is submitted to confirm the new groundwater temperature. The adjusted groundwater temperature generally should not exceed the average ambient air temperature for the project's climate.

PH Case - Foundation Interface

Floor Slab Area

For heated basements, only include the interior floor area. For all other basement conditions, include the entire floor slab area calculated to the exterior of the thermal boundary.

Floor Slab Perimeter

For heated basements, only include the interior perimeter. For all other basement conditions, include the entire (exterior-adjacent portion of the) floor slab perimeter measured at the exterior of the thermal boundary.

6.4 Zone 1

The Net Volume requires a calculation of the interior volume, subtracting interior walls, adding window niches, etc. This is the interior volume that will be used for the air pressurization test.

Reference Volume

This value is not used for the 'Passive House Verification' calculation; it refers to the volume of the visualized 3D model. This will be equal to the gross volume in most cases (when the model is drawn to the exterior dimensions).

Interior Conditioned Floor Area (iCFA)

As of March 2015, PHIUS changed calculation methods for floor area from the Treated Floor Area (TFA) to the Interior Conditioned Floor Area (iCFA). The space conditioning criteria (heating and cooling annual demands and peak loads) are per square foot of iCFA. See Section 4.4.1.4 for the definition of iCFA.

Specific Heat Capacity/Thermal Mass

With regard to thermal mass, it's not just the total mass that matters but the distribution, so that it can interact with the infrared radiation bouncing around the room. The way of figuring this is based on the number of heavy surfaces (0 to six) per room, in an average sense. For example, a two-story building with a first floor concrete slab would have 1/2 of a heavy surface per room on average.

Thermal mass is determined by the equation = [60+n(heavy)*24]*0.176 (BTU/ft^2.F)

Guidelines for counting heavy surfaces

- Drywall = 0 heavy surfaces - (first ½" included in the baseline)
- 5/8" Drywall = 0.34 heavy surfaces
- Double or High Density Drywall = 0.5 heavy surfaces
- Two-inch-thick concrete or more, Phase-change materials = 1 heavy surface

- Flagstone/Tile = 0.5 heavy surfaces

Example:

Concrete Floor = 1 heavy surface
Other 5 surfaces = 0.34 each = 1.7 heavy surfaces
total n (heavy surfaces) = 2.7
Specific capacity = (60+2.7*24) *0.176 = 21.96 BTU/ft²F

6.5 Visualized Components

Wall Components

Framing factors

Use 25% for regular/typical framing, or retrofit situations.

- Use no lower than 15% for advanced framing, 24 in. o.c.
- As low as 12% is acceptable if window installation thermal bridge calculations ("psi-install") are done, because some of the framing is accounted for in this calculation.

Insulation Specs

Some insulation is temperature-dependent; use the R-value at 75 F for the energy model. Some insulation is thickness-dependent; use the R-value at the appropriate thickness for the assembly.

If using WUFI Passive, please note that default conductivity values are used from the existing database. Conductivity or thermal resistance values should be updated in the project file to match the insulation specification. This can be done under the Edit Assembly screen by clicking into the 'Conductivity' input, for the specific assembly layer, selecting the [R/in] button, and inputting the accurate R per inch.

Surface / Radiation Balances / Solar absorption/emission

The radiation balances need to be input for every opaque surface above grade. This includes values for: emissivity, absorptivity, and shading. Rough values are acceptable.

Window Components

PHIUS has certified data for many windows, found here.

If the project is using windows with PHIUS Certified Data, PHIUS' data must be used.

Psi-Install / Frame-Wall Psi Value

The psi-installation value is dependent on how the window is installed within the wall. Please do not use values from manufacturers' data sheets unless they have completed a project specific calculation for you.

- Without a THERM calculation, we can accept as low as (0.020 Btu/hr.ft.F) for a mid-wall mounted window that is not over-insulated.

- Without a THERM calculation, we can accept as low as 0.015 (Btu/hr.ft.F) for a mid-wall mounted window that is over-insulated.
- Psi-install values below these thresholds are acceptable when validated by a THERM calculation.

Solar Protection/Shading

- See the Solar Pathfinder Protocol for information on analyzing and documenting site shading. [Download Shading Protocol Package (.zip)]

Reveal Shading

Often windows are not installed flush with the exterior of the building façade which causes reveal shading to the left and right sides of the window from the window in-set in the wall. Reveal shading should be input for all windows. In WUFI Passive, this can be done quickly with the [Assign Data] function.

Mulled windows & windows with different reveal conditions left and right due to building geometry

The first thing to do is decide what's the limiting factor on the reveal shading, and to do that separately for the left and the right. Is it a mullion, the edge of the window opening, or something like a garage sticking out. The deeper the reveal and the closer to the window it is, the more it will shade. In heating-dominated climates, enter the dominant reveal, conservatively assuming more shading. In cooling-dominated climates, enter the smaller reveal, conservatively assuming less shading.

In general, the controlling reveal conditions on the left and right could have both a different daylight-opening-to-reveal and a different reveal depth.

In the case where the depth of the controlling reveal is about the same on both sides but the edge-to-reveal distance is different left and right, take a shortcut and just enter the average edge-to-reveal distance. Mulled windows for example.

Likewise, in the case where the daylight-opening-to-reveal is the same but the depth is different left and right, one could just average the depths. This seems less common.

Blinds/Sunscreen devices

Sunscreen devices in WUFI Passive are assumed to be used only during the cooling season. If year round blinds are used, please input as an "other shading fraction of solar exposure".

The effectiveness of window blinds needs to be de-rated if they are manually operated, to account for occupant behavior. If the shading reduction factor for a blind in the closed position is "z", and "Z effective" is in the input in WUFI Passive then:

For exterior blinds, use:

Z effective = 0.3 + 0.7 * z

Example: If blinds allow 46% solar access when closed, use that for z, and z effective turns out to be 62%.

Z effective = 0.3 + (0.7*0.46) = 0.622

For interior blinds, use:

Z effective = 1- (1-z) * (1-0.6)

<u>Example</u>: If blinds allow 46% solar access when closed, use that for z, and z effective turns out to be 78%.

Z effective = 1 – (1-0.46) * (1-0.6) = 0.784

Insulated Interior Blinds

Unless the blind is air sealed to the window opening and is airtight, much of the insulating value of the blind can be bypassed. Because of this, we are giving credit for essentially, the R-value of the two air films on either side of the blind and not the blind itself. We generally round this to R-2 in IP units. We also assume that user behavior impacts the use of the blinds and that somewhere around half the time, the blinds are not in the right spot, or are removed. Therefore, we currently allow an R-1 adjustment to be made directly to the glass R-value and the Frame R-value. One word of caution is that if they do work as intended/advertised, there is a significant risk of condensation on the window in cold climates, which over time could lead to problems and durability issues. This must be checked and managed.

Overhangs

Please note in WUFI Passive, if no overhangs are assigned to a window, the reveal shading dimensions are automatically set as the overhang. If this inaccurately represents the shading condition, please assign an overhang to the specific window.

Mulled windows, Divided Lites

Mulled Windows

If the connector for the frame mullion is similar in material to the frame, adding a bit of thickness to the frame may work. If the connector is substantially more conductive than the frame, a thermal bridge calculation may be necessary.

Divided Lites

There are some different ways to deal with true divided lites which bridge the gas cavity. The SHGC could be adjusted to account for the blocked light, and linear thermal bridges added to account for the extra conduction loss.

If these are a kind of divided lites such that the gas cavity is not actually bridged, we will still reduce the SHGC, but no additional thermal bridging need be accounted for.

6.6 Internal Loads/Occupancy

6.6.1 Residential

Occupant Quantity

See section 6.3.1.

Number of Bedrooms

Based on the total number of bedrooms in the building.

Humidity Sources

Internal sources due to respiration or evaporation. Default value of 0.0041 [lb/(ft²hr)].
Per ASHRAE standard 160, clause 4.3.2.1.1, if there is a jetted [whirlpool] tub installed in a room without an automatically controlled (e.g. humidistat) exhaust fan, it would be appropriate to add 1.3 liters/day or 0.12 lb/h to the moisture generation rate.

Devices

Annual energy use for dishwashers, clothes washers, dryers, and cooktops are proportional to the number of occupants.

For fridge/freezers, consumption is not dependent on occupancy, it is proportional to the number of devices.

- **Dishwasher:** For Energy Star rated dishwashers, use the Annual kWh divided by 215 cycles/year for the kWh per use. As of mid-2016, the Energy Star median value was 1.0 kWh/cycle and this may be used as a default for pre-design work.
  - If only 1 zone in the project, select 'PH Case Occupants' as the 'Reference Quantity'. If multiple zones in the project, select 'Zone Occupants' as the 'Reference Quantity'.
- **Washer:** For Energy Star rated clothes washers, use the Annual kWh divided by 392 cycles/year. Median value 0.28 kWh/cycle.
  - Utilization Factor: Usually 1. If the standard electricity consumption for washing is referred to boiling wash: 0.65
  - If only 1 zone in the project, select 'PH Case Occupants' as the 'Reference Quantity'. If multiple zones in the project, select 'Zone Occupants' as the 'Reference Quantity'.
- **Refrigerator/Freezer Combo:** use Annual kWh divided by 365 days. Median value 0.95 kWh/day.
  - Select 'PH Case Units' as the 'Reference Quantity'
- **Deep Freeze:** use annual kWh divided by 365 days. Median value 1.0 kWh/day.
  - Select 'PH Case Units' as the 'Reference Quantity'
- **Dryer:** As of mid-2014 Energy Star began rating dryers with a CEF factor. If there is no rating, use 3.5 kWh/use as a default. Energy Star median value 2.8 kWh/use.
  - **11/CEF = kWh/use (regardless if standard or compact)**
  - If gas dryer, match the electrical kWh/use of the washer, and assign the rest to Gas consumption. For example, if using the default 3.5 kWh/use for the dryer, and the washer is rated at 0.5 kWh/use, input for the gas consumption 3.5-0.5

  = 3.0 kWh * 3412 Btu/kWh = 10236 Btu.
  - Remaining Dampness: Dependent on washer spin cycle
    - 800-1000 rpm: 70%
    - 1000-1100 rpm: 60%
    - 1400-1500 rpm: 50%
  - A compendium of information on washer spin speeds is published at https://enervee.com/washers/. Use manufacturer's specifications directly, if available.
  - If only 1 zone in the project, select 'PH Case Occupants' as the 'Reference Quantity'. If multiple zones in the project, select 'Zone Occupants' as the 'Reference Quantity'.

- **Kitchen Cooktop:**
  - Cooking with gas: 0.25 kWh/use
  - Cooking with electricity/induction cooktop: 0.20 kWh/use
  - This input actually accounts for cooking energy from ovens, microwave, etc., not just the cooktop. It is assumed that 500 single serving size meals are cooked annually, per occupant.
  - If only 1 zone in the project, select 'PH Case Occupants' as the 'Reference Quantity'. If multiple zones in the project, select 'Zone Occupants' as the 'Reference Quantity'.

- **PHIUS+ 2015 Interior Lighting:**
  - Should be used for all single family PHIUS+ 2015 projects.
  - If only 1 zone in the project, select 'PH Case Floor Area' as the 'Reference Quantity'. If multiple zones in the project, select 'Zone Floor Area' as the 'Reference Quantity'.
  - Input a fraction of high efficiency lighting.

- **PHIUS+ 2015 Exterior Lighting:**
  - Should be used for all single family PHIUS+ 2015 projects.
  - If only 1 zone in the project, select 'PH Case Floor Area' as the 'Reference Quantity'. If multiple zones in the project, select 'Zone Floor Area' as the 'Reference Quantity'.
  - Input a fraction of high efficiency lighting.

- **PHIUS+ 2015 Garage Lighting**
  - Should be used for all single family PHIUS+ 2015 projects with a garage.
  - No 'Reference Quantity' required.
  - Input a fraction of high efficiency lighting.

- **PHIUS+ 2015 MELS**
  - Includes all miscellaneous electric loads, including televisions and plug loads.
  - Should be used for all single family PHIUS+ 2015 projects.

- Select 'PH Case Floor Area' as the 'Reference Quantity'.
- If multiple zones in the project, only add the PHIUS+ 2015 MELS device to one zone.

- **User Defined**
  - Input any device not covered in the common device list, units are in kWh/yr.
  - User Defined devices will be used for multi-unit projects, see details below in Section 6.6.1.1.

- **PHIUS+ 2015 Interior Lighting, Exterior Lighting, Garage Lighting & MELS:**
  - If not using WUFI Passive, these values can be calculated externally using the PHIUS+ 2015 Calculator.

Multi-unit Projects

- Energy use calculated for most appliances (dishwasher, washer, dryer, cooktop) are driven by occupancy. The 'Reference quantity' that should be selected for these appliances is 'PH Case Occupants' if the whole building is in one zone, or 'Zone occupants' if the model has multiple zones.
- Fridge/freezer inputs are driven by the number of units input under the PH Case branch. The 'Reference Quantity' in WUFI Passive for the fridge/freezer should be 'PH Case Units'.
- Calculating the lighting & plug loads should be done on a 'per unit' basis using the PHIUS+ 2015 Multifamily Calculator.
- User Defined inputs are not applied to any internal patterns, and inputs are simply in kWh/yr. Therefore, when inputting lighting and plug loads as User Defined inputs, this should be for the whole building. (Or, if there are identical units, input per unit and adjust the quantity as needed).

6.6.1.1 Lighting and Miscellaneous Loads

Download the PHIUS+ 2015 Multifamily Calculator, which has all of the protocol below embedded.

The basic protocol for lighting and miscellaneous electric loads is that they are calculated at 80% of RESNET (2013) levels for the "Rated Home". [25] RESNET's formulas are intended to apply to living/dwelling units, whether detached or attached, and strictly speaking to buildings of three stories or less. RESNET does not yet have protocol for multifamily common spaces. For PHIUS certification, the scope of the RESNET formulas is expanded to include multifamily buildings four stories or more in height, but applies only to the dwelling units. Supplemental protocol for multifamily common spaces and certain outdoor loads follows Building America House Simulation Protocols (2014). [26] In the formulas, iCFA is used in place of RESNET's CFA and Building America's FFA. The RESNET lighting formulas have been expressed more compactly here but are algebraically equivalent to the published versions. There are additional options for calculating the energy use of pools and elevators.

Miscellaneous Electric Loads (MELs)

For whole-building certification:

$$MEL = MEL_{DWELL} + MEL_{COMM} + MEL_{YARD} \text{ (kWh/yr)}$$

MEL_{DWELL} accounts for the living units.
MEL_{COMM} accounts for the common spaces (if the design includes any).
MEL_{YARD} accounts for Large / Uncommon Electric and Gas loads (if the design includes any).

To facilitate verification, the MEL_{DWELL} calculation must be itemized. This may be done by unit type or floor-by-floor.

<u>For itemization by unit type *k*:</u>

$$MEL_{DWELL} = \sum_k units_k * (413 + 69 * Nbr_k + 0.91 * iCFA_k) * 0.8$$

k are the unit types.

$units_k$ is the number of units of type k in the building.

Nbr_k is the number of bedrooms in a unit of type k.

$iCFA_k$ is the interior conditioned floor area of a unit of type k. [27]

For purposes of this calculation, $iCFA_k$ may include or exclude the projected floor area of interior partition walls within or between units, whichever approach is simpler to document.

<u>For itemization by floor *n*:</u>

$$MEL_{DWELL} = \sum_n \left(units_n * 413 + 69 * Nbr_n + 0.91 * iCFA_{DWELL,n}\right) * 0.8$$

n are the floors.

$units_n$ is the number of units on floor n.

Nbr_n is the number of bedrooms on floor n.

$iCFA_{DWELL,n}$ is the interior conditioned floor area of all the dwelling units on floor n, including the partition walls within and between units, but not including the floor area of the common spaces.

For purposes of this calculation, $iCFA_{DWELL,n}$ may include or exclude the projected floor area of interior partition walls to common spaces, whichever approach is simpler to document.

For MEL_{COMM} add the following, or submit a more detailed accounting.

Multifamily Common Space MELs [28]

Room Type	Electricity (kWh/yr)
Office	3.2 x iCFA

Workout room	9.8 x iCFA
Corridor/restroom/mechanical	0
Elevator	1,900

Alternate for Elevators: More detailed calculation may be made using:

https://www.thyssenkruppelevator.com/Tools/energy-calculator

http://www.schindler3300na.com/cgi-bin/calc/calc.pl

Although BAHSP has protocol for some "Multipurpose Room MELs", in a whole-building model any television, dishwasher, range, or microwave in a multipurpose room may be neglected – usage of these in the multipurpose room is assumed to displace usage in the units. However, any refrigerators or freezers in a multipurpose room should be added as additional appliances at their rated kWh/day.

For MEL_{YARD} use the table below or perform a more detailed calculation.

Large Uncommon Electric and Gas Loads [29]

Appliance	Electricity (kWh/yr)	Natural Gas (therms/yr)
Pool heater, gas	-	3/0.014 × F_{scale}
Pool heater, electric	10.1/0.0044 × F_{scale}	-
Pool pump	158.5/0.07 × F_{scale}	-
Hot tub/spa heater, gas	-	0.87/0.011 × F_{scale}
Hot tub/spa heater, electric	49/0.048 × F_{scale}	-
Hot tub/spa pump	59.5/0.059 × F_{scale}	-
Well pump	50.8/0.127 × F_{scale}	-
Gas fireplace	-	1.95/0.032 × F_{scale}
Gas grill	0.87/0.029 × F_{scale}	-
Gas lighting	0.22/0.012 × F_{scale}	-

Where the scaling factor, F_{scale} = (0.5 + 0.25 Nbr/3 + 0.25 iCFA/1920).

1 therm = 100 kBtu / [3.412 kBtu/kWh] = 29.3 kWh

Alternate for Pools/Spas: More detailed calculations may be made using this calculator: http://energyexperts.org/CalculatorsTools/PoolEnergyUseCalculator.aspx

Lighting

The lighting formulas below refer to "qualifying" light fixtures or locations, which means high-efficacy lighting. For residential projects fluorescent hard-wired (i.e. pin-based) lamps with ballast, screw-in compact fluorescent bulb(s), LEDs, or light fixtures controlled by a photocell and motion sensor, are all considered high-efficacy.

Interior lighting

For whole-building certification:

$$LIGHTS_{INT} = LIGHTS_{INT,DWELL} + LIGHTS_{INT,COMM} \text{ (kWh/yr)}$$

$LIGHTS_{INT,DWELL}$ accounts for the living units. [30]
$LIGHTS_{INT,COMM}$ accounts for the common spaces (if the design includes any).

As with MELs, the $LIGHTS_{INT,DWELL}$ calculation must be itemized. This may be done by unit type or floor-by-floor.

For itemization by unit type *k*:

$$LIGHTS_{INT,DWELL} = \sum_k units_k * (0.2 + 0.8 * (4 - 3 * qFFIL)/3.7) * (455 + 0.8 * iCFA_k) * 0.8$$

$qFFIL$ is the ratio of the Qualifying interior Light Fixtures to all interior light fixtures in Qualifying interior Light Fixture Locations.

For itemization by floor *n*:

$$LIGHTS_{INT,DWELL} = \sum_n (0.2 + 0.8 * (4 - 3 * qFFIL)/3.7) * \left(units_n * 455 + 0.8 * iCFA_{DWELL,n}\right) * 0.8$$

For $LIGHTS_{INT,COMM}$ use the table below for any of the listed Room Types that are included in the design, or submit a more detailed calculation.

Multifamily Common Space Lighting [31]

Room Type	Operating Hours (hrs/day)	LPD (W/ft^2)
Central Restroom	1.6	0.9
Common Laundry	24	0.7
Common Mail	12	2.8
Common Office	9	1
Elevator	24	1.25
Equip. Room	0	1.5
Indoor Corridor	24	0.5
Multi-Purpose	12	1.1
Workout Room	16	0.9

$$LIGHTS_{INT,COMM} = (Operating\ hours * operating\ days\ * LPD * iCFA_{COMM})/1000$$

Operating hours are per day.

Operating days are per year.

LPD is the lighting power density of the space in W/ft^2.

$iCFA_{COMM}$ is the interior conditioned floor area of each unique common space, not including interior partition walls.

Exterior Lighting

$$LIGHTS_{EXT} = LIGHTS_{EXT,DWELL} + LIGHTS_{EXT,COMM} + LIGHTS_{GAR}\ \text{(kWh/yr)}$$

$LIGHTS_{EXT,DWELL}$ pertains to exterior lighting for the dwelling units (balcony/porch or general building lights). [32]

$LIGHTS_{EXT,COMM}$ pertains to exterior lighting for the common spaces (exterior courtyards, exterior corridors/stairs, outdoor walkways, etc.)

$LIGHTS_{GAR}$ pertains only if the project includes a garage.*

For itemization by unit type *k*:

$$LIGHTS_{EXT,DWELL} = \sum_k units_k * (1 - 0.75 * FFEL) * (100 + 0.05 * iCFA_k) * 0.8$$

FFEL is the Fraction of exterior fixtures that are Qualifying Light Fixtures

For itemization by floor *n*:

$$LIGHTS_{EXT,DWELL} = \sum_n (1 - 0.75 * FFEL) * (units_n * 100 + 0.05 *\ iCFA_n) * 0.8$$

For $LIGHTS_{EXT,COMM}$ use the table below for any of the listed Room Types that are included in the design, or submit a more detailed calculation.

Exterior Lighting [33]

Room Type	Operating Hours (hrs/day)	LPD (W/ft^2)
Open Parking*	12	0.15
Outdoor Stairs	12	0.3
Outdoor Walkways	12	0.3

$LIGHTS_{EXT,COMM} = (Operating\ hours * operating\ days\ * LPD * iCFA_{COMM})/1000$

Operating hours are per day.

Operating days are per year.

LPD is the lighting power density of the space in W/ft^2.

$iCFA_{COMM}$ is the interior conditioned floor area of each unique common space, not including interior partition walls.

Garage lighting may be calculated by the "80% RESNET" formula [34], BA default, or a more detailed calculation.

$LIGHTS_{GAR} = Units * 100*(1-0.75*FFGL) * 0.8$

Units is the total number of dwelling units in the building

FFGL is the fraction of garage fixtures that are Qualifying Light Fixtures.

Garage Lighting* [35]

Room Type	Operating Hours (hrs/day)	W/ft^2
Parking Garage*	24	0.2

*Note: PHIUS does not require projects to include lighting energy for an open parking lot / parking garage, block heaters, or vehicle charging in the energy model for certification. For now, these are considered to be part of the 'transportation sector' as opposed to the 'building sector'.

6.6.2 Non-residential

The internal loads and occupancy calculation for nonresidential projects begins with the definition of utilization patterns. These patterns are used for two purposes: lighting energy calculation and internal gains due to people.

A utilization pattern consists of a set of several parameters, namely:

- beginning hour,
- ending hour,
- days/year,
- illumination level,
- height of utilization 0.8 or 0.0 m,
- relative absenteeism,
- part use factor of building period for lighting,
- average occupancy m2/person)

A set of standard default patterns (per DIN V 18599-10:2007-02, Table 4) is shown on the next page.

[36]

The illumination level, height of utilization, and part-use factor for lighting enter only into the lighting calculation.

The average occupancy enters only into the calculation of gains from people, and only if mode of planning for occupancy is floor-area-based rather than direct entry.

The other parameters enter into both the lighting and internal gains calculations.

Often, more utilization patterns will be needed for lighting purposes than for internal gains. For example in an office building with single-shift operation and everyone typically sitting at desks, a single pattern could suffice for internal gains due to people, but if there are space types that require a number of different illumination levels, more patterns would be needed for lighting. That is, it may be necessary / appropriate to define utilization patterns that “overlap” in order to support the calculations for internal gains, lighting, and equipment electricity use.

In the table on the next page, the patterns are grouped by required illumination level. The first step in the analysis is to identify the different space types that are present, from the floorplan. In the lighting calculation, the patterns can be applied room-by-room. Grouping of rooms may be appropriate if they share a pattern (or ones with similar required illumination) and also have similar access to daylight.

Serial no.	Type of usage	Beginning of usage [Time]	End of usage [Time]	Annual Utilisation Days [d/a]	Maintained illuminance [lux]	Height of the work plane [m]	Relative Absenteeism	Reduction factor for lighting relative to the building operation time
32	Garage buildings (for offices and private use)	7:00	18:00	250	75	0	0.95	1
33	Garage buildings (public use)	9:00	0:00	365	75	0	0.8	1
19	Traffic / circulation areas	7:00	18:00	250	100	0	0.8	1
18	Auxiliary spaces (without habitable rooms)	7:00	18:00	250	100	0.8	0.9	1
20	Storeroom, technical equipment room, archive	7:00	18:00	250	100	0.8	0.98	1
30	Library - magazine and stores	8:00	20:00	300	100	0.8	0.9	1
5	Booking hall	7:00	18:00	250	200	0.8	0	1
11	Hotel bedroom	21:00	8:00	365	200	0.8	0.25	0.3
12	Canteen	8:00	15:00	250	200	0.8	0	1
13	Restaurant	10:00	0:00	300	200	0.8	0	1
16	Toilets and sanitary facilities in non-residential buildings	7:00	18:00	250	200	0.8	0.9	1
23	Spectator and audience areas (theaters and event locations)	19:00	23:00	250	200	0.8	0	1
27	Exhibition rooms and museums with conservation requirements	10:00	18:00	250	200	0.8	0	1
29	Library - open stacks areas	8:00	20:00	300	200	0.8	0	1
6	Retail shop / department store	8:00	20:00	300	300	0.8	0	1
7	Retail shop / department store (food department with refrigerated products)	8:00	20:00	300	300	0.8	0	1
8	Classroom (school and nursery school)	8:00	15:00	200	300	0.8	0.25	0.9
10	Hospital ward or dormitory	0:00	24:00	365	300	0.8	0	0.5
15	Kitchen - preparation room or storeroom	7:00	23:00	300	300	0.8	0.5	1
17	Other Habitable Rooms	7:00	18:00	250	300	0.8	0.5	1
24	Foyer (theaters and event locations)	19:00	23:00	250	300	0.8	0.5	1
26	Fair / congress building	13:00	18:00	150	300	0.8	0.5	1
31	Sports hall (without public viewing area)	8:00	23:00	300	300	1	0.3	1
1	Personal office (single occupant)	7:00	18:00	250	500	0.8	0.3	0.7
2	Workgroup office (two to six workplaces)	7:00	18:00	250	500	0.8	0.3	0.7
3	Landscaped office (seven or more workplaces)	7:00	18:00	250	500	0.8	0	1
4	Meeting, conference and seminar room	7:00	18:00	250	500	0.8	0.5	1
9	Lecture room, auditorium	8:00	18:00	150	500	0.8	0.25	0.7
14	Kitchens in non-residential buildings	10:00	23:00	300	500	0.8	0	1
21	Server room, computer center	0:00	24:00	365	500	0.8	0.5	0.5
22	Workshop, assembly, manufacturing	7:00	16:00	250	500	0.8	0	1
28	Library - reading rooms	8:00	20:00	300	500	0.8	0	1
25	Stage (theaters and event locations)	13:00	23:00	250	1000	0.8	0	0.6

6.7 Ventilation/Rooms

Utilization Pattern

The *maximum* design airflow is determined by the largest of 3 factors:

1. Supply air requirement (based on occupancy).
2. Exhaust air requirement (based on kitchens, baths, ….)
3. Volumetric requirement (0.3 ACH)

The average air flow rate (cfm) and average air change rate (1/hr) is calculated as a reduction from the 'Design air flow rate'. It is determined by the daily operation schedule and "fraction of design" airflow at the scheduled hours.

Rooms Ventilation

In WUFI Passive, "supply rooms" must be entered if there is to be more than one H/ERV.

When adding exhaust rooms, input 0 cfm supply. When adding supply rooms, input 0 cfm exhaust.

Summer Ventilation

Summer ventilation night may be notionally either natural, via windows, or mechanical automatically controlled (e.g. whole house exhaust fan.)

Summer Bypass

- [Summer/HRV Humidity Recovery]

Most heat recovery ventilation units (Both ERV's and HRV's) have the ability to bypass heat recovery in the summer condition, when outdoor temperatures are more favorable than indoor. Typically, this is temperature controlled bypass.

Additional Summer Mechanical Ventilation

- [ACH via mechanical ventilation exhaust air]
- [Mechanical automatic controlled ventilation]
- [Specific Power Consumption]

Use these inputs when implementing a mechanical exhaust system <u>in addition to</u> the ERV. Ex: whole house fan. Use [Mechanical automatic controlled ventilation] if the system is tied to sensors for either temperature or humidity difference, and define the control system in WUFI Passive.

Summer Natural Ventilation (day)

- [ACH via natural ventilation (day)]

It's not a bad idea to add in a small air change rate to account for times when windows/doors are open yet not accounted for. This can be about 0.1 ACH.

Summer Mechanical Ventilation by the HRV/ERV

- [ACH via mechanical ventilation]

This value should match the year round average ACH from the ERV/HRV. In WUFI Passive, if you leave this cell empty, it will use your typical year round operation rate of the ERV.

If the climate allows for summer ventilation to be taken care of through windows and other passive features, and the HRV/ERV will be shut off, please input 0 here.

Additional Summer Ventilation (night)

- [ACH via natural ventilation (night)]

Be cautious and realistic with the amount of natural ventilation being counted on for cooling. There are two main concerns with the amount of cooling. The first is humidity - look for dewpoint temperature in the Climate Data. In many climates in the United States, there are high levels of humidity in the cooling situations.

The second is that the summer ventilation calculator can generate quite high air change rates, but during the night usually interior doors are closed so that cross ventilation is cut off.

For PHIUS+ Certification, either:

1. Account for no higher than 0.3 ACH for nighttime ventilation;
   OR
2. Follow Building America House Simulation Protocol which states: 33% of the open-able windows are opened. This can happen 3 days a week (M, W, F) which would translate to a fraction of opening duration of 43%, Or 10.3 hrs/day.
   a. Use the additional calculator found under Summer Ventilation in WUFI Passive (or the SummVent page in PHPP). Model each window in one column. A second window group is allowed for stack effect and cross ventilation only for day, not night (unless there are no intervening doors.)

Exhaust Ventilation

Exhaust air appliances:

- In WUFI Passive, account for the exhaust appliances on the Ventilation/Rooms > Exhaust Appliances tab.
  - There are pre-defined devices for dryers and kitchen cooktops which are tied to the annual usage of the dryer and cooktop.
- If not using WUFI Passive, please follow PHIUS+ protocol on accounting for exhaust air appliances, found in the side calculator here.

Tips:

- Consider moving an exhaust dryer to the mudroom or outside the thermal envelope.
- Make-up air for a directly vented range hood is acceptable as long as the total meets the primary energy requirements. If a make-up air system is planned then it can be tied directly

to a vented dryer as well, i.e. it comes on when the dryer is running and venting.

Multiple exhaust dryer protocol:

If a community building or similar is serving multiple buildings with a laundry room, multiple exhaust dryers with high usage patterns put a lot of load on the space conditioning system. If the makeup air is either fully ducted to the dryer case, or even near / behind it, then the makeup air may be regarded as not mixing with the room air and therefore does not increase the load/demand on the space heating/cooling system, because the room thermostat will not ever feel it. The extra energy must be accounted for, but it is considered to be moved from the space-conditioning category to the primary energy category. That accounting may be done as follows:

- Use the Exhaust Appliances tab in WUFI Passive (or the makeup air calculator) to find the difference, the added annual heat demand and cooling demand due to the dryer ventilation. Take the *difference* between the added heat demand and the added cooling demand. (On the theory that cold air makes the dryer work harder, warm air makes it work easier, than it does under its rated conditions.) Convert that to a primary energy using the COP and PE factor of the dryer. Divide by 3.16 and enter the result as an auxiliary electric load outside the thermal envelope.
- Furthermore, it is recommended to install an electric heater in the makeup air duct (near the point of entry) capable of raising the air temperature to at least 49 F (dew point of 68 F air at 50% RH.)
- If the dryer is not electric resistance, the PE factor in the above energy calculation should be adjusted with a seasonal weighting based on the percentage of the year that the makeup air heater would be expected to operate. This would prevent the makeup air from causing a frost or condensation problem.

Notice that, if the space heating system is efficient or has a low source energy factor, such a heated makeup air duct may actually use more energy overall in a site or source energy sense. Therefore this is not necessarily the best strategy in all cases. It is offered as an option that may help some smaller buildings meet the certification criteria for space conditioning.

6.8 Thermal Bridges

To learn how to use LBNL THERM to calculate thermal bridges, an introductory training package for THERM may be purchased here.

If accounting for any negative thermal bridges, all thermal bridges in the project must be calculated, no matter how small. In general, we recommend against taking negative thermal bridges in the design phase, and only using these as a "last line of defense".

Temperature Zone Assignments in WUFI Passive

- **Ambient:** Use this selection for thermal bridges occurring above grade. Only two temperatures will be used in the THERM/psi value calculation -- ambient and interior.
- **Perimeter:** Use this selection for thermal bridges occurring at grade. In this case, there will be three temperature zones used in the THERM calculation -- ambient, ground, and interior.

- **Ground Floor:** Use this selection for thermal bridges below grade. Only two temperatures will be used in the THERM calculation -- ground and interior.

6.9 Attached Zones

Reduction Factors for Tempered Spaces

In passive house verification mode, the lowest reduction factor currently allowed for PHIUS+ Certification is >0.95. One example of this is a garage. Garages may be warmer in the winter and afford a reduction to the assemblies that come into contact with it. However, it also could be warmer in the summer. The exact reduction factor can't be calculated in passive house verification mode and a conservative approach is being taken.

6.10 Systems

6.10.1 Distribution

DHW

- **Length of Circulation Pipes:** Recirculation systems are found most often in large or commercial buildings. A true circulation loop has hot water running through it for a certain period of time each day. For this entry, determine the length of the circulation loop.
  The default calculation for the recirc pumping energy auto-sizes a pump based on the gross enclosed volume of the building, and conservatively assumes 24 hour a day operation. This can be overridden.
- **Design Flow Temp:** This is used to calculate the pipe losses. PHIUS will accept between 120-140°F.
  It's recommended, and common, to insulate plumbing in passive houses. This is mostly to improve efficiency and slow the heat transfer from the pipe to the interior environment. Although this is recommended, it is not required.
- **On-Demand Recirculation Loop:** Do not enter this as circulation pipes. The cautious view is that an on-demand system saves water, but it does not save much water heating energy, because the pipes cool off between uses like the individual branch pipes, therefore the system should be represented as a non-recirculating system. Based on some dynamic modeling, the following reduction factors may be applied to the total hot water demand, depending on the hot water distribution technology:
  - Uninsulated, trunk and branch, copper 1.0
  - Uninsulated, home-run, PEX 0.95
  - R-2, home-run, PEX 0.93
  - R-2, trunk and branch, copper, demand-recirc 0.90
  - R-2, trunk and branch, PEX, demand-recirc 0.86
- **Application:** Make sure the reviewer can verify the distribution technology from the mechanical drawings. Document the actual pipe lengths, but enter a reduced pipe length so as to achieve the reduction in overall hot water demand due to the distribution upgrade. The appropriate reduction factors are listed above.

Also, add Auxiliary energy for a demand-recirc pump.

- **Length of Individual Pipes:** To determine this, determine the distance from the HW tank/tankless heater to each individual hot water tap. Sum these distances to find the total length of individual pipes.
    - For hot water pipes to the clothes washer and dishwasher, exclude the length of these pipes, or more conservatively, apply a reduction factor of 0.06 to the length.
    - If the project is using a circulation loop, determine the distance from the recirc loop to each individual hot water tap. Sum these distances to find the total length of individual pipes. (Note that a supporting drawing / diagram is part of the required documentation.)
- **Exterior Pipe Diameter:** Typically add ⅛" inch to the nominal pipe dimension to determine the exterior dimension. Projects using a variety of HW pipe thicknesses may use a weighted average for this value.

6.10.2 Cooling

- For the **Recirculation Cooling COP** use ((SEER + EER)/2) / 3.412.

6.10.3 Ventilation

Duct Length and Duct Separation

Supply and exhaust duct lengths should be measured from the inside of the exterior wall to the outside of the ventilation unit. Often, these lengths are different.

If entering H/ERVs in quantity greater than one, use the average duct lengths per ventilator.

On the outside of the building the supply and exhaust diffusers should be located at least 10 feet apart to keep from short circuiting exhaust air back into the house.

Taking the supply air from above the roof is generally not recommended, because of the possibility of excessive heat and hot-roof odor.

Auxiliary Energy

This should include any additional fans, pumps, etc.

If using any type of DHW recirculation system, please add the DHW pump energy here.

6.10.5 Heating

Heat Pump

COP may be entered as HSPF/3.412. For colder climates, the COP is likely less than this and conservative entries are favored. If COP data for two temperature setpoints can be found, use the project specific calculator found in the Heat Pump protocol packet, downloadable below. This takes the monthly heating demand and climate data into consideration to calculate a more accurate COP.

Download Heat Pump COP protocol kit.

Boiler

It is acceptable, and quicker, to enter this as a 'User Defined' system. Find the Energy Factor (EF) of the model you are using. We recommend derating the EF by a factor of 0.92 (as in RESNET protocol), to account for the discrepancies between the heavy draws used in the DOE water heater testing protocol and the real world. This de-rated value can be thought of as a % efficiency for the boiler. Then, in WUFI Passive, input the inverse of the efficiency as the 'Performance Ratio of Heat Generator'. If a specification sheet is available containing information to support the detailed entries for the Boiler device, feel free to use the Boiler option. The part-load efficiency curves in LBNL report 42175 may be used as defaults (See Figure 1 in the report for old boilers and Figure 6 for sealed combustion.) [37]

6.10.6 Domestic Hot Water

- **Heat pump water heaters:** Enter these as 'User Defined'. Find the Energy Factor (EF) of the specified model and express this as a % for efficiency. If using multiple heat pumps, de-rate the efficiency of the HPWH heater to account for the heat pumps working against each other in the heating season. Please see link above to download the heat pump protocol.
- **Boiler:** See above.
- **Gas Tankless:** Enter the same as boiler; do not add water storage as a system.
- **Electric Tankless:** Choose electric heating; do not add water storage as a system.
- **Standard Electric with tank:** Choose electric and add water storage as a system.
- **Solar Collector:** In cases where the energy model report shows a solar fraction above 65%, we require a predicted annual output from the solar inspector as to the kBtu/yr energy production.
    - OR, a BeOpt model run according to this protocol.

6.10.7 Mechanical Ventilation

- PHIUS+ 2015 projects should model the ventilation efficiency according to the protocol described in work by the PHIUS Technical Committee found here.
- See this directory of common ventilation units.
- AHRI ratings for commercial units do not include electrical efficiency data. For pre-certification calculations, estimate electrical consumption from manufacturer's specifications.
- **Defrost:** No matter the method of defrost, PHIUS requires that accounting for defrost energy and entering 23 F for the temperature in which defrost must be used.
- **Latent/Humidity Recovery Efficiency:** If this value is not specified for the ERV, 40% may be entered as a default. For an HRV, leave the cell blank or enter 0%.
  When a project falls under the Summer test conditions (Climate zones 1A,2A,2B,3B), then request the HRV manufacturer provide their CSA 439 summer test point data. You can use this to break out ASE and LR. You'll see that most projects should use the HVI's Winter test point data. Only the 2B and 3B zones will use different test data for the ASE and LR inputs.
- **Subsoil Heat Exchanger (earth air tubes and liquid-based ground loops for tempering**

supply air): Typical efficiency ranges from 40-60%. For entries above 60% efficiency, a corresponding calculation is required for certification.

6.11 PV Systems – example calculations

Example (for WUFI Passive): Chicago, IL, Climate Zone 5A, 2000 iCFA, 5 occupants

- 2kW system
- 3879 kWh/yr estimated annual electricity demand
- Current Primary Energy Demand = 6881 kWh/person.yr (34,405 kWh/yr total)

1. 2526 kWh/yr estimation from PV Watts
2. 2526/3879 = 0.65
3. Utilization % = ~50%

- In WUFI Passive, add a photovoltaic device under Systems.
- Input the value in Step 1 as the 'Photovolatic/Renewable energy'.
- Input the value in Step 3 as the Onsite Utilization

Internal calculation in WUFI Passive

4. 2526 * 3.16 * 0.5 = 3991 kWh/yr
5. (34,405 – 3991 kWh/yr) = 30,414 kWh/yr
6. 30,414 kWh/5 people = 6083 kWh/person.yr

Primary Energy Offset by PV: 3991 kWh/yr
Adjusted Primary Energy Demand: 6083 kWh/person.yr

Example (for PHPP): Chicago, IL, Climate Zone 5A, 2000 ft^2 **iCFA, 5 occupants**

- 2kW system
- 3879 kWh/yr estimated annual electricity demand
- Current Primary Energy Demand = 58.7 kBTU/ft^2.yr

1. 2526 kWh/yr estimation from PV Watts
2. 2526/3879 = 0.65
3. Utilization % = ~50%
4. 50% * 2526 kWh/yr = 1263 kWh/yr
5. 1263 kWh/yr * 3.412 kBTU/kWh = 4309.4 kBTU/yr
6. 4309.4 kBTU/yr * 3.16 kWh/kWh = 13617.7 kBTU/yr
7. 13617.7 kBTU/yr / 2000 sf = 6.81 kBTU/ft^2.yr
8. 58.7 – 6.81 = 51.89 kBTU/ft^2.yr

Primary Energy Offset by PV: 6.81 kBTU/ft^2.yr
Adjusted Primary Energy Demand: 51.9 kBTU/ft^2.yr

Appendix A – Renewables credits and co-generation in the calculation of source energy

Renewables

The annual source energy for a building is calculated by multiplying the site energy by the fuel-dependent primary energy factor, and then subtracting credit for renewable energy production multiplied by the fuel-dependent primary energy factor of the fuel type it is offsetting. Generally, the total annual source energy use of the building PE_A is calculated as

$$PE_A = \sum_{Fuel} \sum_{EndUse} SE_{A,Fuel,EndUse} F_{PE,Fuel} - TE_{DHW} F_{PE,DHW} - TE_{SH} F_{PE,SH} - RE_A C_{RE} F_{PE,elec}$$

where

$Fuel$ = gas, oil, coal, propane, biomass, electricity

SE_A = total annual site energy use (from the building energy model)

F_{PE} = primary energy factor

TE_{DHW} = usable onsite solar thermal energy for domestic hot water

TE_{SH} = usable onsite solar thermal energy for space heating

RE_A = total annual onsite renewable electricity generation

C_{RE} = coincident production-and-use fraction of renewable electricity generation (zero to 1)

F_{PE} = 3.16 for electricity, 0.2 for biomass, and 1.1 for fossil fuels.

The end uses specifically include space heating, cooling, humidification, dehumidification, ventilation fans, pumps, domestic hot water heating, major appliances, lighting, elevators, miscellaneous electric loads and miscellaneous gas loads. Electric vehicle charging is specifically excluded.

In the particular case where the only onsite renewable electricity generation is by PV and the system is grid-tied without battery storage, RE_A may be obtained from NREL's PVwatts calculator, and C_{RE} may be obtained from the pre-calculated utilization curves as described above.

More generally if the building is grid-tied without battery storage and with one or more renewable electricity generation technologies onsite, then

$$RE_A = \sum_{hour=1}^{8760} \sum_{tech} RE_{tech,hour}$$

And

$$C_{RE} = \sum_{hour} \frac{\min\left(LE_{hour}, \sum_{tech} RE_{tech,hour}\right)}{\sum_{tech} RE_{tech,hour}}$$

Where

LE = electrical load of the building
$tech$ = PV, wind, hydroelectric

If the building is grid-tied with battery storage, C_{RE} can be higher, and can be calculated as follows:

$$C_{RE,batt} = \frac{\sum_{hour} \max\left(0, B_{hour} + \min\left(LE_{hour}, RE_{hour}\right)\right)}{\sum_{hour} RE_{hour}}$$

Where B is the energy exchange with the battery, signed positive-from-the-battery.

At each hourly time step

$$\begin{aligned} &\text{if } \left[SOC \le 0 \text{ or } SOC \ge BC\right] \text{then} \\ &\qquad B = 0 \\ &\text{else} \\ &\qquad B = B' \\ &\text{end if} \end{aligned}$$

Where SOC is the battery state-of-charge, BC is the battery capacity, and

$$B' = LE - RE$$

The battery state of charge at each step is calculated as

$$SOC_{hour} = \min\left(BC, \max\left(0, SOC_{hour-1} - B'_{hour} \cdot \left(1 + k_{LOSS} \operatorname{sign} B'_{hour}\right)\right)\right)$$

Where k_{LOSS} is a fractional loss imposed on energy transfers into or out of the battery, nominally 0.05.

The above logic prioritizes the use of renewable generation to meet any building electrical load before charging the battery, and ensures that the battery charge stays between zero and the battery capacity.

The use of hourly time resolution in the calculation of C_{RE} overestimates it some because even with no battery it effectively attributes about an hour's worth of storage to the system whereas in reality the inverter capacitors store less than a second's worth of energy. Thus, for a system with a battery the battery capacity should be derated by an hour. For example, if the nominal battery capacity is 4.5 kWh and the average electrical load is 0.9 kW, use *BC*=3.6 kWh.

The calculation may be initialized with $SOC_0 = BC$ but should be iterated until $SOC_0 = SOC_{8760}$.

If the building is off-grid or served by an island grid powered by 100% renewable energy, C_{RE} is not automatically 1.0, because it may happen that the load is met, the battery is full, and the renewable system could still deliver more energy, but there is no place for it to go and therefore it would idle instead of producing its maximum power. Therefore, the C_{RE} would be computed as for grid-tied-with-battery, but the daily end-use load profiles or schedules may be altered to reflect lifestyle choices that would increase C_{RE}.

Co-generation

With a combined-heat-and power (CHP) unit, the adjusted annual primary energy PE for the building is given by

$$PE = D_{ELEC}F_{ELEC} + D_{HEAT}F_{HEAT}$$

where

D_{ELEC} is the annual electricity demand of the building (excluding any supplemental heat provided by grid electricity.)
D_{HEAT} is the annual heating demand plus hot water demand (including storage and distribution losses) of the building.
F_{ELEC} is the adjusted PE factor for electricity.
F_{HEAT} is the adjusted PE factor for heating.

The adjusted PE factor for electricity F_{ELEC} is given by

$$F_{ELEC} = \frac{E_{CHP}F_{E,CHP}}{D^*_{ELEC}} + \frac{\left(D^*_{ELEC} - E_{CHP}\right)\cdot F_{E,GRID}}{D^*_{ELEC}}$$

The annual electrical energy production E_{CHP} by the CHP units / generators is given by

$$E_{CHP} = \begin{cases} \text{the intended amount, for E-priority} \\ D_{HEAT}K_{COVG}\cdot\dfrac{\eta_{ELEC}}{\eta_{HEAT}}, \text{ for H-priority} \end{cases}$$

η_{ELEC} is the electrical generation efficiency of the CHP units (e.g. typically 25%.)
η_{HEAT} is the heat and hot water generation efficiency of the CHP units (e.g. typically 50%.)

$F_{E,GRID}$ is the source energy factor for grid electricity (currently 3.16).

$$D^*_{ELEC} = \begin{cases} D_{ELEC} + H_{GRID}, \text{ for H-priority with grid electric backup heat} \\ D_{ELEC}, \text{ otherwise} \end{cases}$$

H_{GRID} is the supplemental heat from grid electricity on the H-priority path with electric backup, given by

$$H_{GRID} = D_{HEAT} \cdot (1 - K_{COVG})$$

K_{COVG} is the fraction of the heat demand intended to be covered by CHP for H-priority, e.g. 90%.

The source energy factor for electricity from CHP, $F_{E,CHP}$, is given by

$$F_{E,CHP} = \begin{cases} F_{FUEL} / \eta_{ELEC}, & \text{for E-priority} \\ 0, & \text{for H-priority} \end{cases}$$

in which

F_{FUEL} is the source energy factor of the fuel for the CHP units (e.g. currently 1.07 for gas.)

The adjusted PE factor for <u>heating</u> F_{HEAT} is given by

$$F_{HEAT} = \begin{cases} \dfrac{(H_{CHP} \cdot K_{UTIL}) F_{H,CHP}}{D_{HEAT}} + \dfrac{(D_{HEAT} - H_{CHP} \cdot K_{UTIL}) \cdot F_{FUEL}}{D_{HEAT}}, & \text{for E-priority} \\ K_{COVG} \cdot F_{H,CHP} + (1 - K_{COVG}) \cdot F_{FUEL}, & \text{for H-priority with fuel heat for backup} \\ F_{H,CHP}, & \text{for H-priority with grid electric heat for backup} \end{cases}$$

where the annual CHP heating byproduct H_{CHP} is given by

$$H_{CHP} = E_{CHP} \cdot \frac{\eta_{HEAT}}{\eta_{ELEC}}$$

K_{UTIL} is the usable fraction of CHP heat (if CHP heat is available when the building needs heat, $K_{UTIL} = 1$). This may require an additional side calculation, depending on how the CHP unit is intended to run.

The source energy factor for heat generation from CHP, $F_{H,CHP}$, is given by

$$F_{H,CHP} = \begin{cases} 0, & \text{for E-priority} \\ F_{FUEL} / \eta_{HEAT}, & \text{for H-priority} \end{cases}$$

Appendix B – Moisture control guidelines

Excerpted from Straube (2012). [38]

3.4.1 Vapor Control Recommendations

Different types of assemblies have different vapor control requirements. Although the requirements can be developed through rational engineering analysis, a simplified summary of recommendations, many from the "I" codes, is presented below.

Above-Grade Wall Assemblies

Four categories of above-grade wall assemblies include most of the possible enclosures:

a) framed assemblies with all or most of the insulation inside of the sheathing and between the framing members;

b) framed assemblies with some insulation outboard of the framing and some insulation between the framing members;

c) assemblies with all or most of the insulation outboard of the structure (framed or solid); and

d) assemblies with insulation comprised of only air-impermeable and Class II vapor control insulation between, within, or outside of the structure.

a) Framed wall assemblies with all or most of the insulation value installed between the framing or structure (e.g. wood or steel stud) as vapor permeable (more than 10 perm) insulation (e.g., fiberglass, rockwool, cellulose, or open cell foam)

The goal of the vapor control design is to prevent vapor diffusing easily and condensing on either the cold sheathing in cold weather or the cold interior finish during warm weather

- No vapor control layer is needed in climate zones 1,2,3,4a or 4b.
- A Class I or Class II vapor control layer is required on the interior side of framed walls in zones 4c, 5, 6, 7, and 8, with the exceptions of basement walls, below-grade portion of any wall, and wall construction that is not sensitive to moisture or freezing (e.g., concrete).
- Class I vapor control layers, including non-perforated vinyl wallpaper, reflective foil, glass, epoxy paint, white boards, melamine, etc. are not recommended and should be avoided on the interior of air-conditioned building occupancies in climates with humid summers in zones 1-6. The dividing line between dry (B) and moist (A) can be found in ASHRAE 90.1. Enclosures clad with unvented water absorbent claddings (e.g., stucco, masonry, fiber cement, wood) are at especially high risk of summer condensation.

- A Class III vapor retarder can be used instead of a Class I or Class II when:
  - in zones 4c, or 5, vented cladding is used over sheathing with a perm rating of more than 1 (wet-cup), i.e., OSB, plywood, or exterior gypsum sheathing, OR
  - in zone 6, vented cladding is used over high permeance (more than 10 perm) sheathings such as fiberboard and exterior gypsum

Vented claddings include vinyl siding, metal panels, terra cotta, wood or fiber cement sidings on air gaps, and masonry veneers with clear airspaces and vent openings top and botto. A clear gap of around ⅜” (10mm) will generally provide sufficient airflow to allow for ventilation, but at least 1” (25mm) should be specified for masonry walls.

b) Framed assemblies with some insulation value outside of the framing or structure.

The recommendation in the previous assembly category may be used, but it is usually desirable to design for more drying, especially in warmer climate zones (4 and 5 especially). The use of insulation on the exterior of the sheathing increases its temperature in cold weather, thereby relaxing the need to control cold-weather vapor diffusion. Exterior insulation made of foamed plastic has the benefit that it also tends to reduce inward vapor drives during warm weather. MFI insulation work different in that they allow more outward drying. [24]

A Class III vapor retarder can be used instead of a Class I or Class II in zones 4c, 5, 6, 7, or 8 where any of the criteria for the specific zone from the list below is met. These criteria may depend upon the climate zone and the ratio of the insulation value in the stud space to the insulation value installed outboard of the sheathing. [25]

A Class III vapor control layer may be used on the interior of framed walls in zone 4c and higher, if any of the following criteria are met:

- Zone 4c (e.g., Vancouver, Seattle, or Portland)
  - Sheathing-to-cavity R-value ratio of >0.20
  - Insulated sheathing with an R-value >2.5 on a 2x4 framed wall
  - Insulated sheathing with an R-value >3.75 on a 2x6 framed wall
- Zone 5 (e.g., Chicago, Windsor, Boston)
  - Sheathing-to-cavity R-value ratio of >0.35
  - Insulated sheathing with an R-value >= 5 (e.g., 1” XPS) on a 2x4 framed wall
  - Insulated sheathing with an R-value >= 7.5 (e.g., 1.5” XPS) on a 2x6 framed wall.
- Zone 6 (e.g., Toronto, Ottawa, Helena, Montreal, Halifax, Minneapolis)
  - Sheathing-to-cavity R-value ratio of >0.50
  - Insulated sheathing with an R-value >= 7.5 (e.g., 1.5” XPS) on a 2x4 framed wall

    - Insulated sheathing with an R-value >= 11.25 (e.g. 2” PIC) on a 2x6 framed wall
- Zones 7 and 8 (e.g., Calgary, Edmonton, Whitehorse, Anchorage, Fairbanks)
    - Sheathing-to-cavity R-value ratio of >0.70
    - Insulated sheathing with an R-value >=10 (e.g., 2” XPS) on a 2x4 framed wall
    - Insulated sheathing with an R-value >=15 (e.g., 3” XPS) on a 2x6 framed wall

Insulated sheathing can be installed in the form of expanded polystyrene (EPS) or semi-rigid glassfiber and rockwool with approximately R-4 per inch, extruded polystyrene (XPS) with R-5 per inch, polyisocyanurate (PIC) with approximately R-6 per inch, or closed-cell spray foam (usually around R-6/inch).

c) Assemblies with all or most (more than 75% of the total) of the insulation value located outboard of the structure (framing or solid)

This is the simplest and most robust wall to design with respect to vapor control. Such walls should ideally have all moisture sensitive components and materials located on the inside of the insulation. In this location, a Class I or II layer on the inside of all or most of the insulation value is acceptable and recommended if all outboard components are moisture tolerant. [26] A Class III layer on the interface of a high permeance (more than 10 perms) insulation layer outboard of a moisture-sensitive structure should only be used if warm weather and inward vapor drive condensation are not an issue or are controlled by other means.

d) Assemblies comprised of only air-impermeable and Class II vapor control insulation between, within, or outside the structure.

The EPS and urethane foam cores of wood or metal SIPS, board foams, and medium density closed cell spray foam (between wood or steel studs), if installed as continuous layers, all provide their own vapor control layers and require no additional vapor-diffusion control in any climate. Wood studs themselves and small cracks between steel or wood studs do not allow significant vapor to flow by diffusion. Their use does not change the recommendations.

Cracks between framing members and insulation boards are often significant for airflow control and must be addressed in all of the systems described in the previous paragraph.

Below-Grade Wall Assemblies

Below-grade spaces, such as basements, are of particular concern with respect to improperly located Class I vapor control layers. Because the moisture drive in below-grade walls is always from the exterior to the interior in zones 6 and lower, installing a low-permeance layer on the interior side of insulation wall will cause moisture related durability issues by trapping moisture in the enclosure. A Class I vapor control layer outside a concrete or masonry basement wall is recommended to control the flow of vapor from damp soil into the assembly. Installing a Class II vapor control layer on the inside of below-grade framed assemblies is recommended for zones 7 and higher.

In cold climates (zone 5 and higher), condensation may occur on the interior side of concrete/masonry structure of a below-grade wall assembly if insulated on the inside with an air and vapor permeable (Class II or more, e.g., fibrous insulation) layer. To control both inward and outward drives, it is recommended that a Class II or III insulation product (e.g. most foams) be used in contact with the interior face of the concrete/masonry, and any insulation installed between interior framing follow the rules of "Framed assemblies with some insulation value outside of the framing or structure."

Below-Grade Floor Assemblies

Locating all of the insulation below the structure (concrete slab, or framed) with a Class I vapor control layer between the structure and the insulation is the practical and economical manifestation of the perfect enclosure. Some insulations provide the same level of vapor control (foil-faced polyiso or EPS, plastic-faced XPS) but many products will require a special low-permeance layer (polyethlyene sheet is commonly used, inexpensive, and effective).

If no impermeable floor finishes are likely to be used during the life of the structure, the vapor control class requirement can be relaxed to a Class II. See also BSI-003: Concrete Floor Problems and BSI-009: New Light in Crawlspaces online at buildingscience.com for more discussion of vapor control and flooring.

Roof Assemblies

Roofing behaves differently than walls from a vapor control point of view for a number of reasons: most roof membranes are located on the exterior and provide Class I vapor control. Roof membranes, shingles, metal roofing are all vapor impermeable. Only back-ventilated roofing such as concrete ties perform in a similar manner to walls.

Assuming a vapor impermeable roofing membrane, four categories of roof assemblies will include most practical roofing systems:

a) unvented roof assemblies with all or most of the insulation outboard of the structure (framed or solid)

b) vented, framed roof assemblies with all or most of the insulation inside of the sheathing and between the framing members

c) unvented, framed roof assemblies with either some insulation outboard of the framing and some insulation between the framing members, or some air-impermeable insulation outboard of air-impermeable insulation, and

a) unvented roof assemblies with insulation comprised of air-impermeable and Class II vapor control between, within, or outside the structure.

a) unvented roof assemblies with all or most (>75%) of the insulation outboard of the structure (framed or solid)

These types of roofs comprise most of the low-slope, rigid board insulated; commercial roof systems installed over metal and concrete decks. However, there is no technical difference between a low-slope roof built in this manner and a sloped roof. This type of roof has very little need for additional vapor control as all of the common board foam roofing insulations (PIC, EPS, XPS) provide sufficient vapor control for most climate zones

- No additional vapor control layer is needed if a Class II vapor control insulation layer is used (>2" of XPS, PIC, >3" of EPS)
- To control diffusion at joints in board foam, all board insulation should be installed in two layers or more, with joints offset vertically and horizontally. This is especially important in zones 5 and higher.

Such roofs should ideally have all moisture sensitive components and materials located to the inside of the insulation. In this location a Class I or II layer on the inside of all or most of the insulation value (e.g., 75%) is acceptable but will restrict desirable and effective inward drying. For zones 5 and lower, a vapor control layer of Class III or higher is recommended to allow for inward drying of incidental moisture due to solar heating to roof membranes (e.g., gypsum board on metal deck).

b) Vented, framed roof assemblies with all or most of the insulation value installed between the framing (e.g., wood/steel stud, metal buildings) as vapor permeable (more than 10 perm) insulation (e.g., fiberglass, rockwool, cellulose, or open cell foam)

If a compact roof is well-vented above the insulation (i.e., with soffit and ridge vents connected by an open air-space of 1.5"/38mm or more),

- no vapor control layer is required in zones 1 through 3
- Class III vapor control in zones 4 through 6
- Class II vapor control in zones 7 and higher

If a roof is sloped over a well-vented attic (i.e., with soffit and ridge vents connected by an open air volume of at least 12" (300mm) average height, and no less than 1.5"/38mm anywhere),

- no vapor control layer is required in zones 1 through 4,
- Class III vapor control layer is recommended for zones 5 through 6,
- Class II vapor control layer is recommended in zones 7 and higher,

Unvented, framed assemblies with all the insulation value comprised of air permeable insulation (fiberglass, rockwool, cellulose) between the framing are not recommended due to the potential for air leakage condensation

c.) Unvented framed roof assemblies with some insulation provided by air impermeable insulation.

Roofs need not be vented if diffusion and air leakage related wetting can be strictly limited. To accomplish this, some air impermeable, some Class II insulation can be located outside of air and vapor permeable (more than 10 perm) insulation (e.g., fiberglass, rockwool, cellulose are both).

The ratio of the insulation value of the exterior air- and vapor-control insulation to the insulation value of the interior air- and vapor-permeable insulation increases as the climate becomes colder, and the interior more humid. For normal commercial and residential occupancies the following recommendations can be made (Note: painted drywall or more than about 150mm/6" of open cell foam are Class III retarder).

- For zones 1 through 3A, 3B
  - Outer air-impermeable insulation value >15% of total
  - No vapor control layer required
- For zones 3c/4c (e.g. Vancouver, Seattle, Portland, San Francisco)
  - Outer air-impermeable insulation value >25% of total
  - Class III vapor control
- Zone 4A, 4B, 5 (e.g. Windsor, Kansas City, Boston)
  - Outer air-impermeable insulation value >35% of total
  - Class III vapor control in zone 5
- Zone 6 (e.g. Toronto, Ottawa, Montreal, Halifax, St Johns, Minneapolis)
  - Outer, air-impermeable insulation value >50% of total
  - Class III vapor control
- Zones 7 and 8 (e.g. Edmonton, Calgary, Winnipeg, Whitehorse, Fairbanks)
  - Outer, air-impermeable insulation value >65% of total
  - Class III vapor control

Air-impermeable insulation can be in the form of expanded polystyrene (EPS) with approximately R-4 per inch, extruded polystyrene (XPS) with R-5 per inch, polyisocyanurate (PIC) with approximately R-6 per inch, 2 pcf (32 kg/m^3) closed-cell spray foam (usually around R-6 per inch) or 0.5 pcf (8 kg/m^3) open cell spray foam (usually around R-4 per inch). All of these products, other than open-cell spray foam and EPS, provide a Class II vapor control layer in thicknesses of 1.5" or more. EPS and 1 pcf density (16 kg/m^3) which requires between 3" and 5" (depending on density) to reach Class II performance, and open cell foam requires a special vapor control coating.

d.) unvented roof assemblies with insulation comprised of only air-impermeable and Class II vapor control insulation between, within, or outside the structure.

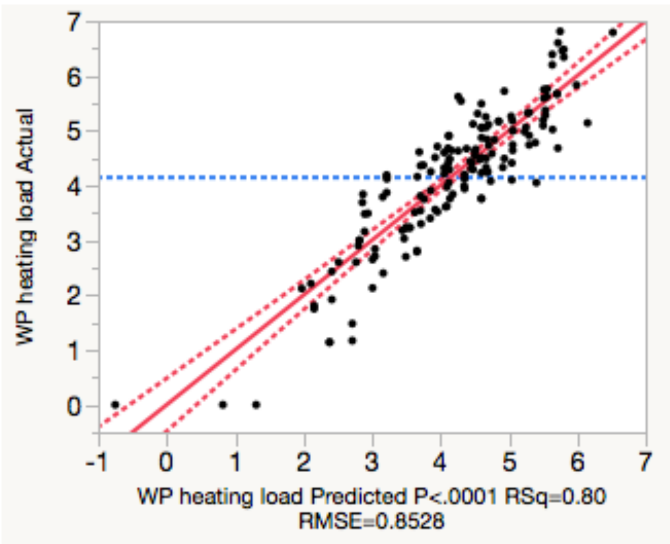
The EPS and urethane foam cores of wood or metal SIPS, board foams, and medium density closed cell spray foam (between wood or steel studs), if installed as continuous layers, all provide their own vapor control layers and require no additional vapor diffusion control in any climate with normal residential and commercial interior humidity conditions. Wood studs and cracks between steel or wood studs do not allow significant vapor to flow by diffusion and hence do not change the recommendations.

Cracks between framing members and panels are significant for airflow control and must be addressed in all of the systems described above. A very effective airflow control layer is required on the inside of the insulation and/or framing for all unvented roof assemblies.

Appendix C – Updated formulae for the peak load criteria

The following regression formulas update section 2.4 of the development report, completing the "peak load crossover" work mentioned in section 2.6. [39] These were generated by re-implementing the study building configurations in Wufi Passive and redoing the regression model-fitting on the resulting peak load values.

Wufi Passive peak heating load - Actual by Predicted Plot



Summary of Fit

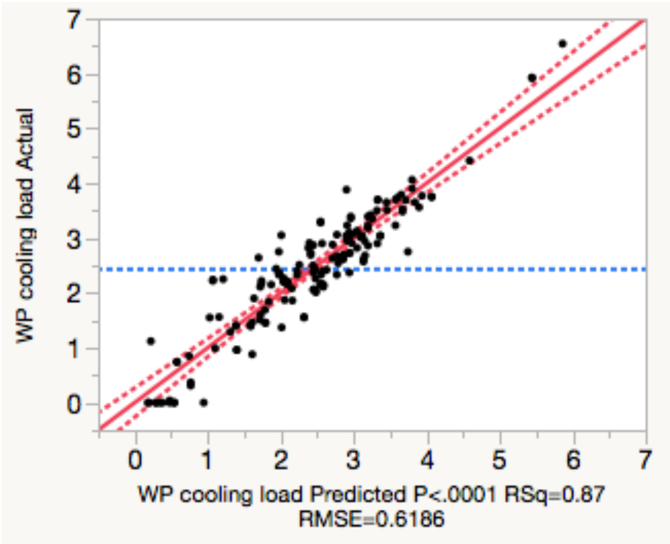
RSquare	0.804196
RSquare Adj	0.800253
Root Mean Square Error	0.8528
Mean of Response	4.144235
Observations (or Sum Wgts)	327

$$WP\ peak\ heating\ load\ [\frac{\text{Btu}}{\text{h·ft}^2}] = 5.5 - \frac{T_{D,H}}{17.2} - \frac{P_{ELEC}}{0.218} + \frac{(HDD65 - 4705) \cdot (CDD65 - 1376)}{15.9e6}$$

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.4799676	0.167231	32.77	<.0001*
Heating design dry bulb temp 99.6% [F]	-0.058096	0.002652	-21.91	<.0001*
Electricity price $/kWh	-4.589818	1.513149	-3.03	0.0029*
(HDD65 F.days-4705.24)*(CDD65 F.days-1375.71)	6.288e-8	1.436e-8	4.38	<.0001*

Wufi Passive peak cooling load - Actual by Predicted Plot



Summary of Fit

RSquare	0.873887
RSquare Adj	0.869597
Root Mean Square Error	0.618559
Mean of Response	2.429664
Observations (or Sum Wgts)	327

$$WP\ peak\ cooling\ load[\frac{\mathrm{Btu}}{\mathrm{h{\cdot}ft^2}}]$$
$$= -4.7 + \frac{HDD65}{2735} + \frac{CDD65}{561} + \frac{T_{D,C}}{26.4} + \frac{(HDD65 - 4705)\cdot(CDD65 - 1376)}{3.95e6}$$
$$+ \frac{(I_G - 1547)\cdot(CDD65 - 1376)}{1.92e6}$$

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.707172	0.779755	-6.04	<.0001*
HDD65 F.days	0.0003656	4.037e-5	9.06	<.0001*
CDD65 F.days	0.001782	0.000145	12.33	<.0001*
Cooling design dry bulb temp 0.4% [F]	0.0378564	0.010276	3.68	0.0003*
(HDD65 F.days-4705.24)*(CDD65 F.days-1375.71)	2.5341e-7	2.711e-8	9.35	<.0001*
(CDD65 F.days-1375.71)*(Global solar radiation kWh/m2.yr-1546.77)	5.2172e-7	1.36e-7	3.84	0.0002*

References

[1] "Operating Energy." Measures of Sustainability Series. Canadianarchitect.com, Jan. 2002. Web. 13 May 2016. https://www.canadianarchitect.com/asf/perspectives_sustainibility/measures_of_sustainablity/measures_of_sustainablity_operating.htm

[2] Wright, Graham S., and Katrin Klingenberg. *Climate-Specific Passive Building Standards*. Golden, CO: National Renewable Energy Laboratory, 2015. Web. 13 May 2016. http://www1.eere.energy.gov/library/asset_handler.aspx?src=http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/climate-specific-passive-building.pdf&id=7134

[3] Lstiburek, Joseph. "BSI-028: Energy Flow Across Enclosures." Building Science Corporation, 1 Dec. 2009. Web. 13 May 2016. http://buildingscience.com/documents/insights/bsi-028-energy-flow-across-enclosures

[4] Cummings, James. "Sensible and Latent Cooling Load Control Using Centrally‐Ducted, Variable‐Capacity Space Conditioning Systems in Low Sensible Load Environments." Office of Energy Efficiency and Renewable Energy. energy.gov, 26 July 2012. Web. 16 May 2016. http://energy.gov/eere/buildings/downloads/sensible-and-latent-cooling-load-control-using-centrally-ducted-variable

[5] "Info-620: Supplemental Humidity Control." Building Science Corporation, 19 May 2009. Web. 16 May 2016. http://buildingscience.com/documents/information-sheets/information-sheet-supplemental-humidity-control

[6] Lstiburek, Joseph. "BSI-001: The Perfect Wall." Building Science Corporation, 15 July 2010. Web. 16 May 2016. http://buildingscience.com/documents/insights/bsi-001-the-perfect-wall

[7] "BSI-091: Flow-Through Assemblies." Building Science Corporation, 13 Jan. 2016. Web. 16 May 2016. http://buildingscience.com/documents/building-science-insights/bsi-091-flow-through-assemblies

[8] "ETW: Wall - Double Stud Wall Construction." Building Science Corporation, 15 Nov. 2014. Web. 16 May 2016. http://buildingscience.com/documents/enclosures-that-work/high-r-value-wall-assemblies/high-r-value-double-stud-wall-construction?topic=doctypes/enclosures-that-work/etw-high-r-value-enclosure-assemblie

[9] Bailes III, Allison A. "Lstiburek's Ideal Double-Stud Wall Design." Green Building Advisor. The Taunton Press, 29 Apr. 2015. Web. 16 May 2016.

http://www.greenbuildingadvisor.com/articles/dept/building-science/lstiburek-s-ideal-double-stud-wall-design

[10] "Home » Green Basics: Encyclopedia » Envelope and Structure » Insulation Choices » Rigid Foam Insulation." Green Building Advisor. The Taunton Press, 9 Aug. 2012. Web. 16 May 2016. http://www.greenbuildingadvisor.com/green-basics/rigid-foam-insulation

[11] *Energy Performance of Buildings — Calculation of Energy Use for Space Heating and Cooling*. ISO 13790, 2008. Print.

[12] *Heating Systems in Buildings - Method for Calculation of the Design Heat Load*. DIN EN 12831, 2003. Print.

[13] Burdick, Arlan. *Strategy Guideline: Accurate Heating and Cooling Load Calculations*. Golden, CO: National Renewable Energy Laboratory, 2011. Web. 16 May 2016. http://www.nrel.gov/docs/fy11osti/51603.pdf

[14] *Peak Cooling and Heating Load Calculations in Buildings Except Low-Rise Residential Buildings*. ANSI/ASHRAE/ACCA Standard 183-2007 (Reaffirmed 2014). Atlanta GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2014. Print.

[15] Christensen, Craig et al. "BEopt: Software for Identifying Optimal Building Designs on the Path to Zero Net Energy." National Renewable Energy Laboratory - Conference Paper NREL/CP-550-37733 (April 2005). Web. 16 May 2016.
http://www.nrel.gov/docs/fy05osti/37733.pdf

[16] "PVWatts Calculator." National Renewable Energy Laboratory. Web. 16 May 2016.
http://pvwatts.nrel.gov

[17] *AAMA CRS-15: A Comparison of Condensation Rating Systems for Fenestration*. Schaumberg Illinois: American Architectural Manufacturers Association, 2015. Web. 16 May 2016.
http://www.aamanet.org/news/1/10/0/all/1212/aama-releases-new-comparison-of-condensation-ratings-systems-for-fenestration-document

[18] "CONDENSATION RESISTANCE FACTOR TOOL." American Architectural Manufacturers Association, n.d. Web. 16 May 2016.
http://www.aamanet.org/crfcalculator/2/334/crf-tool

[19] Straube, John, and Chris Schumacher. "Interior Insulation Retrofits of Load-Bearing Masonry Walls in Cold Climates." *Journal of Green Building* 2.2 (2007): 42–50. Web. 31 May 2016.
https://www.researchgate.net/publication/269493678_Interior_Insulation_Retrofits_of_Load-Bearing_Masonry_Walls_in_Cold_Climates

[20] Lstiburek, Joseph. "BSI-011: Capillarity—Small Sacrifices." Building Science Corporation, 3 June 2014. Web. 31 May 2016.
http://buildingscience.com/documents/insights/bsi-011-capillarity-small-sacrifices

[21] "BSI-095: How Buildings Age." Building Science Corporation, 13 May 2016. Web. 31 May 2016.
http://buildingscience.com/documents/building-science-insights/bsi-095-how-buildings-age

[22] *Mortgage Industry National Home Energy Rating Systems Standards*. Oceanside, CA: Residential Energy Services Network (RESNET), 2013. Print.
http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf

[23] *WaterSense® New Home Specification Guide for Efficient Hot Water Delivery Systems, Version 1.2*. U.S. Environmental Protection Agency (EPA), 2014. Web. 10 May 2016.
http://epa.gov/watersense/docs/hw_distribution_guide.pdf

[24] RESNET, op. cit., Appendix B

[25] RESNET, op.cit., Section 303.4.

[26] Wilson, E. et al. *2014 Building America House Simulation Protocols* (BAHSP). Golden, CO: National Renewable Energy Laboratory, 2014. Print..
http://energy.gov/eere/buildings/house-simulation-protocols-report

[27] RESNET, op. cit., clause 303.4.1.7.2.1 "Residual MELs" and 303.4.1.7.2.6 "Televisions".

[28] BAHSP, op. cit., Table 25. For Office and Workout room, footnote therein refers in turn to "Home Energy Usage Chart," Public Service of New Hampshire, 2013, and assumes 1h/wk usage.

[29] BAHSP, op. cit., Table 26.

[30] RESNET, op. cit., clause 303.4.1.7.2.2 Interior Lighting, and equation 5.

[31] Building America "B10 Analysis – New Construction 2011-01-26" workbook, Detailed Lighting tab, C89:D101 and C120:L132
http://energy.gov/eere/buildings/building-america-analysis-spreadsheets

[32] RESNET, op. cit., clause 303.4.1.7.2.3 Exterior Lighting, and equation 6.

[33] B10 Analysis workbook, op. cit.

[34] RESNET, op. cit., clause 303.4.1.7.2.4 Garage lighting, and equation 7.

[35] B10 Analysis workbook, op. cit.

[36] "DIN V 18599-10:2007-02." *Energy Efficiency of Buildings — Calculation of the Energy Needs, Delivered Energy and Primary Energy for Heating, Cooling, Ventilation, Domestic Hot Water and Lighting — Part 10: Boundary Conditions of Use, Climatic Data*. Deutsches Institut für Normung (DIN), 2007. Table 4. Print.

[37] Henderson, Hugh, Yu Joe Huang, and Danny Parker. *RESIDENTIAL EQUIPMENT PART LOAD CURVES FOR USE IN DOE-2*. Berkeley CA: Lawrence Berkeley National Laboratory, 1999. Web. 31 May 2016.
https://publications.lbl.gov/islandora/object/ir%3A112919

[38] Straube, John F., (2012) *High Performance Enclosures*, Building Science Press, Section 3.4.1, pp 74-81.

[39] Wright and Klingenberg, op. cit., Section 2.4 and 2.6.