TECH CORNER

PHIUS+ 2018 Space Conditioning Criteria Mid-Cycle Evaluation

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PHIUS officially launched the PHIUS+ 2018 Passive Building Standard just over a year ago at the 14th Annual North American Passive House Conference. The passive building market seems to approve: PHIUS+ Certifications continue to increase. The most notable upgrades from the PHIUS+ 2015 standard add nuance to the space conditioning targets, adjusting them for building size and occupant density. Another notable upgrade provides tiered source-energy targets and methods to hit those targets, depending on project goals.

Through the end of September 2019, PHIUS certification staff had the discretion to grant an exception for one of the four main space conditioning target criteria, as outlined in [PHIUS+ 2018 Passive Building Standard-Setting Documentation](), page 6. This allowance gave teams with projects already in planning some assurance that their efforts would not be wasted if their designs could not be revised to meet the new targets. If a project was severely constrained on meeting a target, a "mulligan" could be granted based on majority vote from the certification staff. This also allowed flexibility in case the targets didn't pan out in the real world even for clean-sheet designs.

This "3 out of 4" provision has now come to an end, and a mid-cycle evaluation indicates a need for some adjustments to the heating/cooling criteria.

In particular, for some projects, the cooling demand and cooling load targets were challenging to meet due to internal gains. This was not due to bad design, it mostly showed up with unit-density different from the study buildings used in the target-setting process. We found that the 'occupant density' (in ft^2 iCFA/person) is not a great proxy for internal gains on its own. For example, a building with an occupant density of 420 ft^2/person could have internal heat gains (IHG) ranging from 0.9 BTU/ft^2hr to 1.35 BTU/ft^2hr — that's 50% more in the higher case. Because of the way appliance and plug loads scale in the calculation protocol, *unit density* also has an influence.

Per Section 6.6.1.3 of the [Certification Guidebook](), the calculation of miscellaneous loads in residential application consists of a base-load per unit, plus a scaling factor based on occupancy and unit floor area. The base number is a constant - think of the active and phantom loads for the TV, cable box, coffee maker, etc. that are spread across multiple people in a larger unit but are individual loads in a studio.

Figure 1 shows the relationship between the internal heat gains and occupant density for the PHIUS study buildings as well as sample projects submitted for PHIUS+ 2018

Certification. Notice the amount of scatter around the trendline, as well as the variability in the IHG for projects at the left side which shows that at an occupant density of ~220 ft^2/person results in a wide spread of IHG per square foot. The higher end of IHG's is generally representative of small units with 1 person per unit, and the lower end of the IHG scatter is for larger units with more people per unit. Again, same square footage per person but less plug load density.

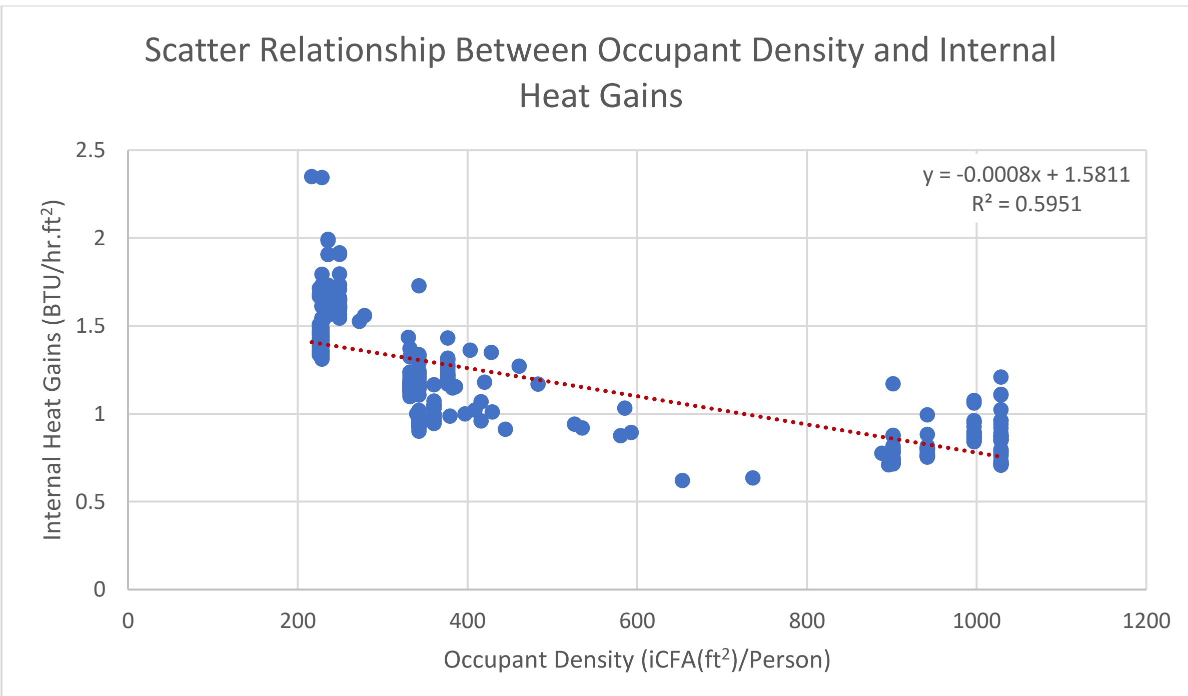

Figure 1: Relationship Between Occupant Density and Internal Heat Gains

Table 1 shows examples from the standard-setting models as well as 5 example projects, listed from highest occupant density to lowest occupant density. Note that the more square footage per person (low occupant density) generally leads to lower internal heat gains, and vice versa, but it's not an exact indicator.

Table 1: Occupant Density & Internal Heat Gain in Sample Buildings

	iCFA (ft2) / Person	Internal Heat Gains (BTU/hr.ft2)	People / Unit
PSB Med Duplex	225	1.3	4
PSB High-Rise	229	1.45	6
PSB Mid-Rise	229	1.6	3
PSB Townhomes	236	1.35	4
PSB Small Duplex	249	1.6	2
Example 6	279	1.56	2
PSB Small Duplex	332	1.2	3
Example 4	340	1	2.8
PSB High-Rise	343	1.2	6
PSB Mid-Rise	343	1.25	3
PSB Med Duplex	361	1	5
PSB Townhomes	377	0.95	5
Example 1	397	1	2.9
Example 2	416	0.96	2.7
Example 3	416	1.07	2.7
Example 5	428	1.35	2.1
PSB Med Duplex	902	0.7	2
PSB Townhomes	942	0.7	2
PSB Small Duplex	997	0.9	1
PSB High-Rise	1029	0.9	2
PSB Mid-Rise	1029	0.8	2

**PSB = PHIUS Study Building*

In the standard-setting process, the results from all study buildings were plotted and a statistical best-fit response-surface formula was used to set the final targets. The correlation coefficients of the fits were good at 0.88 to 0.92, but there is still some scatter - the performance values of the study buildings fall below and above the best fit formula value, as shown in Figures 2,3,4. The root mean square errors RMSE indicate the average magnitude of the difference between the modeled performance and the fitted criterion formula. Another way to think about it is: if the study buildings themselves were submitted for certification, their performance results would be higher or lower than the best-fit target formula by the RMSE amounts on average.

The Cooling Demand and Cooling Load was too stringent in some cases if the internal heat gains were significantly higher than the study building. This typically happens when there are more units and fewer people per unit. Within a given design, once the solar gain is optimized, shading efforts are in place, and internal heat gains are reduced, there is very little designers can do to reduce a Cooling Demand or Cooling Load result. There are simply fewer knobs to turn to reduce the cooling needs.

The Heating Load targets also seemed to be forcing unreasonably costly upgrades on too many real projects. The original Heating Load targets resulted from study buildings with mostly better-than-required values for air-tightness because that proved to be a cost-effective conservation measure during the standard-setting. Measures that make the study buildings perform better have the effect of tightening the targets.

Moving Forward

Moving forward, the space conditioning targets will reflect an 'Inclusive Fit' formula, which adds the RMSE to the 'Best Fit' formula.

The graphs below show the "predicted versus actual" plots for the Cooling Demand, Heating Load, and Cooling Load fits on the study building data.

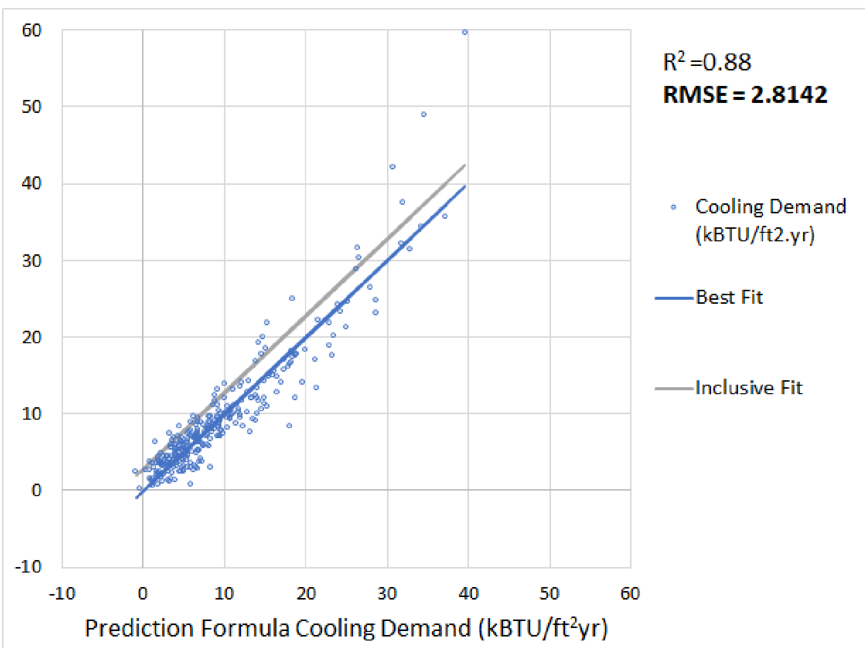

Figure 2: Cooling demand, study buildings actual vs. prediction formula.

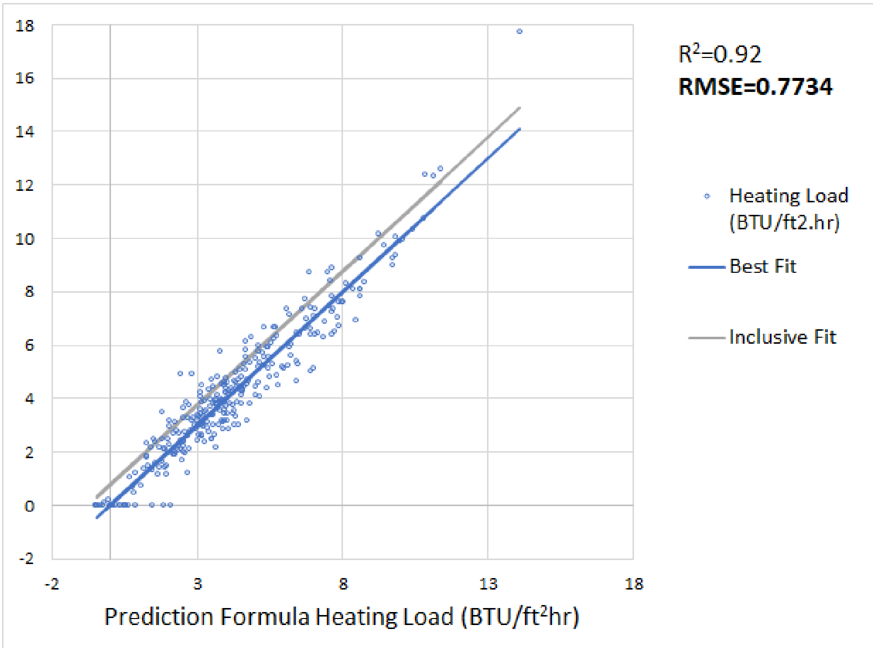

Figure 3: Heating load, study buildings actual vs. prediction formula.

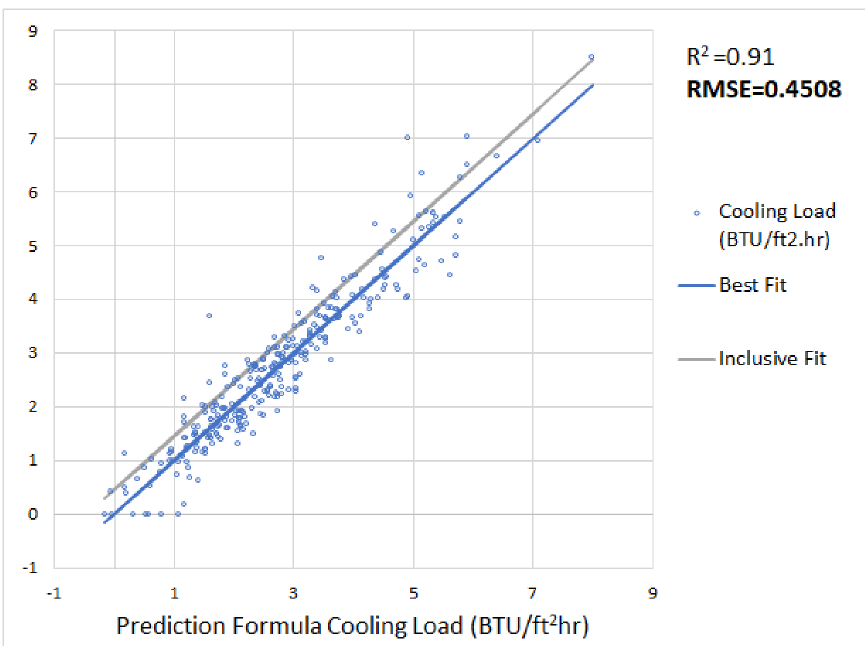

Figure 4: Cooling load, study buildings actual vs. prediction formula

Based on this, the resulting updated targets will be:

Cooling Demand = Original Target + 2.81 kBTU/ft^{2}yr
Heating Load = Original Target + 0.77 BTU/ft^{2}hr
Cooling Load = Original Target + 0.45 BTU/ft^{2}hr

The PHIUS+ 2018 Space Conditioning Criteria Calculator v2 has been updated to reflect this 'Inclusive Fit' line. The updated calculator shows 'v2' at the end of the naming convention.

Note:

- Projects with a contract date before October 1, 2019 must choose **only one** path, (1) Use the updated calculator 'v2' **or** (2) Meet 3 of 4 space conditioning targets as described above.
- Projects with a contract date after October 1, 2019 must use the updated v2 calculator.

Using the data collected from the first year, it appears that the 'Best Fit' method is still appropriate for the Annual Heating Demand target. This is mainly because conservation upgrades can continually lower this value; designers are less 'boxed in' or less likely to 'hit a wall' than they are with the other targets.

Note that source energy, the total impact metric, has not been adjusted. The source energy targets are the same (depending on the tier), but the new adjustments give designers more flexibility to meet that goal.

Appendix A - Heating/Cooling Criteria Formulas

The Original Target formulas mentioned above are shown in Figures A.1 to A.4, where all are per unit of interior conditioned floor area iCFA, and the nomenclature is as follows:

EnvFlr	- Ratio of envelope area to interior conditioned floor area.
Occ	- Residential-equivalent design occupancy in square feet per person.
HDD65	- Heating degree-days, base 65 F, per ASHRAE Fundamentals 2017.
CDD50	- Cooling degree-days, base 50 F, per ASHRAE Fundamentals 2017.
DDD	- Dehumidification-days, base humidity ratio 0.010, from PHIUS climate data.
IGA	- Irradiance, global, annual, in kWh/m^2, per PHIUS climate data.
$elec	- Marginal electricity price, state average, in $/kWh.
THD	- Temperature, heating design day, F, per PHIUS climate data.
TCD	- Temperature, cooling design day, F, per PHIUS climate data.
IGHL	- Irradiance, global, heating design day, Btu/h.ft^2, per PHIUS climate data.
IGCL	- Irradiance, global, cooling design day, Btu/h.ft^2, per PHIUS climate data.

$$
\begin{aligned}
&3.0741786353 \\
&+ 1.7570744179 \cdot EnvFlr \\
&+ 0.0006094673 \cdot HDD65 \\
&+ -0.002236765 \cdot IGA \\
&+ -10.26787567 \cdot \$elec \\
&+ (EnvFlr - 1.766) \cdot (EnvFlr - 1.766) \cdot 1.1967248787 \\
&+ (EnvFlr - 1.766) \cdot (HDD65 - 5860.0833333) \cdot 0.0002735396 \\
&+ (HDD65 - 5860.0833333) \cdot (HDD65 - 5860.0833333) \cdot -5.520236e\text{-}8 \\
&+ (EnvFlr - 1.766) \cdot (IGA - 1451.0633333) \cdot -0.001480515 \\
&+ (HDD65 - 5860.0833333) \cdot (IGA - 1451.0633333) \cdot -4.578714e\text{-}7 \\
&+ (EnvFlr - 1.766) \cdot (\$elec - 0.2029333333) \cdot -2.773120743 \\
&+ (HDD65 - 5860.0833333) \cdot (\$elec - 0.2029333333) \cdot -0.001507354
\end{aligned}
$$

Figure A.1: Criterion formula for Annual Heating Demand in kBtu/ft^{2}yr.

$$
\begin{aligned}
&-13.16054549 \\
&+ 1.0757390192 \cdot EnvFlr \\
&+ 922.1823816 \cdot Occ \\
&+ 0.0006576419 \cdot CDD50 \\
&+ 0.0053886756 \cdot IGA \\
&+ 9.3572058306 \cdot DDD \\
&+ 1.3915612101 \cdot \$elec \\
&+ (EnvFlr - 1.766) \cdot (EnvFlr - 1.766) \cdot 3.5725218909 \\
&+ (Occ - 0.0027218) \cdot (Occ - 0.0027218) \cdot 307900.65106 \\
&+ (EnvFlr - 1.766) \cdot (IGA - 1451.0633333) \cdot 0.0036281011 \\
&+ (CDD50 - 4104.8333333) \cdot (IGA - 1451.0633333) \cdot 1.3446195e\text{-}6 \\
&+ (IGA - 1451.0633333) \cdot (IGA - 1451.0633333) \cdot 3.689945e\text{-}6 \\
&+ (Occ - 0.0027218) \cdot (DDD - 0.3233057481) \cdot 1763.4349411 \\
&+ (DDD - 0.3233057481) \cdot (\$elec - 0.2029333333) \cdot -20.48022332
\end{aligned}
$$

Figure A.2: Criterion formula for Annual Cooling Demand in kBtu/ft^{2}yr.

$$
\begin{aligned}
&5.2001065557 \\
&+ 1.0910602698 \cdot EnvFlr \\
&+ 294.92913196 \cdot Occ \\
&+ -0.000169585 \cdot HDD65 \\
&+ -0.085714432 \cdot THD \\
&+ -0.043301638 \cdot IGHL \\
&+ -3.920896922 \cdot \$elec \\
&+ \left(EnvFlr - 1.766 \right) \cdot \left(EnvFlr - 1.766 \right) \cdot 1.0101270679 \\
&+ \left(EnvFlr - 1.766 \right) \cdot \left(THD - 19.736433333 \right) \cdot -0.023102881 \\
&+ \left(HDD65 - 5860.0833333 \right) \cdot \left(THD - 19.736433333 \right) \cdot 2.5574756e\text{-}6 \\
&+ \left(EnvFlr - 1.766 \right) \cdot \left(IGHL - 22.692412967 \right) \cdot -0.021908846 \\
&+ \left(IGHL - 22.692412967 \right) \cdot \left(IGHL - 22.692412967 \right) \cdot 0.0010214681 \\
&+ \left(HDD65 - 5860.0833333 \right) \cdot \left(\$elec - 0.2029333333 \right) \cdot -0.00074824
\end{aligned}
$$

Figure A.3: Criterion formula for Peak Heating Load in Btu/h.ft^2

$$
\begin{aligned}
&-8.894257857 \\
&+ 0.4779165041 \cdot EnvFlr \\
&+ 178.12769665 \cdot Occ \\
&+ 1.9044551\text{e-}6 \cdot CDD50 \\
&+ 0.1019963231 \cdot TCD \\
&+ 0.0170829233 \cdot IGCL \\
&+ (EnvFlr - 1.766) \cdot (EnvFlr - 1.766) \cdot 1.0406068504 \\
&+ (Occ - 0.0027218) \cdot (CDD50 - 4104.8333333) \cdot 0.0235455021 \\
&+ (CDD50 - 4104.8333333) \cdot (CDD50 - 4104.8333333) \cdot 2.1816386\text{e-}8 \\
&+ (EnvFlr - 1.766) \cdot (TCD - 78.127) \cdot 0.0284904137 \\
&+ (TCD - 78.127) \cdot (TCD - 78.127) \cdot 0.0009440729 \\
&+ (EnvFlr - 1.766) \cdot (IGCL - 71.844689133) \cdot 0.0083066462
\end{aligned}
$$

Figure A.4: Criterion formula for Peak Cooling Load (sensible only) in Btu/h.ft^2