ASHRAE 90.1 2016
Appendix G

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Acknowledgements

Learning Objectives

- Communicate the general concept and benefits of the “stable baseline” method introduced in 90.1 2016 Appendix G.
- Establish configuration of the baseline design model for a given project
- Convert information available from design documents into proposed model inputs
- Apply Appendix G to special cases such as core-and-shell projects, tenant fit outs, renovations and projects served by district heating or cooling systems.
- Describe 90.1 Appendix G reporting requirements
- Name reasons why the modeled performance of the proposed design may differ from the post-occupancy energy use

Agenda

- General Concept of ASHRAE 90.1 Appendix G
- Modeling Workflow
- Envelope Geometry and Properties
- Lighting
- Heating, Ventilation, and Air Conditioning Systems
- Service Water Heating (SWH) Systems
- Miscellaneous Loads
- Appendix G Reporting Requirements
- Interpreting Simulation Result

General Concept of ASHRAE 90.1 Appendix G

Poll

What is your professional focus?

(select all that apply)

1. Code official
2. Architect
3. Engineer
4. Energy modeler
5. Administrator of above-code program
6. Other

Appendix G History and Evolution

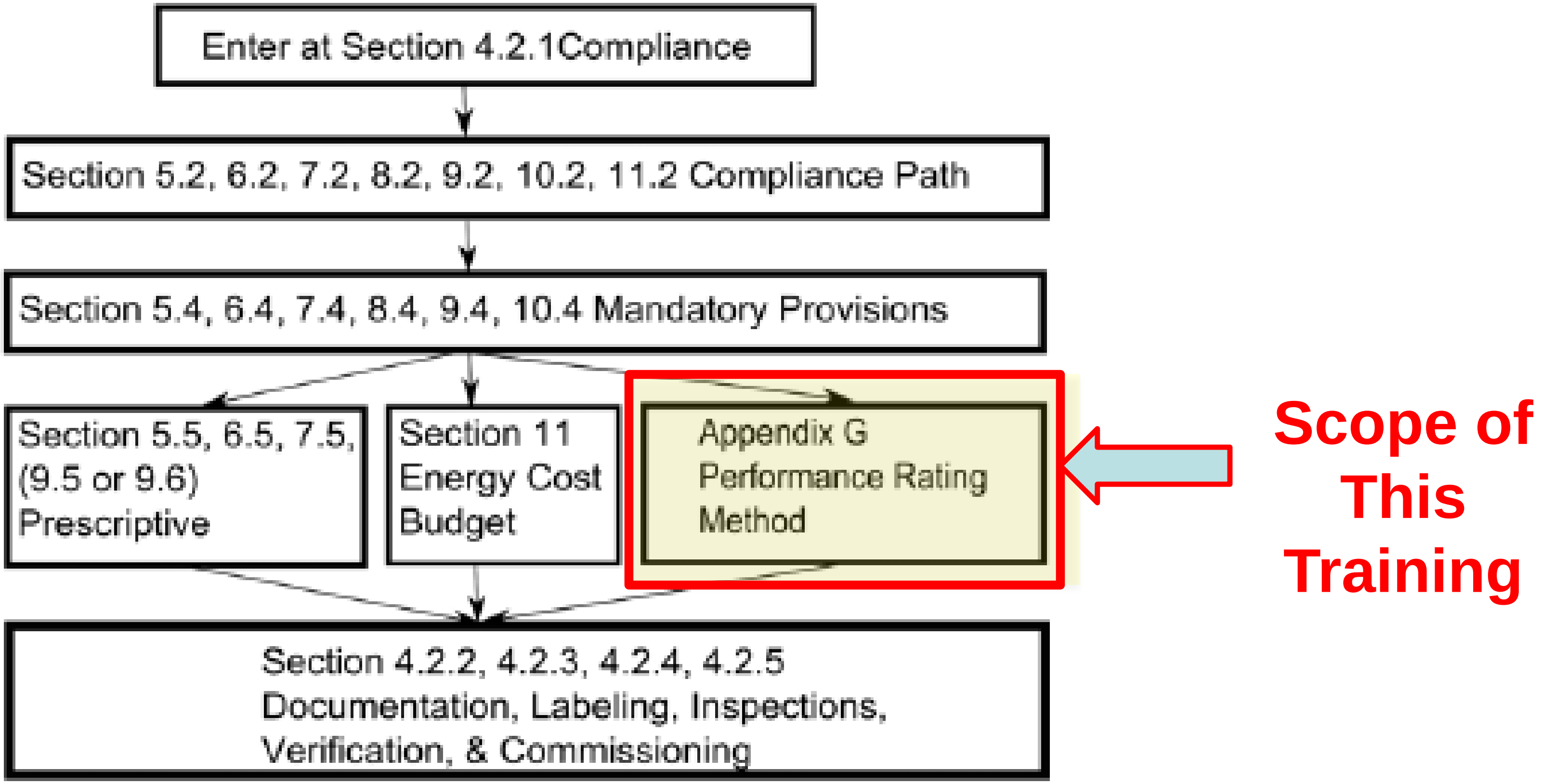
- Introduced in 90.1 2004 as a methodology for quantifying performance of designs that exceed the minimum requirements of the standard
- May be used for new construction, alterations and additions to existing buildings, except designs with no mechanical systems.
- Used in LEED, EPA Energy Star Multifamily High-rise Program, IRS 179D federal tax deduction for commercial buildings, incentive programs, etc.
- Starting with 90.1 2016, an alternative path of demonstrating compliance with the standard

2019 Oregon Zero Energy Ready Commercial Code

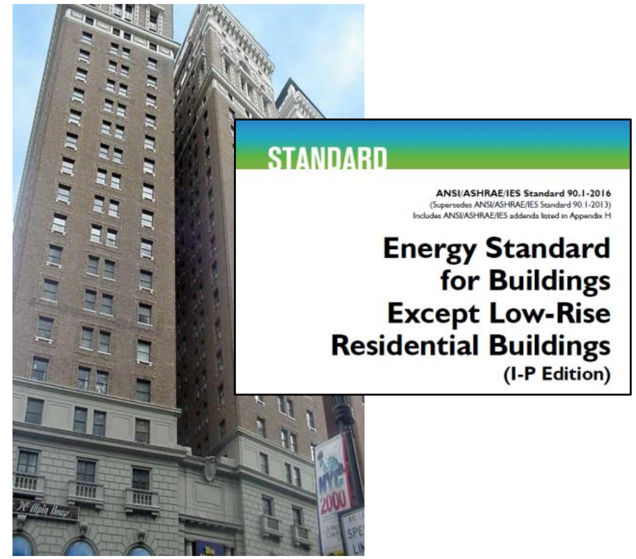
- Effective October 1, 2019

- Based on ASHRAE Standard 90.1-2016 with state amendments
- Includes two whole building performance options
  - ✓90.1 Section 11 Energy Cost Budget Method (ECB)
  - ✓Appendix G Performance Rating Method (PRM)

Standard 90.1 Compliance Options: Whole Building Performance Path



Appendix G: General Approach

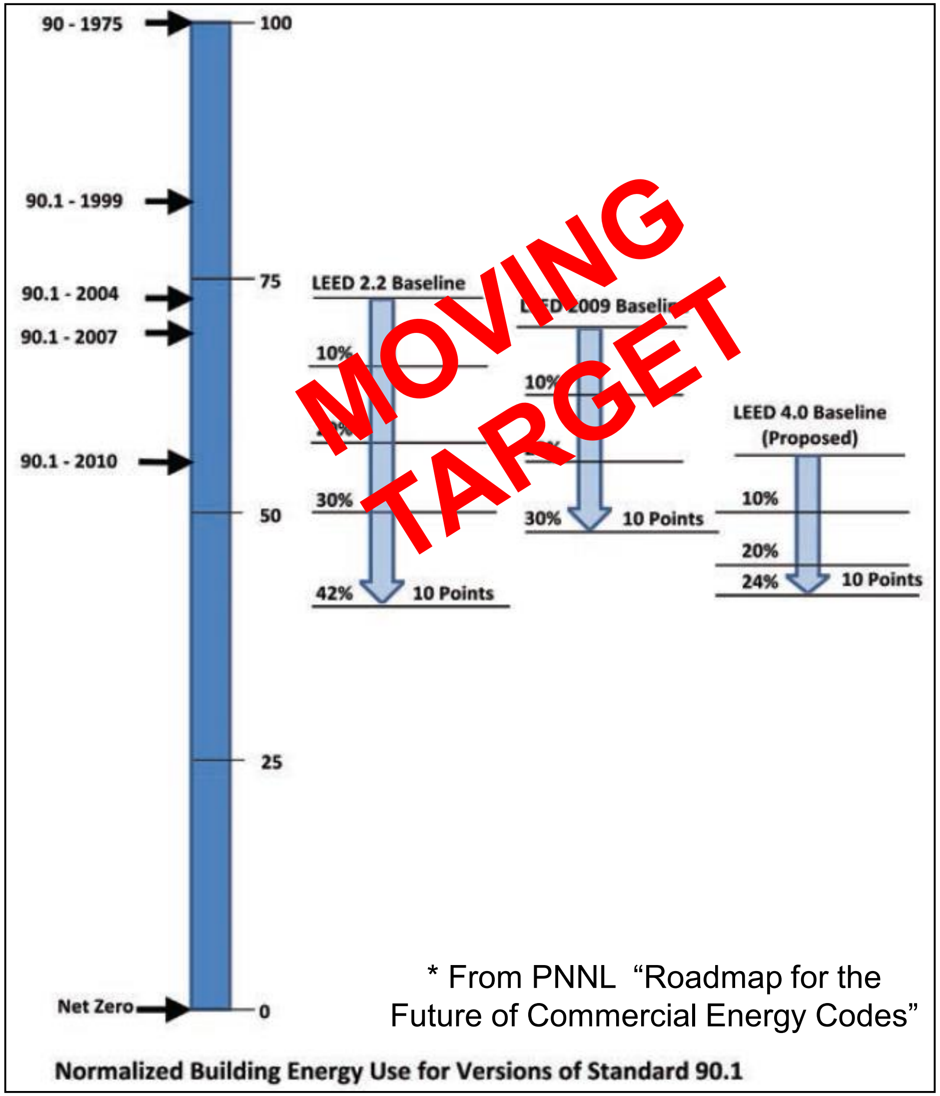


Proposed Building Design

Baseline Building Design

- Prescribes how to establish configuration of the baseline and proposed design models for a given building design, and how to use simulation results to establish compliance
- Models must include all components within and associated with the building
- Must use the same simulation tool, weather and operating schedules (with few exceptions)

From Moving Target to Fixed Baseline



* From PNNL "Roadmap for the Future of Commercial Energy Codes"

Fixed Baseline

- The baseline efficiency is set at ~90.1-2004
- Proposed designs must improve over baseline by a prescribed margin to meet code
- Simplifies modeling, submittal reviews, and maintenance of the compliance forms.
- Increases opportunities for automation in simulation tools.
- Allows use of consistent methodology for code compliance and above code programs.

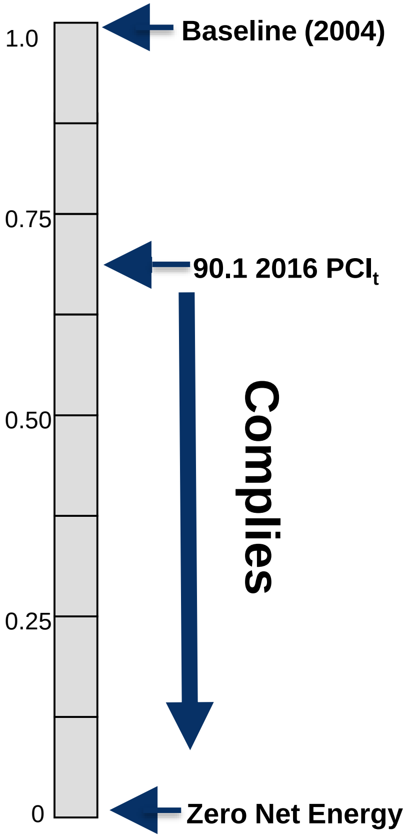
Establishing Compliance

- Performance of the proposed design relative to the baseline is expressed as Performance Cost Index (PCI)

$$PCI = \frac{Proposed\ Building\ Energy\ Cost}{Baseline\ Building\ Energy\ Cost}$$

- Project meets code if its PCI is less than or equal to the Performance Cost Index Target (PCI_T)

$$PCI \leq PCI_T$$



* From PNNL "Roadmap for the Future of Commercial Energy Codes"

Quiz 1

a. **What can we say about design that has PCI=0?**
b. **What can we say about design that has PCI=1?**
c. **What can we say about design that has PCI<PCIT?**

Performance Cost Index Target

$$PCI_t = \frac{(BBUEC + (BPF \cdot BBREC))}{BBP}$$

$$\% \text{ Improvement beyond code} = 100 * \frac{\text{PCI}_\text{t} - \text{PCI}}{\text{PCI}_\text{t}}$$

BPF = Building Performance Factor
BBUEC = Baseline Building Unegulated Energy Consumption
BBREC = Baseline Building Regulated Energy Consumption
BBP = Baseline Building Performance; BBP=BBUEC+BBREC

- BPF quantifies relative stringency of different editions of 90.1
- BPF values are developed for each edition of 90.1 and may be adjusted by adopters to modify stringency
- The same baseline and proposed design models may be used to calculate improvement over different editions of 90.1

ASHRAE Prototype Building Models

Building Type	Prototype building
Office	Small Office
	Medium Office
	Large Office
Retail	Stand-Alone Retail
	Strip Mall
School	Primary School
	Secondary School
Healthcare/hospital	Outpatient Health Care
	Hospital
Lodging/hotel	Small Hotel
	Large Hotel
Warehouse	Warehouse
Restaurant	Fast Food Restaurant
	Sit-Down Restaurant
Apartment (Multi-family)	Mid-Rise Apartment
	High-Rise Apartment

- Representative of the US building stock
- PNNL has created versions of the prototypes for each edition of Standard 90.1 starting with 2004.
- BPF for each building type and climate zone is calculated as the ratio of the regulated energy cost of the prototype model configured to meet the given edition of 90.1 versus the prototype configured to minimally comply with 90.1 2004.
- The results of similar prototype buildings are averaged for the total of 8 general building types.

Regulated Systems

- Any system or component with requirements prescribed in 90.1 Sections 5 through 10.

  Examples:
  - Envelope of conditioned and semi-heated spaces
  - HVAC systems
  - Service water heating systems
  - Lighting
  - Electric motors and belt drives
  - Refrigeration systems with requirements in 90.1 Section 6
  - Elevators
- In the baseline model, the regulated systems are modeled at the efficiency levels prescribed in Appendix G that are generally consistent with the requirements of 90.1 2004
- In the proposed model, regulated loads must match the design documents.

Unregulated Systems

- Systems and components that are not regulated in 90.1 Sections 5 – 10.

  Examples:

  - Lighting that is specifically designated as required by a health or life safety statute, ordinance, or regulation
  - Plug-in equipment such as kitchen appliances, consumer and office electronics
  - Industrial process equipment with no requirements in 90.1.
- As a general rule, unregulated components must be identical in the baseline and proposed models.

Building Performance Factors

- BPFs are provided in 90.1 Section 4 for different climate zones and building types
- The BPFs are updated for each new edition of 90.1

Table 4.2.1.1 *Building* Performance Factor (BPF)

Building Area Type[a]	Climate Zone															
	0A and 1A	0B and 1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Multifamily	0.73	0.73	0.71	0.69	0.74	0.73	0.68	0.78	0.81	0.81	0.76	0.80	0.81	0.76	0.79	0.74	0.80
Healthcare/ hospital	0.64	0.56	0.60	0.56	0.60	0.56	0.54	0.57	0.53	0.55	0.59	0.52	0.55	0.57	0.52	0.56	0.56
Hotel/motel	0.64	0.65	0.62	0.60	0.63	0.65	0.64	0.62	0.64	0.62	0.60	0.61	0.60	0.59	0.61	0.57	0.58
Office	0.58	0.62	0.57	0.62	0.60	0.64	0.54	0.58	0.60	0.58	0.60	0.61	0.58	0.61	0.61	0.57	0.61
Restaurant	0.62	0.62	0.58	0.61	0.60	0.60	0.61	0.58	0.55	0.60	0.62	0.58	0.60	0.63	0.60	0.65	0.68
Retail	0.52	0.58	0.53	0.58	0.54	0.62	0.60	0.55	0.60	0.60	0.55	0.59	0.61	0.55	0.58	0.53	0.53
School	0.46	0.53	0.47	0.53	0.49	0.52	0.50	0.49	0.50	0.49	0.50	0.50	0.50	0.49	0.50	0.47	0.51
Warehouse	0.51	0.52	0.56	0.58	0.57	0.59	0.63	0.58	0.60	0.63	0.60	0.61	0.65	0.66	0.66	0.67	0.67
All others	0.62	0.61	0.55	0.57	0.56	0.61	0.59	0.58	0.57	0.61	0.57	0.57	0.61	0.56	0.56	0.53	0.52

Quiz 2

How do the BPFs change in each new edition of 90.1 compared to the previous edition?

1. The values of BPF go up, due to increase in stringency of future editions of 90.1
2. The value of BPF will go down because energy use of regulated systems and components decreases in future editions
3. The values of BPF will remain unchanged, because the 90.1 Appendix G baseline is fixed

General Modeling Logic (Table G3.1#1)

- All building systems and equipment must be modeled identically in the proposed and baseline design except as specifically instructed in Appendix G.
- In few instances, 90.1 2016 Appendix G allows differences between baseline and proposed design models but does not prescribe what to model in the baseline (e.g., credit for low flow plumbing fixtures is allowed, but baseline flow rates are not provided)
- This is fixed in 90.1 2019 Table G3.1 #1:

  Where the baseline building systems and equipment are permitted to be different from the proposed design but are not prescribed in this appendix, the baseline must be determined based on the following, in the order of priority:

  a. Requirements in Sections 5 through 10

  b. Requirements of other efficiency or equipment codes or standards applicable to the design of the building systems and equipment

Modeling “Yet to be Designed” Systems

- Baseline follows the general rules
- Yet to be designed proposed systems must be modeled as minimally compliant with the current edition of 90.1

  Example: temporary lighting must be modeled in the proposed design based on the maximum allowance in 90.1 Section 9, not the specified lighting power density
- **90.1 2019** eliminated inconsistencies in the language, which in places suggested modeling yet-to-be-designed systems the same in the baseline and proposed

Modeling Renovation Projects

- Same baseline as for the new construction projects irrespective of the scope of retrofit

  Exception: The fenestration area equals the existing area prior to the proposed work

- Proposed design must reflect the project after completion of the retrofit, including existing systems that were left as is, existing systems that were retrofitted, and new systems and equipment.

Quiz 3

A renovation project is modeled following 90.1 2016 Appendix G. As part of the renovation, roof is retrofitted from R-10 to R-40 and exterior walls are left as is at R-19. What roof and wall R-value should be modeled in the baseline? (select one)

1. R-10 roof, R-19 walls (existing conditions prior to retrofit)
2. Roof R-value as prescribed in Appendix G, based on 90.1 2004 insulation requirements for new construction; R-19 walls (Appendix G baseline rules do not apply because walls were not retrofitted).
3. Roof and wall baseline R-value as prescribed in Appendix G (based on 90.1 2004 insulation requirements for new construction)

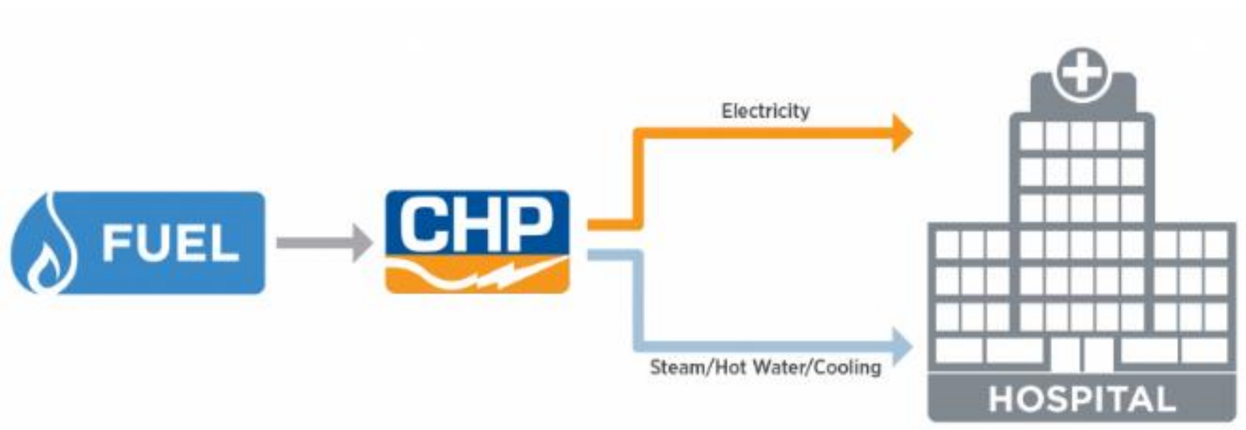
90.1 2019: Renewable Energy Trade-off Cap

- Limits the amount of on-site renewable energy available for trade-off to 5% of the baseline energy cost when using Appendix G for minimum compliance. (No limit in above-code applications.)
- Allows credit even if the building owner does not own the system provided that the owner has signed either of the following:
  - a lease agreement for a minimum of 15 years
  - an agreement to purchase the renewable energy for a minimum of 15 years

90.1 2019 On-site Electricity Generation

Clarified modeling rules that were often misinterpreted:

If proposed design includes on-site electricity generation systems (such as CHP, fuel cells, etc.), baseline includes same generation system, but no recovered heat.



Modeling Workflow

Collect the Necessary Project Information

- Architectural
  - Building shape and orientation, programming, fenestration thermal and solar properties and areas by space, exterior and interior shading, thermal and solar properties of opaque assemblies
- Mechanical
  - Equipment types, sizes, efficiencies, ventilation rates, demand controlled ventilation, economizer, energy recovery, air and water flows and controls, equipment control sequences, fan and pump power, chilled and hot water plant details
- Electrical
  - Lighting fixture schedules and plans, lighting controls, peak occupancy by zone, equipment loads by zone

Collect the Necessary Project Information

- **Full set of design documents**
- **Additional data from manufacturer**

Architectural

Building shape and orientation, programming, fenestration thermal and solar properties and areas by space, exterior and interior shading, thermal and solar properties of opaque assemblies

Mechanical

Equipment types, sizes, efficiencies, ventilation rates, demand controlled ventilation, economizer, energy recovery, air and water flows and controls, equipment control sequences, fan and pump power, chilled and hot water plant details

Electrical

Lighting fixture schedules and plans, lighting controls, peak occupancy by zone, equipment loads by zone

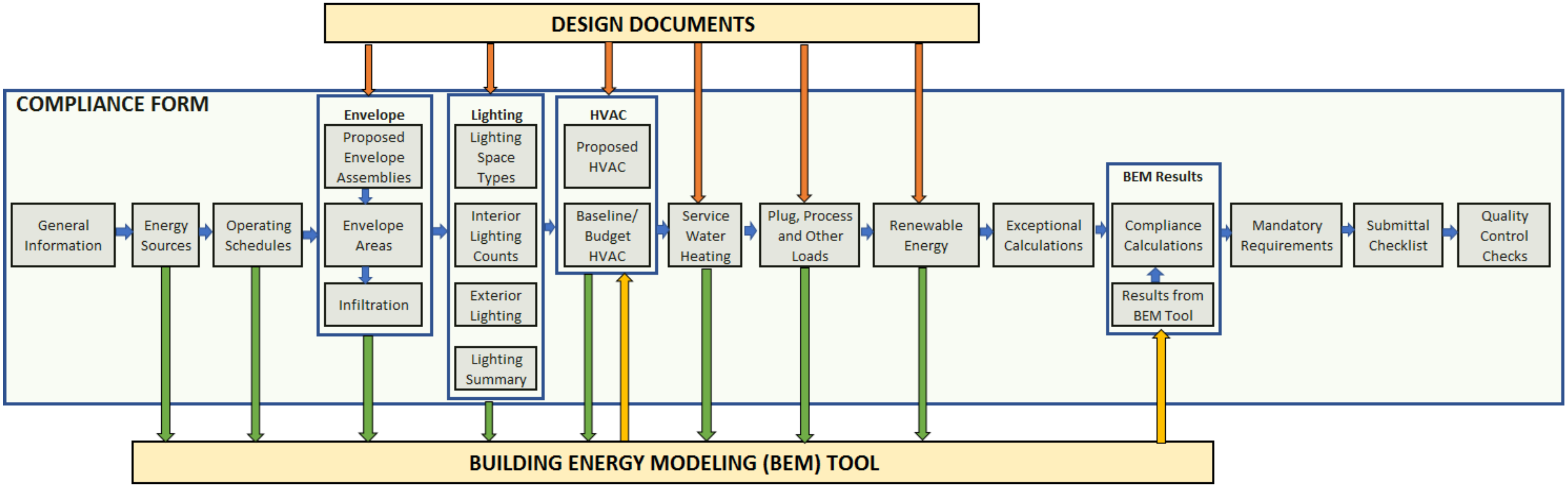
Operating Conditions

Anticipated occupied hours, thermostat setpoints, lighting and equipment runtime based on interviews with the building owner or typical for the building types

Modeling and Documentation Process

- ✓ Organize simulation inputs
  - Extract information from the design documents and the manufacturer data and perform supporting calculations to convert it to the simulation inputs.
- ✓ Create baseline model
  - Transfer information into simulation tool to create the baseline model, or model the propose design first. Starting with the baseline helps establish the impact of design alternatives on compliance.
- ✓ Create proposed model
- ✓ Perform model quality control
  - Check that simulation inputs reflect project design
  - Verify that simulation outputs such as overall energy use intensity, energy use intensity by end use, and change in energy consumption by end use between baseline and proposed designs show expected trends
- ✓ Use simulation results to perform compliance calculations

Compliance Documentation Process



Simulation Tool Requirements

G2.2.1 The *simulation program* shall be approved by the *rating authority* and shall, at a minimum, have the ability to explicitly model all of the following:

(a) 8,760 hours per year;

(b) hourly variations in occupancy, lighting power, miscellaneous equipment power, thermostat setpoints, and HVAC system operation, defined separately for each day of the week and holidays;

(c) thermal mass effects;

(d) ten or more thermal zones;

(e) part-load performance curves for mechanical equipment;

(f) capacity and *efficiency* correction curves for mechanical heating and cooling equipment;

(g) air-side economizers with integrated control;

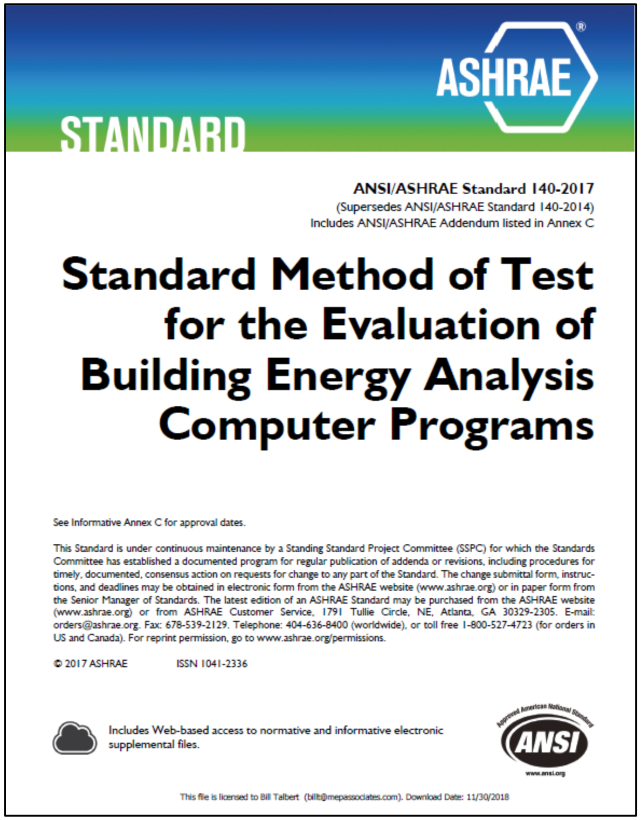
(h) *baseline building design* characteristics specified in G3.

G2.2.3 The *simulation program* shall be capable of performing design load calculations to determine required HVAC equipment capacities and air and water flow rates in accordance with generally accepted engineering standards and handbooks (for example, *ASHRAE Handbook—Fundamentals*) for both the *proposed design* and *baseline building design*.

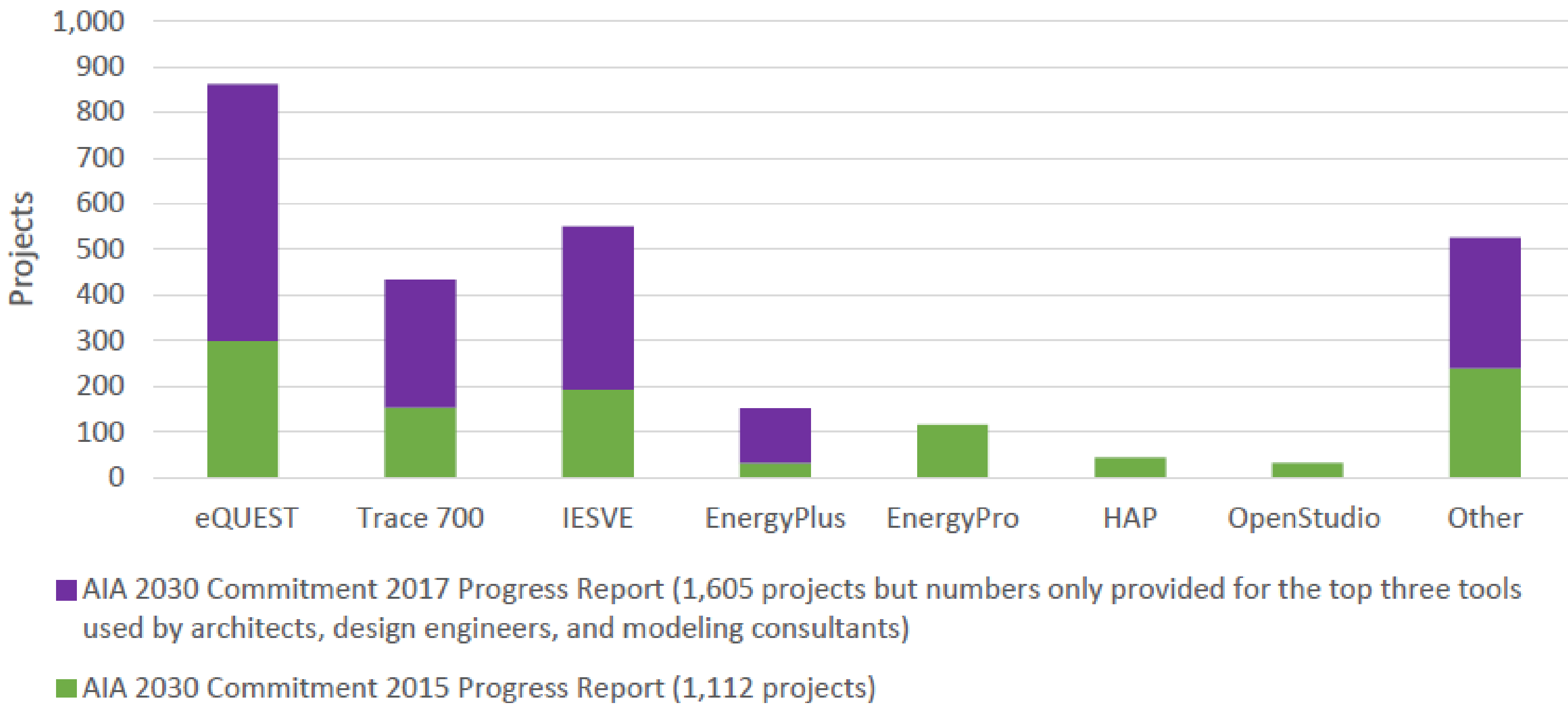
New in 90.1 2019 Appendix G

Testing to ASHRAE Standard 140

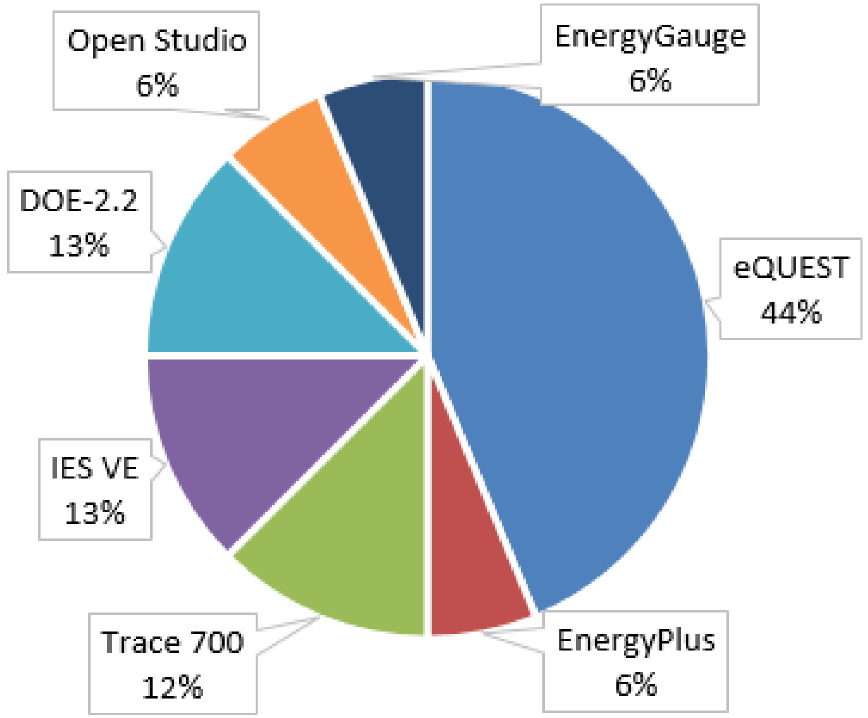
- Simulation tools previously been required to test in accordance with Standard 140
- Now must also:
  - Post results on a public website alongside results from reference software
  - Complete Standard 140 reports for results falling outside reference values
  - Submit information about software version and link to results
  - Still no pass/fail criteria provided



Simulation Tools Market Share



Simulation Tools Market Share



- DOE/PNNL and NEEA Performance-based Compliance Research Project stakeholder survey
- Percentage of stakeholders that picked given tool as most commonly used.

Envelope Geometry and Properties

Case Study Description

- **General Description**
  - New mixed use building in Portland
  - Floors 2-7 are multifamily occupancy
  - 1st floor is 60,000 square feet and will house a retail store and has no lighting or mechanical systems specified, to be designed by a future tenant.

- **Envelope**
  - Exterior walls: U-0.042
  - Roof: U-0.040
  - Windows: NFRC U-0.15 / SHGC - 0.3
  - Slab-on-grade: R-15 for 24”
  - Shading: exterior shading from balconies + blinds or curtains on all windows
  - Infiltration: 0.05 ACH at wind pressure

Case Study Description

HVAC

Apartments and corridors:

- VRF heat pumps cycling with load, EER 12.4 / COP 3.7, fan 0.214 W/CFM
- Balanced ERV 80% sensible recovery effectiveness, 0.76 W/CFM fan

Stairwells

- HW baseboards (95% efficient condensing boiler)

Service Water Heating: 95% efficient condensing boiler, low-flow fixtures

Lighting

- LED fixtures in apartment bathrooms and kitchens, no fixtures specified in living rooms and bedrooms,
- 0.25 W/SF lighting power density in corridors and stairwells.

Other: Energy star refrigerators and dishwashers.

Thermal Blocks – HVAC Zones Designed (Table G3.1 No 7)

Where HVAC zones are defined on HVAC design drawings, each HVAC zone shall be modeled as a separate thermal block.

Exception: Different HVAC zones may be combined to create a single *thermal block* or identical *thermal blocks* to which multipliers are applied, provided that all of the following conditions are met:

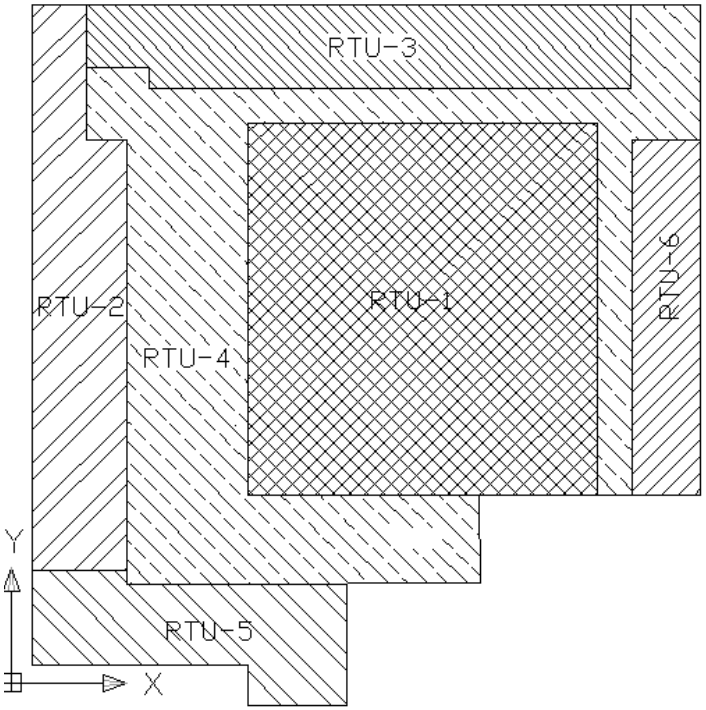
(a) The space use classification is the same throughout the *thermal block*

(b) All HVAC zones in the *thermal block* that are adjacent to glazed exterior walls face the same orientation or their orientations vary by less than 45 degrees.

(c) All of the zones are served by the same HVAC system or by the same kind of HVAC system.

Quiz 4

The proposed design is a one story town hall served by six single-zone roof-top units (RTU 1 – RTU 6). How many thermal blocks should be modeled?

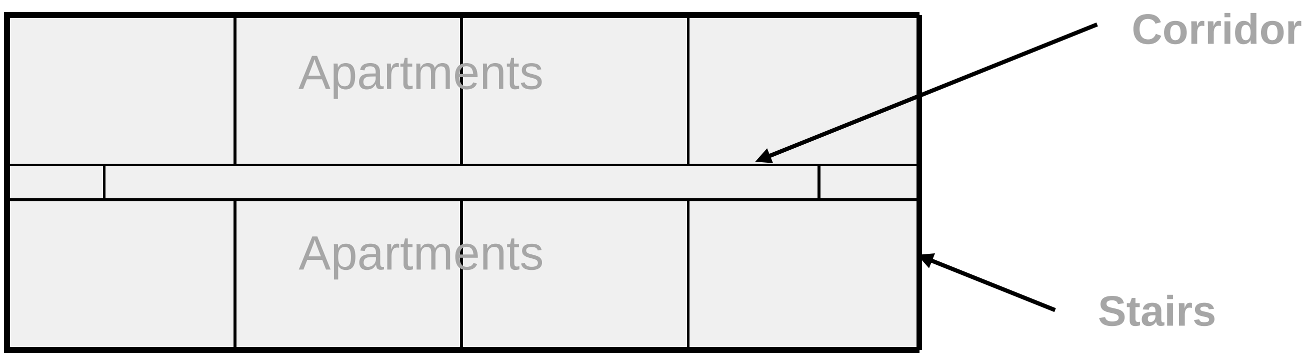


Thermal Blocks – Multifamily (Table G3.1 No 9)

- *Residential spaces* shall be modeled using at least one *thermal block* per *dwelling unit*
- Units facing the same orientations may be combined into one *thermal block*.
- Corner units and units with *roof* or *floor* loads shall only be combined with units sharing these features.

Quiz 5

Case study multifamily floor plan view



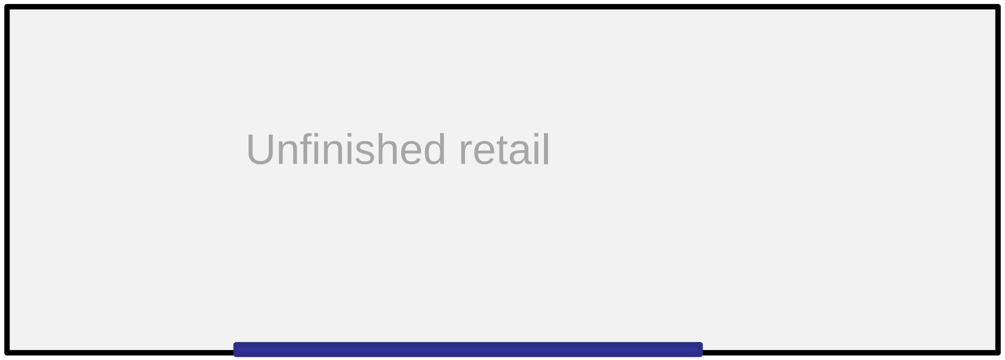
a. **How many thermal blocks must be explicitly modeled on each multifamily floor?**
b. **How many multifamily floors must be explicitly modeled?**

Thermal Blocks – HVAC Zones Not Designed (Table G3.1 No 8)

- Thermal blocks shall be defined based on similar space use classification (if known).
- Separate thermal blocks shall be assumed for…
  - interior spaces versus perimeter *spaces* within 15 ft of *exterior* or *semi-exterior wall*.
  - *spaces* adjacent to glazed *walls, with a separate zone* provided for each *orientation*, except orientations that differ by less than 45 degrees
  - *spaces with floors adjacent to ground, or with floor, ceiling, or roof adjacent to exterior, versus* zones that do not share these features.

Quiz 6

1st floor plan



How many thermal blocks must be explicitly modeled for the retail floor?

Baseline Opaque Surfaces Table G3.1-5

- Same gross area of each exterior envelope component type as in the proposed design.
- U-factors in Tables G 3.4-1 to G 3.4-8, conforming with assemblies detailed in 90.1 Appendix A
  - Roofs – insulated entirely above deck
  - Above-grade walls – steel framed
  - Below-grade walls—concrete block
  - Floors – steel joist
  - Same opaque door type as in proposed design
  - Slab-on-grade floors with F-factor for unheated slabs

Thermal Properties

Table G3.4-4 *Performance Rating Method Building Envelope* Requirements for Climate Zone 4 (A,B,C)*

	Nonresidential	*Residential*	Semiheated
Opaque Elements	Assembly Maximum	Assembly Maximum	Assembly Maximum
Roofs			
Insulation entirely above deck	U-0.063	U-0.063	U-0.218
Walls, Above-Grade			
Steel-framed	U-0.124	U-0.064	U-0.124
Wall, Below-Grade			
Below-grade wall	C-1.140	C-1.140	C-1.140
Floors			
Steel-joist	U-0.052	U-0.038	U-0.069
Slab-on-Grade Floors			
Unheated	F-0.730	F-0.730	F-0.730
Opaque Doors			
Swinging	U-0.700	U-0.700	U-0.700
Nonswinging	U-1.450	U-0.500	U-1.450

*Assigned according to space type and not building type

Space Use Classification (90.1 Section 3)

residential: *spaces* in buildings used primarily for living and sleeping. *Residential spaces* include, but are not limited to, *dwelling units*, hotel/motel guest rooms, dormitories, nursing homes, patient rooms in hospitals, lodging houses, fraternity/sorority houses, hostels, prisons, and fire stations.

nonresidential: all occupancies other than *residential*.

Surface Classification

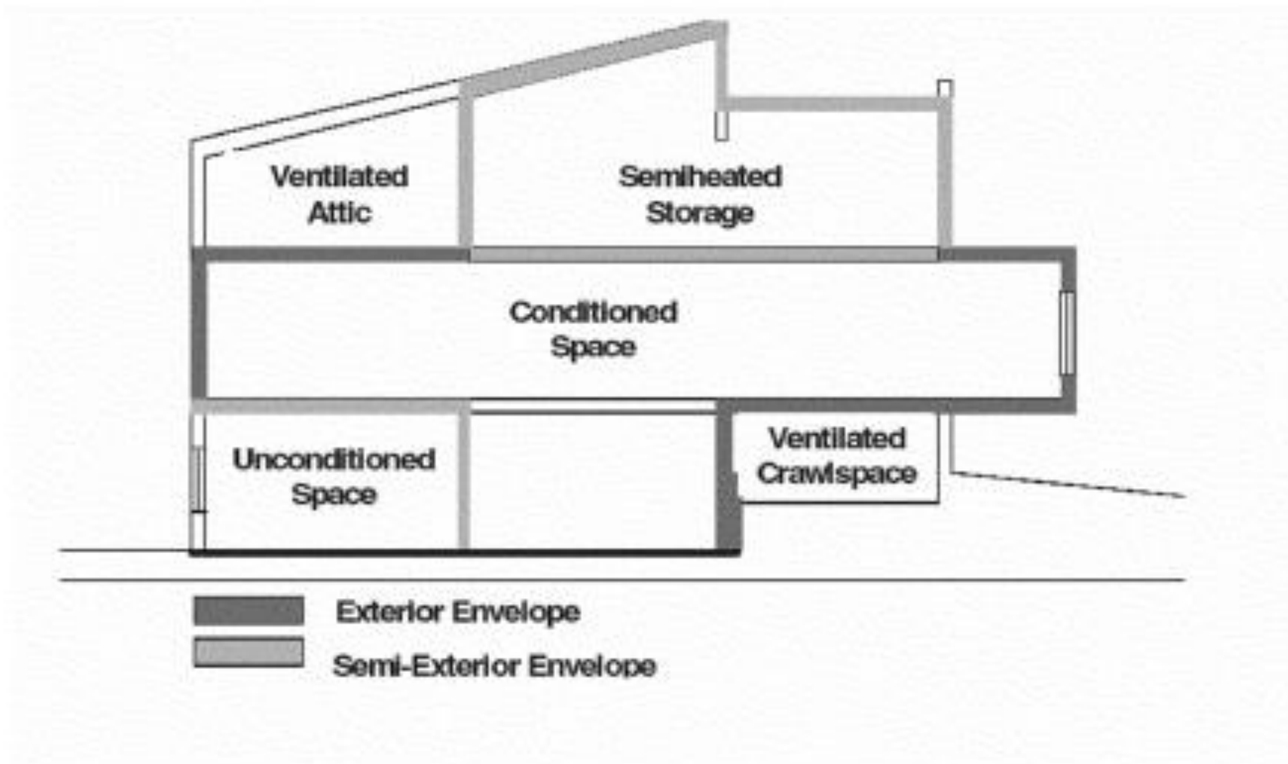


Figure 5-5 Exterior and semi-exterior building envelope.

Conditioned Space (Section 3)

conditioned space: a *cooled space*, *heated space*, or *indirectly conditioned space* defined as follows:

a. ***cooled space:*** an *enclosed space* within a *building* that is cooled by a cooling *system* whose sensible output capacity is 3.4 Btu/h·ft2 of *floor* area.

b. ***heated space:*** an *enclosed space* within a *building* that is heated by a heating *system* whose output capacity relative to the *floor* area is greater than or equal to the criteria in Table 3.2.

Table 3.2 *Heated Space* Criteria

Climate Zone	Heating Output, Btu/h·ft^2
0	>5
1	>5
2	>5
3A, 3B	>9
3C	>7
4A, 4B	>10
4C	>8
5	>12
6	>14
7	>16
8	>19

c. ***indirectly conditioned space:*** an *enclosed space* within a *building* that is not a *heated space* or a *cooled space*, which is heated or cooled indirectly by being connected to adjacent *spaces*, provided:

- sum of UA of all surfaces adjacent to conditioned spaces exceeds the sum of UA for all surfaces adjoining outdoors, *unconditioned spaces*, and *semiheated spaces*
- that air from heated or *cooled spaces* is intentionally transferred (naturally or mechanically) into the *space* at a rate exceeding 3 ach (e.g., atria).

Semiheated and Unconditioned Spaces

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

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

Baseline Opaque Surfaces in the Case Study

Table G3.4-4 *Performance Rating Method Building Envelope* Requirements for Climate Zone 4 (A,B,C)*

Opaque Elements	*Nonresidential* Assembly Maximum	*Residential* Assembly Maximum	Semiheated Assembly Maximum
Roofs			
…ck	U-0.063	U-0.063	U-0.218
	U-0.124	U-0.064	
	C-1.140	C-1.140	C-1.140
Floors			
Steel-joist	U-0.052	U-0.038	U-0.069
Slab-on-Grade Floors			
Unheated	F-0.730	F-0.730	F-0.730
Opaque Doors			
Swinging	U-0.700	U-0.700	U-0.700
Nonswinging	U-1.450	U-0.500	U-1.450

All spaces except dwelling units (retail, stairwells, corridors, etc.)

Dwelling units only

Quiz 7

a. **What is the baseline roof U-factor of the roof?**

b. **What is the baseline U-factor of the exterior walls of the retail floor?**

Baseline Assemblies

A2.2 Roofs with Insulation Entirely Above Deck

A2.2.1 ….. The U-factor includes R-0.17 for exterior air film, R-0 for metal deck, and R-0.61 for interior air film heat flow up. Added insulation is continuous and uninterrupted by framing. The framing factor is zero.

Quiz

What R-value of continuous insulation should be modeled to get the overall U-0.063 roof?

Quiz

What R-value of continuous insulation should be modeled to get the overall U-0.063 roof?

1/0.063 - 0.17 - 0.61 = 15

Baseline Steel-frame Wall Assembly

A3.3 Steel-Framed Walls

A3.3.1 ….. ….. The *U-factors* include R-0.17 for exterior air film, R-0.08 for stucco, R-0.56 for 0.625 in. gypsum board on the exterior, R-0.56 for 0.625 in. gypsum board on the interior, and R-0.68 for interior vertical surfaces air film. The performance of the insulation/framing layer is calculated using the values from **Table A9.2-2**. Additional assemblies include continuous insulation uncompressed and uninterrupted by framing.

Table A9.2-2 Effective Insulation/Framing Layer *R-Values* for *Wall* Insulation Installed Between Steel Framing

Nominal Depth of Cavity, in.	Actual Depth of Cavity, in.	Rated *R-Value* of Air *Space* or Insulation	Effective Framing/Cavity *R-Value* at 16 in. on Center	Effective Framing/Cavity *R-Value* at 24 in. on Center
Empty Cavity, No Insulation				
4	3.5	R-0.91	0.79	0.91
Insulated Cavity				
4	3.5	R-11	5.5	6.6
4	3.5	R-13	6.0	7.2
4	3.5	R-15	6.4	7.8
6	6.0	R-19	7.1	8.6
6	6.0	R-21	7.4	9.0
8				

Baseline Vertical Fenestration Area (Table G3.1 No 5)

Table G3.1.1-1 Baseline *Building Vertical Fenestration* Percentage of Gross *Above-Grade-Wall* Area

Building Area Types[a]	Baseline *Building* Gross *Above-Grade-Wall* Area
Grocery store	7%
Healthcare (outpatient)	21%
Hospital	27%
Hotel/motel (≤75 rooms)	24%
Hotel/motel (>75 rooms)	34%
Office (≤5000 ft^2)	19%
Office (5000 to 50,000 ft^2)	31%
Office (>50,000 ft^2)	40%
Restaurant (quick *service*)	34%
Restaurant (full *service*)	24%
Retail (stand alone)	11%
Retail (strip mall)	20%
School (primary)	22%
School (secondary and university)	22%
Warehouse (nonrefrigerated)	6%

- The specified percentages are relative to the **gross above grade wall area**, including walls of conditioned and semiheated spaces.
- For other building area types, vertical fenestration area is equal to the *proposed design* or 40% of gross *above-grade wall* area, whichever is less.
- In mixed use buildings, the rule must be applied to each building area type

Fenestration (90.1 Section 3)

fenestration: all areas (including the frames) in the *building envelope* that let in light, including windows, plastic panels, clerestories, *roof monitors*, *skylights*, *doors* that are more than one-half glass, and glass block *walls*.

fenestration area: total area of the *fenestration* measured using the rough opening and including the glazing, sash, and frame. For *doors* where the glazed vision area is less than 50% of the *door area*, the *fenestration area* is the glazed vision area. For all other *doors*, the *fenestration area* is the *door area*.

wall area, gross: the area of the wall measured on the exterior face from the top of the floor to the bottom of the roof.

Baseline Fenestration Area

1st Floor (Retail)

Proposed design:

- 600' x 100' footprint;
- 15' floor-to-floor height
- windows account for 80% of gross wall area on S side with no windows on other exposures

Baseline: (600+100)*2*15*11%=2,310 ft^2

Multifamily Floors

Proposed Design

- 10' floor-to-floor height
- windows account for 45% of S/N gross wall area with no windows on E/W

Baseline

- Gross exterior wall area per floor: (600+100)*2*10=14,000 ft^2
- Proposed fenestration area per floor: 600*10*2*45%=5,400 ft^2
- % fenestration in proposed design: 5,400/14,000=38.6% <40%
- Same fenestration area in baseline as in the proposed

Baseline Fenestration Exposure

- Fenestration must be distributed on each face of the *building* in the same proportion as in the *proposed design*.

1st Floor (Retail)

Proposed design

- 15' floor-to-floor height
- windows account for 80% of gross wall area on S side with no windows on other exposures.

Baseline

- 2,310 ft^2 fenestration on South wall

Multifamily Floors

Proposed design

- 10' floor-to-floor height
- windows account for 35% of S/N gross wall area with no windows on E/W

Baseline:

- Fenestration is distributed equally on S/N exposures; no windows on E/W

Baseline Fenestration Properties

- U-values from Tables G3.4-1 to G3.4-8

Table G3.4-4 *Performance Rating Method Building Envelope* Requirements for Climate Zone 4 (A,B,C)*

	Nonresidential		*Residential*		Semiheated	
Fenestration	Assembly Max. U	Assembly Max. *SHGC*	Assembly Max. U	Assembly Max. *SHGC*	Assembly Max. U	Assembly Max. *SHGC*
Vertical Glazing, % of *Wall*						
0% to 10.0%	U_{all}-0.57	*SHGC*$_{all}$-0.39	U_{all}-0.57	*SHGC*$_{all}$-0.39	U_{all}-1.22	*SHGC*$_{all}$-NR
10.1% to 20.0%	U_{all}-0.57	*SHGC*$_{all}$-0.39	U_{all}-0.57	*SHGC*$_{all}$-0.39	U_{all}-1.22	*SHGC*$_{all}$-NR
20.1% to 30.0%	U_{all}-0.57	*SHGC*$_{all}$-0.39	U_{all}-0.57	*SHGC*$_{all}$-0.39	U_{all}-1.22	*SHGC*$_{all}$-NR
30.1% to 40.0%	U_{all}-0.57	*SHGC*$_{all}$-0.39	U_{all}-0.57	*SHGC*$_{all}$-0.39	U_{all}-1.22	*SHGC*$_{all}$-NR
Skylight All, % of *Roof*						
0% to 2.0%	U_{all}-0.69	*SHGC*$_{all}$-0.49	U_{all}-0.58	*SHGC*$_{all}$-0.36	U_{all}-1.36	*SHGC*$_{all}$-NR
2.1%+	U_{all}-0.69	*SHGC*$_{all}$-0.39	U_{all}-0.58	*SHGC*$_{all}$-0.19	U_{all}-1.36	*SHGC*$_{all}$-NR

90.1 2019 filled in the blanks: NR = SHGC - 0.40

Baseline Orientation and Interior Shading

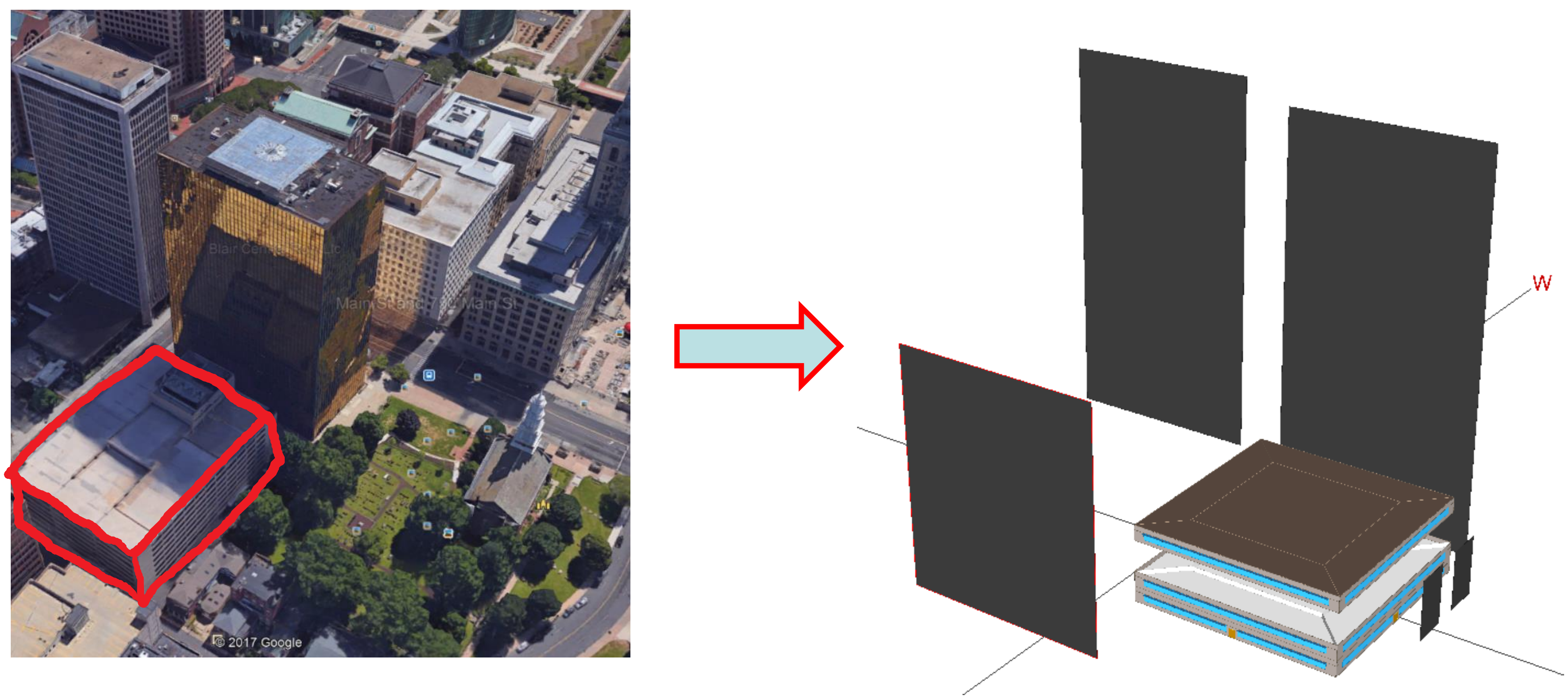
- The baseline building performance is calculated as an average of four orientations.

  Exceptions:
  - If orientation is dictated by site, as determined by rating authority.
  - Vertical fenestration area on each orientation varies by less than 5%.
- All *windows* shall be modeled flush with the *exterior wall*, with no shading projections
- *Manual* window shading such as blinds or shades may be modeled or not modeled, the same as in proposed design.

Site Shading

Shading by adjacent structures and terrain must be modeled the same as in proposed design.

-Elements with the height greater than their distance from a proposed *building* and with width facing the proposed *building* is greater than one-third that of the proposed *building* shall be accounted for in the analysis.



Baseline Envelope of Renovation Projects

- Baseline for opaque assemblies must conform with assembly types and thermal properties prescribed for new buildings and additions

- Fenestration baseline must have the same U-value, SHGC, and VT as for the new buildings and additions

- The fenestration area shall equal the existing area prior to the proposed work

Envelope Air Leakage

90.1 2016

- Must be modeled using the same methodology, rate, and adjustments for weather and building operation in the proposed and the baseline design.
- Modeled air leakage rate must be equivalent to 0.4 cfm/ft^2 of the building envelope at a fixed building pressure differential of 0.3 in. H2O

  Exception: When whole-building air leakage testing is specified during design and completed after construction, the proposed design air leakage rate of the building envelope shall be as measured.

90.1 2019

- Proposed Design
  - 0.6 cfm/ft^2 if prescriptive air barrier requirements met;
  - As measured when whole-building air leakage testing is specified during design and completed after construction
- Baseline Design
  - 1.0 cfm/ft^2

2019 is less stringent!

Infiltration Inputs (G3.1.1.4)

$$I_{FLR} = 0.112 \times I_{75Pa} \times S/A_{FLR}$$

$$I_{EW} = 0.112 \times I_{75Pa} \times S/A_{EW}$$

I_{FLR} [cfm/ft^2] = adjusted air leakage rate at a reference wind speed of 10 mph per unit of the total gross floor area

I_{EW} [cfm/ft^2] = adjusted air leakage rate at a reference wind speed of 10 mph per unit of the above ground exterior wall area

A_{EW} = total above-grade exterior wall area, ft^2

I_{75Pa} [cfm/ft^2] = leakage at pressure differential of 0.3 in. H_2O per ft^2 of envelope air pressure boundary

S [ft^2] = total area of the envelope air pressure boundary <u>including the lowest floor, any below- or above-grade walls, and roof (or ceiling) including windows and skylights, separating the interior conditioned space from the unconditioned environment</u>

A_{FLR} = total gross floor area, ft^2

Infiltration Input Example

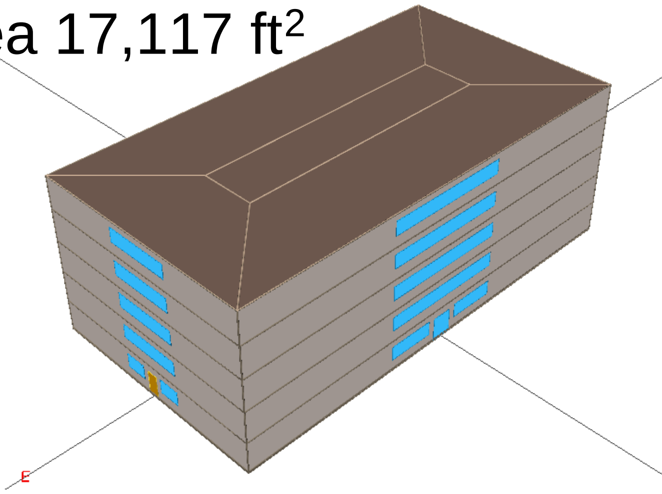
5 story multifamily building:

Gross Floor Area: 40,000 ft^2

Gross roof & floor area: 8,000 ft^2 each

Total gross above grade exterior wall area 17,117 ft^2

Total conditioned volume 360,068 ft^3



$S = 8{,}000*2 + 17{,}117 = 33{,}117$ [ft^2]

$I_{75Pa} = 0.4$ [cfm/ft^2]

$Q = 0.112*0.4* 33{,}117 = 1{,}484$ [cfm]

$I_{FLR} = 1{,}484 / 40{,}000 = 0.037$ [cfm/ft^2]

$I_{EW} = 1{,}484 / 17{,}117 = 0.087$ [cfm/ft^2]

$ACH = 1{,}484 *60 / 360{,}068 = 0.25$ [ACH]

Air Leakage Schedule

- Not prescribed in 90.1
- The default schedule is 100% of the rate (schedule fraction of 1) when the fan system is off, and 0.25 when the fan system is on.

Proposed Design Envelope (Table G3-1)

- All components of the *building envelope in the proposed design shall be modeled as* shown on architectural drawings or as built for existing building envelopes.
- Uninsulated assemblies (e.g., projecting balconies, perimeter edges of intermediate floor stabs, concrete floor beams over parking garages, roof parapet) must be modeled using either of the following techniques:
  1. Separate model of each of these assemblies within the energy simulation model.
  2. Separate calculation of the U-factor for each of these assemblies. The U-factors of these assemblies are then averaged with larger adjacent surfaces using an area-weighted average method. This average U-factor is modeled within the energy simulation model.

Modeling un-insulated Wall Conditions (90.1 User's Manual)

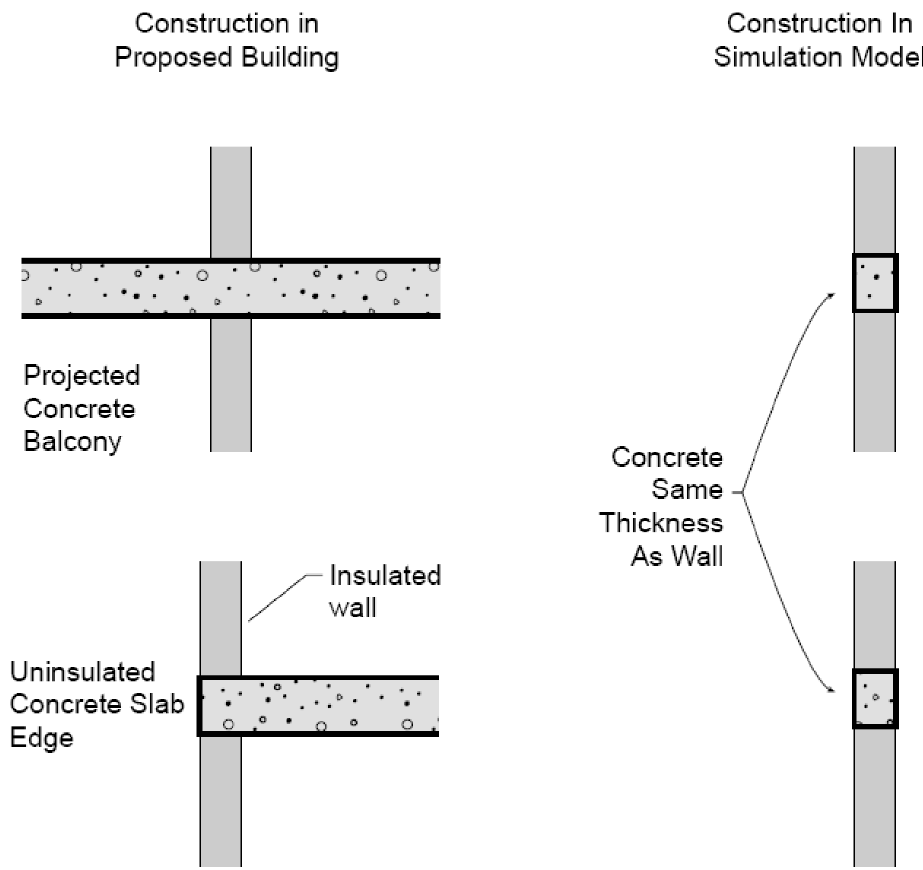
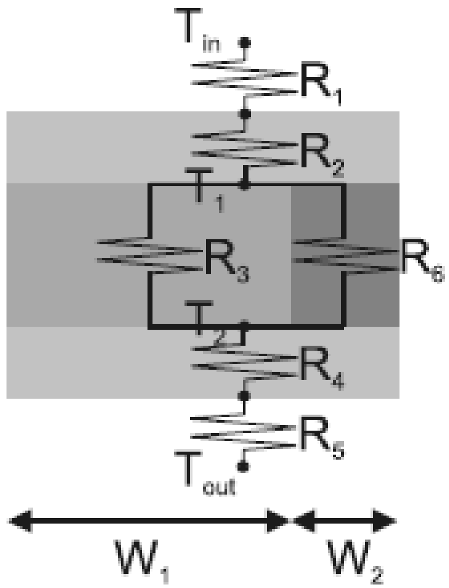


Figure G-A—Modeling Uninsulated Wall Conditions

Effective R-Value, Parallel Path Method

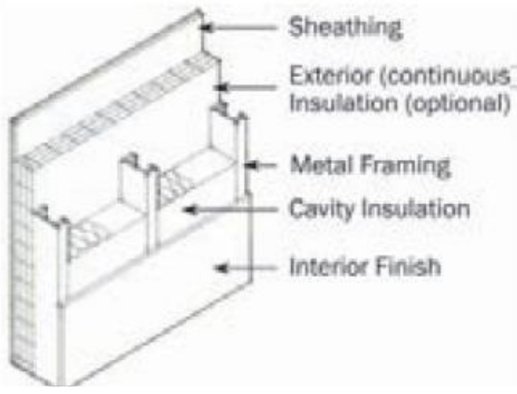


$$U = \frac{1}{R_1 + R_2 + R_{Effective} + R_4 + R_5}$$

$$R_{Effective} = \frac{1}{W_1\left(\frac{1}{R_3}\right) + W_1\left(\frac{1}{R_6}\right)}$$

W – weighting factors for each sub-area

Thermal Bridging – Steel-framed Wall



Thermal resistance of surfaces that have sections with widely diverging conductivities, such as steel frame wall sections, cannot be approximated by the parallel path method

Table A9.2-2 Effective Insulation/Framing Layer *R-Values* for *Wall* Insulation Installed Between Steel Framing

Nominal Depth of Cavity, in.	Actual Depth of Cavity, in.	Rated *R-Value* of Air *Space* or Insulation	Effective Framing/Cavity *R-Value* at 16 in. on Center	Effective Framing/Cavity *R-Value* at 24 in. on Center
Empty Cavity, No Insulation				
4	3.5	R-0.91	0.79	0.91
Insulated Cavity				
4	3.5	R-11	5.5	6.6
4	3.5	R-13	6.0	7.2
4	3.5	R-15	6.4	7.8
6	6.0	R-19	7.1	8.6
6	6.0	R-21	7.4	9.0
8	8.0	R-25	7.8	9.6

Quiz

Exterior walls in the proposed design have the following construction (starting from exterior):

- stucco finish (R-0.08)
- 0.625 in. gypsum board (R-0.56)
- 2” continuous insulation uninterrupted by framing (R-10)
- steel framing 6” deep 16” on center with R-19 cavity insulation
  0.625 in. gypsum board (R-0.56)

What is the total R-value of the exterior walls in the proposed design?

Allowed Envelope Simplifications (Table G3.1)

- Any <u>insulated</u> envelope assembly that covers less than 5% of the total area of that assembly type (e.g., exterior walls) need not be separately described provided that it is similar to an assembly being modeled. If not separately described, the area of an envelope assembly must be added to the area of an assembly of that same type with the same orientation and thermal properties.
- Exterior surfaces whose azimuth orientation and tilt differ by less than 45 degrees and are otherwise the same may be described as either a single surface or by using multipliers.

Proposed Design – Exterior Shading (Table G3.1)

- Manual fenestration shading devices such as blinds or shades must be modeled the same as in the baseline.
- Automatically controlled fenestration shades or blinds and permanent shading devices such as fins, overhangs, and light shelves shall be modeled.
- Shading by adjacent structures, vegetation or topographical features whose height is greater than their distance from a proposed building and whose width facing the proposed building is greater than one-third that of the proposed building shall be modeled.

Lighting

Baseline Lighting Power (Table G3.1-6)

- Lighting power density (LPD) from Table G3.7 using Space-by-space method
- No baseline allowance for decorative lighting or additional retail lighting even when specified in the proposed design.

Common Space Types[a]	***Lighting Power Density, W/ft***^{2}
Audience Seating Area	
Auditorium	0.90
Convention center	0.70
Exercise center	0.30
Gymnasium	0.40
Motion picture theater	1.20
P...itentiary	0.70
...er classroom/lecture hall/training room	
Conference/Meeting/Multipurpose Room	1.30
Confinement Cells	0.90
Copy/Print Room	0.90
Corridor	
Facility for the visually impaired (and used primarily by residents)	1.15
Hospital	1.00
Manufacturing facility	0.50
A other corridor	0.50
Courtroom	1.90
Res...	
Facility for the ...	
All other restroom	0.90
Sales Area	1.70
Seating Area, General	0.68
Stairwell	0.60
Storage Room	
Hospital	0.90
$\geq$50 ft^2	0.80
<50 ft^2	0.??

Case study baseline lighting power

Baseline Lighting Power (Table G3.1-6)

Exception: For multifamily dwelling units, hotel/motel guest rooms, and other spaces in which lighting systems are connected via receptacles and are not shown or provided for on building plans, assume identical lighting power for the proposed design and baseline building design

This made the requirements more stringent than was intended

Quiz 10

a) What baseline lighting power must be modeled in the case study for corridors?

b) What baseline lighting power must be modeled in the case study for the retail floor?

c) What baseline lighting power must be modeled in the case study for the stairwell?

Changes in 90.1 2019

- Cleaned up the rules for spaces with partially specified lighting including dwelling units, hotel/motel guest rooms, and other spaces in which lighting systems are connected via receptacles and are not shown on *design documents*
  - Baseline based on Table G3.7 (same as for spaces with specified lighting)
  - Proposed equal to the lighting power allowance in Table 9.6.1 for the appropriate *space* type or as designed, whichever is greater.
  - Credit for increased efficacy in such spaces based on an approved analysis

    Lighting use can be reduced for the portion of the space illuminated by the specified fixtures provided that they maintain the same illuminance level as in the baseline.

- Prescribed lighting inputs for the dwelling units

  Affects case study

  Proposed design: 0.60 W/ft2 or as designed, whichever is greater.

  Baseline: 1.07 W/ft2
- Requires using Building Area Method if space type is not known

Baseline Lighting Controls

Baseline lighting controls are limited to those that were required in 90.1 2004 (occupancy sensors in certain classrooms, conference/meeting rooms, and employee lunch and break rooms).

Proposed Design Lighting Power (G3.1-6)

- Lighting system power shall include all lighting system components shown or provided for on the plans including lamps and ballasts and task and furniture-mounted fixtures.
- Except for incandescent sources, fixture input wattage is not the same as lamp wattage. Input wattage for all discharge sources is determined by the interaction between lamps, ballast, and fixture construction, and must be based on the maximum manufacturer rated fixture wattage.
- Specified lighting must not be worse than prescriptive requirements of **90.1 2004** using either building area or space-by-space method. (G1.2.1)

Proposed Design Lighting Controls

- Lighting controls that exceed requirements of 90.1 2004 are modeled by reducing lighting runtime (the schedules) by the fractions specified in Table G 3.7;
- Daylighting may be modeled directly or via schedule adjustment determined by an approved analysis

Table G3.7 ***Performance Rating Method Lighting Power Density*** **Allowances and Occupancy Sensor Reductions Using the Space-by-Space Method**

Common *Space* Types[a]	*Lighting Power Density*, W/ft^2	Occupancy Sensor Reduction[b]
Audience Seating Area		
Auditorium	0.90	10%
Convention center	0.70	10%
Exercise center	0.30	10%
Gymnasium	0.40	10%
Motion picture theater	1.20	10%
Penitentiary	0.70	10%

Exterior Lighting

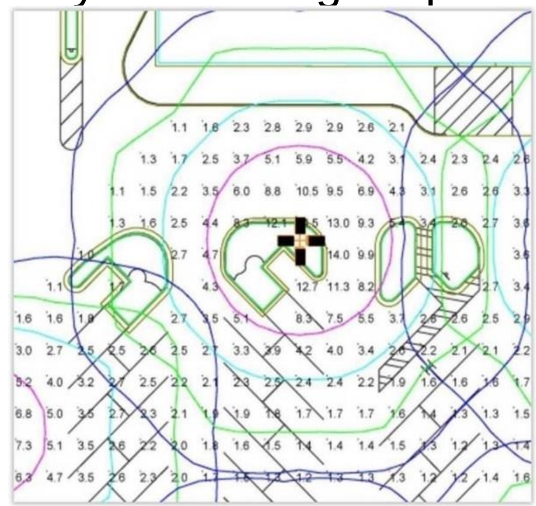
- “Tradable” exterior lighting must be modeled based on Table G3.6 in the baseline, and as specified in the proposed design.
- Baseline non-tradable exterior lighting must be modeled the same as in the proposed design.

Table G3.6 ***Lighting Power Densities*** **for** ***Building*** **Exteriors**

Tradable Surfaces (*Lighting power densities* for uncovered parking areas, *building* grounds, *building entrances* and exits, canopies and overhangs and outdoor sales areas may be traded.)	Uncovered Parking Areas	
	Parking lots and drives	0.15 W/ft^2
	Building Grounds	
	Walkways less than 10 ft wide	1.0 W/linear foot
	Walkways 10 ft wide or greater Plaza areas Special feature areas	0.2 W/ft^2
	Stairways	1.0 W/ft^2
	Building Entrances and Exits	
	Main entries	30 W/linear foot of *door* width
	Other *doors*	20 W/linear foot of *door* width
	Canopies and Overhangs	
	Canopies (free standing and attached and overhangs)	1.25 W/ft^2
	Outdoor Sales	
	Open areas (including vehicle sales lots)	0.5 W/ft^2
	Street frontage for vehicle sales lots in addition to open-area allowance	20 W/linear foot
Nontradable Surfaces (*Lighting power density* calculations for the following applications can be used only for the specific application and	*Building* Facades	0.2 W/ft^2 for each illuminated *wall* or surface or 5.0 W/linear foot for each illuminated *wall* or surface length
	Automated teller machines (ATMs) and night depositories	270 W per location plus 90 W per additional ATM per location

Common Mistakes

- Calculating baseline tradeable exterior lighting allowance based on the areas of the surfaces in the proposed design that are not illuminated to some industry standard, such as the IESNA Handbook, or incorrectly accounting for partially illuminated areas.



- Double-counting areas when calculating the baseline exterior lighting power allowance.

  Lighting power allowance for a walkway that crosses an illuminated parking lot can be determined based on the parking lot allowance or walkway allowance in 90.1 Table G3.6, but not both. If walkway allowance is used, the walkway area must be subtracted from the parking lot area.

Heating, Ventilation, and Air Conditioning Systems

Baseline HVAC System Type (G3.1.1-3)

Determined based on the following criteria in the order of priority:

1. The *building* type with the largest *conditioned floor area*.
2. Number of above grade and below *grade floors excluding floors* solely devoted to parking.
3. *Gross conditioned floor area*.
4. Climate zone

***Building* Type, Number of *Floors*, and Gross Conditioned Floor Area**	**Climate Zones 3B, 3C, and 4 to 8**	**Climate Zones 0 to 3A**
Residential	*System* 1—*PTAC*	*System* 2—*PTHP*
Public assembly <120,000 ft^2	*System* 3—PSZ-AC	*System* 4—PSZ-HP
Public assembly ≥120,000 ft^2	*System* 12—SZ-CV-HW	*System* 13—SZ-CV-ER
Heated-only storage	*System* 9—Heating and *ventilation*	*System* 10—Heating and *ventilation*
Retail and 2 *floors* or fewer	*System* 3—PSZ-AC	*System* 4—PSZ-HP
Other nonresidential and 3 *floors* or fewer and <25,000 ft^2	*System* 3—PSZ-AC	*System* 4—PSZ-HP
Other nonresidential and 4 or 5 *floors* and <25,000 ft^2 or 5 *floors* or fewer and 25,000 ft^2 to 150,000 ft^2	*System* 5—Packaged *VAV* with *reheat*	*System* 6—Packaged *VAV* with PFP boxes
Other nonresidential and more than 5 *floors* or >150,000 ft^2	*System* 7—*VAV* with *reheat*	*System* 8—*VAV* with PFP boxes

Baseline HVAC System Types

Table G3.1.1-4 Baseline *System* Descriptions

System No.	*System* Type	Fan *Control*	Cooling Type [a]	Heating Type [a]
1. *PTAC*	*Packaged terminal air conditioner*	Constant volume	Direct expansion	Hot-water *fossil fuel boiler*
2. *PTHP*	*Packaged terminal heat pump*	Constant volume	Direct expansion	Electric heat pump
3. PSZ-AC	Packaged rooftop air conditioner	Constant volume	Direct expansion	*Fossil fuel* furnace
4. PSZ-HP	Packaged rooftop heat pump	Constant volume	Direct expansion	Electric heat pump
5. Packaged *VAV* with *reheat*	Packaged rooftop *VAV* with *reheat*	*VAV*	Direct expansion	Hot-water *fossil fuel boiler*
6. Packaged *VAV* with PFP boxes	Packaged rooftop *VAV* with parallel fan power boxes and *reheat*	*VAV*	Direct expansion	*Electric resistance*
7. *VAV* with *reheat*	*VAV* with *reheat*	*VAV*	Chilled water	Hot-water *fossil fuel boiler*
8. *VAV* with PFP boxes	*VAV* with parallel fan-powered boxes and *reheat*	*VAV*	Chilled water	*Electric resistance*
9. Heating and *ventilation*	Warm air furnace, gas fired	Constant volume	None	*Fossil fuel* furnace
10. Heating and *ventilation*	Warm air furnace, electric	Constant volume	None	*Electric resistance*
11. SZ–*VAV*	Single-zone *VAV*	*VAV*	Chilled water	See note (b).
12. SZ-CV-HW	*Single-zone system*	Constant volume	Chilled water	Hot-water *fossil fuel boiler*
13. SZ-CV-ER	*Single-zone system*	Constant volume	Chilled water	*Electric resistance*

a. For purchased chilled water and purchased heat, see G3.1.1.3.
b. For Climate Zones 0 through 3A, the heating type shall be *electric resistance*. For all other climate zones the heating type shall be hot-water fossil-*fuel boiler*.

Baseline HVAC System Types

b. Use additional *system* types for nonpredominant conditions (i.e., *residential/ nonresidential)* if those conditions apply to more than 20,000 ft^2 of *conditioned floor area*.

c. If the baseline *HVAC system* type is 5, 6, 7, 8, 9, 10, 11, 12, or 13, use S*ystem* 3 or 4 (depending on climate zone) for any *thermal block* that has occupancy or *process loads* that differ by 10 $Btu/h \cdot ft^2$ or more from the average of other thermal blocks served by the same *system*, or schedules differing by more than 40 equivalent full-load hours per week from the other *thermal blocks* served by the same *system*

e. Thermal zones designed with heating-only *systems* in the *proposed design* serving storage rooms, stairwells, vestibules, electrical/mechanical rooms, and restrooms not exhausting or transferring air from mechanically cooled thermal zones in the *proposed design* shall use *system* type 9 or 10 in the *baseline*.

There are more exceptions!

Quiz 11

Case Study Description

- New mixed use building in Portland
- 1st floor is 60,000 ft^2 and will house a retail store. Mechanical systems are not specified, to be designed by a future tenant.
- Floors 2-7 are multifamily occupancy and include apartments, corridors (16,000 and stairwells (2,000 ft^2). VRF heat pumps serve apartments and corridors; stairwells are served by hot water baseboards

What are the baseline system types in the case study?

Baseline HVAC (G3.1.1)

- For *Systems* 1, 2, 3, 4, 9, 10, 11, 12, and 13, each *thermal block* shall be modeled with its own *HVAC system*.
- For *Systems* 5, 6, 7, and 8, each *floor* shall be modeled with a separate *HVAC system*. *Floors* with identical *thermal blocks* can be grouped for modeling purposes.

Quiz 12

a. How many baseline HVAC systems will be modeled per multifamily floor?
b. How many baseline HVAC systems will be modeled on the retail floor?

Equipment Capacities (G3.1.2.2)

The baseline equipment (i.e. system coil) capacities *shall be based on sizing* runs for each orientation and shall be oversized by 15% for cooling and 25% for heating.

New in 90.1 2019 Appendix G

Baseline Sizing Runs

1. Clarifies that baseline system oversizing applies only to heating and cooling coil capacities, not airflow
2. Specifies that baseline central plant capacities are sized based on coincident loads
3. Specified that design day runs must use *heating design temperature (99.6% DB)* and *cooling design temperature (1% DB &WB)*
4. Specifies internal gains used in sizing runs
   - Heating – values equal to highest annual hourly value
   - Cooling – values equal to highest annual hourly value (except for residential occupancies which use the most frequent value)

Exception: For cooling sizing runs in residential dwelling units, the infiltration, occupants, lighting, gas and electricity using equipment hourly schedule shall be the same as the most used hourly weekday schedule from the annual simulation.

Baseline System Efficiency (G3.1.2.1)

- All HVAC equipment in the baseline building design shall be modeled at the minimum efficiency levels in accordance with Tables G3.5.1 – G3.5.6.

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum *Efficiency*	Test Procedure
Air conditioners, air-cooled	<65,000 Btu/h	All	Single-package	9.7 *SEER*	ARI 210/240
	≥65,000 Btu/h and <135,000 Btu/h		Split-*system* and single-package	10.1 *EER*	ARI 340/360
	≥135,000 Btu/h and <240,000 Btu/h			9.5 *EER*	
	≥240,000 Btu/h and <760,000 Btu/h			9.3 *EER* 9.4 *IEER*	
	≥760,000 Btu/h			9.0 *EER* 9.1 *IEER*	

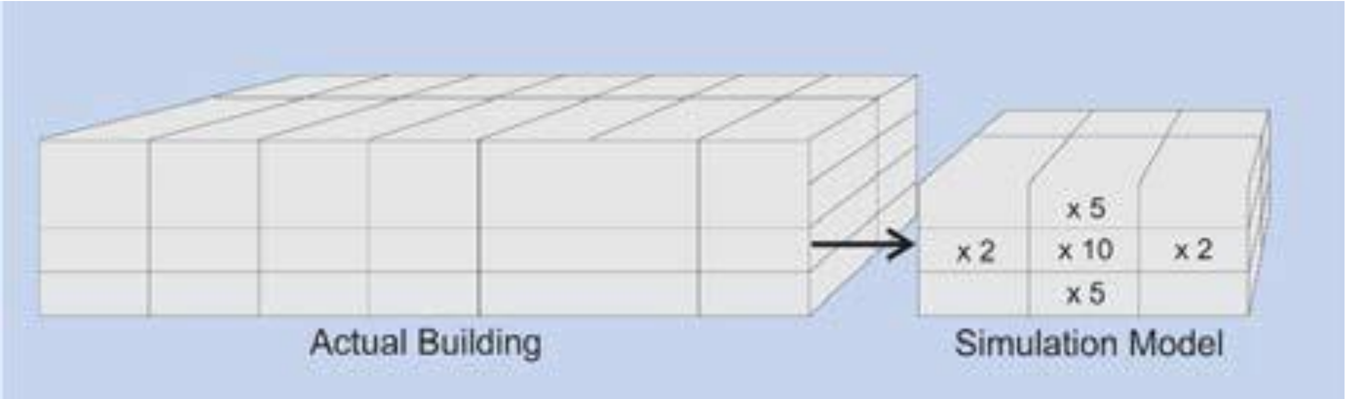
Table G3.5.4 ***Performance Rating Method*** **Electrically Operated** ***Packaged Terminal Air Conditioners, Packaged Terminal Heat Pumps***

Equipment Type	Size Category	Subcategory or Rating Condition	Minimum *Efficiency* [a]	Test Procedure
PTAC (cooling mode)	All capacities	95°F db *outdoor air*	12.5 – (0.213 × Cap/1000) *EER*	ARI 310/380

a. "Cap" means the rated cooling capacity of the product in Btu/h. If the unit's capacity is less than 7000 Btu/h, use 7000 Btu/h in the calculation. If the unit's capacity is greater than 15,000 Btu/h, use 15,000 Btu/h in the calculation.

90.1 2019 Appendix G Loophole Fix

- Where thermal zones are combined into a single thermal block for model simplification, baseline equipment efficiency is determined by individual zone size



Thermal Blocks for Apartment Building

equip capacity for efficiency = equip capacity of thermal block / # zones

Baseline System Efficiency (G3.1.2.1)

Table G3.5.5 Warm-Air Furnaces and Unit Heaters

Equipment Type	Size Category	Subcategory or Rating Condition	Minimum *Efficiency*	Test Procedure
Warm-air furnace, gas-fired	<225,000 Btu/h		78% *AFUE* or 80% E_t	DOE 10 CFR Part 430 or ANSI Z21.47
	≥225,000 Btu/h	Maximum capacity	80% E_c	ANSI Z21.47
Warm-air unit heaters, gas-fired	All capacities	Maximum capacity	80% E_c	ANSI Z83.8

Extracting Fan Energy from Efficiency Ratings in the Baseline

For Baseline *HVAC Systems* 1, 2, 3, 4, 5, and 6, modeled cooling efficiency must be adjusted to remove the supply fan power at AHRI rating conditions.

$$COP_{nfcooling} = 7.84E\text{-}8 \times EER \times Q + 0.338 \times EER$$

$$COP_{nfcooling} = -0.0076 \times \mathrm{SEER}^2 + 0.3796 \times SEER$$

$$COP_{nfheating} = 1.48E\text{-}7 \times COP_{47} \times Q + 1.062 \times COP_{47}$$

(applies to heat pump heating *efficiency* only)

$$COP_{nfheating} = -0.0296 \times \mathrm{HSPF}^2 + 0.7134 \times HSPF$$

Fan System Operation G 3.1.2.4

- Supply and return fans shall operate continuously whenever *spaces* are occupied and shall be cycled to meet heating and cooling loads during unoccupied hours.
- Supply, return, and/or exhaust fans will remain on during occupied and unoccupied hours in *spaces* that have health and safety mandated minimum *ventilation* requirements during unoccupied hours.

Quiz 13

How should baseline fans operate in the case study?

Mechanical Ventilation (G3.1.2.5)

Minimum v*entilation* rates shall be the same for the *proposed and baseline building designs.*

Exceptions:

- When modeling *demand control ventilation (DCV)* in the *proposed design* in *systems* with *outdoor air* capacity no greater than 3000 cfm serving areas with an average *design capacity* of 100 people per 1000 ft2 or less.
- For *HVAC zone* in the *proposed design* with a zone air distribution effectiveness (*Ez*) > 1.0 as defined by Standard 62.1, Table 6-2.
- If ventilation in the *proposed design* is provided in excess of the amount required by the *building* code or the *rating authority*, the *baseline building* shall be modeled to reflect the greater of that required by either the *rating authority* or the *building* code, and will be less than the *proposed design*.

Economizer (G 3.1.2.6)

Table G3.1.2.6 Climate Conditions under which Economizers are Included for Comfort Cooling for Baseline *Systems* 3 through 8 and 11, 12, and 13

Climate Zone	Conditions
0A, 0B, 1A, 1B, 2A, 3A, 4A	NR
Others	Economizer Included

Note: NR means that there is no conditioned *building floor* area for which economizers are included for the type of zone and climate.

Table G3.1.2.7 Economizer High-Limit Shutoff Temperature

Climate Zone	Dry-Bulb Temperature *Set Point*
2B, 3B, 3C, 4B, 4C, 5B, 5C, 6B, 7, 8	75°F
5A, 6A	70°F

Changes in 90.1 2019

- Clarifies that baseline economizers must be simulated as integrated with mechanical cooling

Quiz 14

What is the economizer high-limit shutoff temperature in the baseline HVAC systems?

Exhaust Air Energy Recovery (G3.1.2.10)

- Individual baseline fan systems with design supply air capacity of 5000 cfm or greater AND a minimum design outdoor air supply of 70% or greater shall have an energy recovery system with at least 50% enthalpy recovery ratio, and provisions to bypass or control the heat recovery system to permit air economizer operation, where applicable.
- Exceptions apply, e.g. energy recovery does not have to be modeled if the largest exhaust source is less than 75% of the design outdoor airflow, and if exhaust energy recovery is not specified in the proposed design.

Quiz 15

Do any of the baseline HVAC systems have exhaust air energy recovery?

Baseline Design Airflow Rates (G3.1.2.8)

Baseline Systems except System 9 and 10

- based on a supply-air-to-room-air temperature difference of 20°F or the required ventilation air or makeup air, whichever is greater.
- If return or relief fans are specified in the *proposed design*, the *baseline* shall also be modeled with fans serving the same functions.

Baseline System Types 9 and 10

- based on the temperature difference between a supply air temperature *set point* of 105°F and the design *space*-heating temperature *set point*, the minimum outdoor airflow rate, or the rate required by applicable code, whichever is greater.
- If the *proposed design* includes fans to provide non-*mechanical cooling*, the *baseline* shall also include a separate fan to provide non*mechanical* cooling.

Total Baseline System Fan Power (G3.1.2.9)

The **total** baseline fan power must be calculated as described below, and distributed between supply, return, exhaust, and relief fans in the same proportion as the proposed design:

Systems 1 and 2: *Pfan* = CFMs × 0.3

Systems 9 and 10:

Pfan = CFMs × 0.3 (supply fan)

Pfan = CFM*nmc* × 0.054 (non-mechanical cooling)

Pfan = electric power to fan motor, W

CFMs = the maximum baseline design supply cfm

CFMnmc = the baseline non-mechanical cooling cfm

Total Baseline System Fan Power (G3.1.2.9)

Systems 3 - 8, and 11 – 13:

Pfan = bhp × 746 /fan motor *efficiency*

Table G3.1.2.9 Baseline *Fan Brake Horsepower*

Baseline Fan Motor Brake Horsepower		
Constant-Volume *Systems* 3 to 4	Variable-Volume *Systems* 5 to 8	Variable-Volume *System* 11
$CFM_s \times 0.00094 + A$	$CFM_s \times 0.0013 + A$	$CFM_s \times 0.00062 + A$

Notes:

1. Where *A* is calculated according to Section 6.5.3.1.1 using the pressure-drop adjustment from the *proposed design* and the design flow rate of the baseline *building system*.
2. Do not include pressure-drop adjustments for evaporative coolers or heat recovery devices that are not required in the baseline *building system* by Section G3.1.2.10.

A = sum of (PD × cfm*D*/4131)
PD = pressure drop adjustment from Table 6.5.3.1-2
cfm*D* = the design airflow through each applicable device

Changes in 90.1 2019

- Fixes an oversite where baseline fan power was not prescribed for systems 12 and 13 (single zone, constant volume with hot water and electric heat respectively)

Table G3.1.2.9 Baseline *Fan Brake Horsepower*

Baseline Fan Motor Brake Horsepower		
Constant-Volume *Systems* 3, ~~to~~ 4, 12, and 13	Variable-Volume *Systems* 5 to 8	Variable-Volume *System* 11
$CFM_s \times 0.00094 + A$	$CFM_s \times 0.0013 + A$	$CFM_s \times 0.00062 + A$

Baseline Pressure Drop Adjustment

Device	Adjustment
Credits	
Return or exhaust *systems* required by code or accreditation standards to be fully ducted, or *systems* required to maintain air pressure differentials between adjacent rooms.	0.5 in. of water (2.15 in. of water for laboratory and vivarium *systems*)
Return and/or exhaust airflow *control devices*	0.5 in. of water
Exhaust filters, scrubbers, or other exhaust treatment	The pressure drop of device calculated at *fan system design condition*
Particulate Filtration Credit: MERV 9 through 12	0.5 in. of water
Particulate Filtration Credit: MERV 13 through 15	0.9 in. of water
Particulate Filtration Credit: MERV 16 and greater and electronically enhanced filters	Pressure drop calculated at 2× clean filter pressure drop at *fan system design condition*
Carbon and other gas-phase air cleaners	Clean filter pressure drop at *fan system design condition*
Biosafety cabinet	Pressure drop of device at *fan system design condition*
Energy recovery device, other than coil runaround loop	For each airstream [(2.2 × *Enthalpy Recovery Ratio*) – 0.5] in. of water
Coil runaround loop	0.6 in. of water for each airstream
Evaporative humidifier/cooler in series with another cooling coil	Pressure drop of device at *fan system design condition*
Sound attenuation section (fans serving *spaces* with design [illegible]	0.15 in. of water

Total Baseline System Fan Power (G3.1.2.9)

Systems 3 - 8, and 11 – 13:

$Pfan$ = bhp × 746 / fan motor *efficiency*

Table G3.9.1 *Performance Rating Method* Motor *Efficiency* Requirement

Motor Horsepower	Minimum Nominal Full-Load *Efficiency*, %
1.0	82.5
1.5	84.0
2.0	84.0
3.0	87.5
5.0	87.5
7.5	89.5
10.0	89.5
15.0	91.0
20.0	91.0
25.0	92.4

fan motor *efficiency* = the *efficiency* from Table G3.9.1 for the next motor size greater than the bhp

Quiz 16

What is the fan power of the baseline HVAC systems?

Baseline Hot Water Plant

G3.1.3.2 The *boiler* plant shall be natural draft, with a single boiler if the plant serves a *conditioned floor area* of 15,000 ft2 or less, or two equally sized *boilers* for plants serving more than 15,000 ft2.

Table G3.5.6 Gas-Fired *Boilers*—Minimum *Efficiency* Requirements

Equipment Type	Size Category	Subcategory or Rating Condition	Minimum *Efficiency*	Test Procedure
Boilers, gas-fired	<300,000 Btu/h	Hot water	80% *AFUE*	DOE 10 CFR Part 430
	≥300,000 Btu/h and ≤2,500,000 Btu/h	Maximum capacity	75% E_t	DOE 10 CFR Part 431
	>2,500,000 Btu/h	Hot water	80% E_c	

G3.1.3.3 HW design supply temperature shall be modeled as 180°F and design return temperature as 130°F.

G3.1.3.4 Hot-water supply temperature shall be reset based on the following schedule: 180°F at 20°F and below, 150°F at 50°F and above, and ramped linearly between 180°F and 150°F at temperatures between 20°F and 50°F.

Baseline Hot Water Plant

G3.1.3.5 Hot-Water Pumps

The *baseline building design* hot-water pump power shall be 19 W/gpm. The pumping *system* shall be primary-only with continuous variable flow and a minimum of 25% of the design flow rate. Hot-water *systems* serving 120,000 ft2or more shall be modeled with variable-speed drives, and *systems* serving less than 120,000 ft2 shall be modeled as riding the pump curve.

G3.1.3.6 Piping Losses

Piping losses shall not be modeled in either the *proposed or baseline building design* for hot-water, chilled-water, or steam piping.

Quiz 17

What is the baseline hot water plant heating efficiency, pump power and control?

Baseline Chilled Water Plant

- Electric chillers shall be used in the *baseline building design* regardless of the cooling *energy* source, e.g. direct-fired absorption or absorption from purchased steam.
- The *baseline building* chiller plant configuration depends on the baseline peak cooling load.
- Efficiency prescribed in Table G3.5.3

Table G3.1.3.7 Type and Number of Chillers

Building Peak Cooling Load	Number and Type of Chillers
≤300 tons	1 water-cooled screw chiller
>300 tons, <600 tons	2 water-cooled screw chillers sized equally
≥600 tons	2 water-cooled centrifugal chillers minimum with chillers added so that no chiller is larger than 800 tons, all sized equally

Baseline Chilled Water Plant

- 44°F chilled-water design supply temperature; 56°F return water temperature.
- *Reset* based on outdoor dry-bulb temperature : 44°F at 80°F and above, 54°F at 60°F and below, and ramped linearly between 44°F and 54°F at temperatures between 80°F and 60°F.
- An axial-fan open-circuit cooling tower with variable speed fan control and efficiency of 38.2 gpm/hp
- Primary/secondary loop arrangement
  - Primary loop: 9 W/gpm pump power, constant volume
  - Secondary loop: 13 W/gpm pump power at design conditions; variable-speed drives with minimum flow 25% of the design rate if cooling load over 300 tons, otherwise righting the pump curve.

Purchased Chilled Water and Purchased Heat

- Projects with purchased heat and/or chilled water in the proposed design must be modeled with purchased heat/chilled water in the baseline.
- In some cases, this requires changing the baseline HVAC system type to replace DX cooling and/or fossil fuel furnace with chilled and/or hot water coils
- Lower baseline pump power allowances compared to on-site chiller / boiler
- For example, if the case study used purchased chilled water and steam, it would be modeled as follows:
  - *System* 1 replaced by a constant-volume fan-coil units with *fossil fuel boilers*.
  - *System* 3 replaced by a constant-volume single-zone air handlers with hot water and chilled water coils

Proposed HVAC (G3.1- 10)

- Where an HVAC system has been designed, the HVAC model shall be consistent with design documents.

- Where no heating *system* exists or has been submitted with design documents, the *system* type shall be the same as in the *baseline,* and shall comply with but not exceed the requirements of Section 6.

- Where no cooling *system* exists or has been submitted with design documents, the cooling *system* type shall be the same as in the *baseline building design* and shall comply with the requirements of Section 6.

  Exception: *Spaces* using baseline *HVAC system* types 9 and 10.

Quiz 18

a. How should proposed HVAC be modeled in apartments, multifamily corridors, stairwells and retail spaces?
b. If apartments had no cooling specified in the proposed design, how would proposed HVAC be modeled in apartments?

REMOVING SUPPLY FAN POWER FROM PROPOSED PACKAGED EQUIPMENT

$$EER = \frac{\text{Net Cooling}[\text{Btu/h}]}{\text{Total Input Power}[\text{W}]}$$

$$\text{Indoor Fan Power}[\text{W}] = \frac{\text{Gross Cooling}[\text{Btu/h}] - \text{Net Cooling}[\text{Btu/h}]}{3.413[\text{Btu/h} \times \text{W}]}$$

$$COP_{nfcooling} = \frac{\text{Gross Cooling}[\text{Btu/h}]}{(\text{Total Input Power}[\text{W}] - \text{Indoor Fan Power}[\text{W}]) \times 3.413[\text{Btu/h} \times \text{W}]}$$

- All the inputs above are from the manufacturer's catalogs for AHIR Rated conditions.
- $COP_{nfcooling}$ equations provided for the baseline cannot be used for the proposed design.

Proposed COP_{nfcool} Calculation Example

TRANE

General Data

Table 2. General data - 6 to 10 tons with eFlex™ and eDrive™ technology (208/230 volt)

	6 Tons	7.5 Tons	8.5 Tons	10 Tons
	T/YZC072F3	T/YZC090F3	T/YZC102F3	T/YZC120F3
Cooling Performance[a]				
Gross Cooling Capacity - Full Load	71,000	92,000	103,000	117,000
EER/IEER[b]	12.8/23.2	12.8/22.4	12.6/22.5	12.1/23.0
Nominal cfm/AHRI Rated cfm	2,400/2,400	3,000/2,850	3,400/2,975	4,000/4,000
AHRI Net Cooling Capacity - Full Load	70,000	90,000	99,000	114,000
System Power (kW)	5.47	7.03	7.86	9.42

			T/YZC102F3	Case Study RTU
Net Cooling Capacity	Btu/hr	A	99,000	98,000
EER		B	12.6	14
Total Packaged Unit Power	W	C=A/B	7,857	7,000
Gross cooling capacity	Btu/hr	D	103,000	100,615
Supply fan power	W	E= (D-A)/3.412	1172	766
COPnfcool		F=D/3.412/(C-E)	4.52	4.73
EIR		1/F	0.2214	0.2114

Service Water Heating

Baseline SWH System Type

- Where a complete *service water-heating system* exists or a new *service water-heating system* has been specified, **one** *service water-heating system* shall be modeled for each *building* area type in the proposed *building*, with the minimum *efficiency* requirements in Section 7.4.2.
- Where no *service water-heating system* exists or has been specified but the *building* will have *service water heating* loads, one *service water-heating system* shall be modeled for each anticipated *building* area type in the *proposed design*.
- For *buildings* that will have no *service water-heating* loads, no *service water-heating* shall be modeled.
- Where recirculation pumps are used to ensure prompt availability of *service water-heating* at the end use, the *energy* consumption of such pumps shall be calculated explicitly.

Baseline Service Water Heating System (Table G3.1 No 11)

Table G3.1.1-2 Baseline *Service Water-Heating System*

***Building* Area Type**	**Baseline Heating Method**
Automotive facility	Gas storage *water heater*
Convenience store	*Electric resistance water heater*
Convention center	*Electric resistance* storage *water heater*
Courthouse	*Electric resistance* storage *water heater*
Dining: Bar lounge/leisure	Gas storage *water heater*
Dining: Cafeteria/fast food	Gas storage *water heater*
Dining: Family	Gas storage *water heater*
Dormitory	Gas storage *water heater*
Exercise center	Gas storage *water heater*
Fire station	Gas storage *water heater*
Grocery store	Gas storage *water heater*
Gymnasium	Gas storage *water heater*
Health-care clinic	*Electric resistance* storage *water heater*
Hospital and outpatient surgery center	Gas storage *water heater*
Hotel	Gas storage *water heater*
Library	*Electric resistance* storage *water heater*
Manufacturing facility	Gas storage *water heater*
Motel	Gas storage *water heater*
Motion picture theater	*Electric resistance* storage *water heater*
Multifamily	Gas storage *water heater*
Museum	*Electric resistance* storage *water h*
Performing arts theater	Gas storage *water heater*
Police station	*Electric resistance* storage *water heater*
Post office	*Electric resistance* storage *water heater*
Religious *facility*	*Electric resistance* storage *water heater*
Retail	*Electric resistance* storage *water heater*
School/university	Gas storage *water heater*
Sports arena	Gas storage *water heater*
Town hall	*Electric resistance* storage *water heater*
Transportation	*Electric resistance* storage *water heater*
Warehouse	*Electric resistance* storage *water heater*
Workshop	*Electric resistance* storage *water heater*
All others	Gas storage *water heater*

Baseline Water Heater Efficiency Requirements

TABLE 7.8 Performance Requirements for Water Heating Equipment

Equipment Type	Size Category (Input)	Subcategory or Rating Condition	Performance Required [a]	Test Procedure[b]
Electric water heaters	≤12 kW	Resistance ≥20 gal	0.93–0.00132V EF	DOE 10 CFR Part 430
	>12 kW	Resistance ≥20 gal	$20 + 35\sqrt{V}$ SL, Btu/h	ANSI Z21.10.3
	≤24 Amps and ≤250 Volts	Heat Pump	0.93–0.00132V EF	DOE 10 CFR Part 430
Gas storage water heaters	≤75,000 Btu/h	≥20 gal	0.62–0.0019V EF	DOE 10 CFR Part 430
	>75,000 Btu/h	<4000 (Btu/h)/gal	80% E_t $(Q/800 + 110\sqrt{V})$ SL, Btu/h	ANSI Z21.10.3
Gas instantaneous water heaters	>50,000 Btu/h and <200,000 Btu/h	≥4000 (Btu/h)/gal and <2 gal	0.62–0.0019V EF	DOE 10 CFR Part 430
	≥200,000 Btu/h[c]	≥4000 (Btu/h)/gal and <10 gal	80% E_t	ANSI Z21.10.3
	≥200,000 Btu/h	≤4000 (Btu/h)/gal and ≥10 gal	80% E_t $(Q/800 + 110\sqrt{V})$ SL, Btu/h	

Proposed Service Hot Water System G3.1-11

- Where a *service water-heating system* has been designed and submitted with design documents, the *service water heating model* shall be consistent with design documents.
- Where no *service water-heating system* exists or has been designed and submitted with design documents but the *building* will have *service water-heating* loads, a *service water-heating system* shall be modeled that matches the *system* type in the *baseline building design*, serves the same *water-heating* loads, and shall comply with but not exceed the requirements of Section 7.
- Where a service hot water system has been specified, the service hot water model shall be consistent with design documents.

Quiz 19

What service water heating systems should be modeled in the baseline?

HW Demand (Table G3.1 No 11)

Service water loads and use shall be the same for both the *proposed design* and *baseline building design* and shall be documented by the calculation procedures described in Section 7.4.1.

Exceptions: Service hot-water usage can be demonstrated to be reduced due to the following:

- reducing the physical volume of service water required, such as with low-flow shower heads.
- reducing the required temperature of service mixed water or by increasing the temperature of the entering makeup water, such as alternative sanitizing technologies for dishwashing and heat recovery to entering makeup water.

Reduction shall be demonstrated by calculations.

Hot Water Heating Loads

- Service water loads and usage shall be the same for both the *baseline building design and the proposed design*
- Service water load defaults from 90.1 User's Manual

I-P Version			
Building Type	Occupancy Density[2] ft^2/person (Btu/h·ft^2)	Receptacle Power Density[3] W/ ft^2 (Btu/h·ft^2)	Service Hot-Water Quantities[4] Btu/h·person
Assembly	50 (4.60)	0.25 (0.85)	215
Health/Institutional	200 (1.15)	1.00 (3.41)	135
Hotel/Motel	250 (0.92)	0.25 (0.85)	1,110
Light Manufacturing	750 (0.31)	0.20 (0.68)	225
Office	275 (0.84)	0.75 (2.56)	175
Parking Garage	n.a.	n.a.	n.a.
Restaurant	100 (2.30)	0.10 (0.34)	390
Retail	300 (0.77)	0.25 (0.85)	135
School	75 (3.07)	0.50 (1.71)	215
Warehouse	15,000 (0.02)	0.10 (0.34)	225

HW Demand Assumption

- ASHRAE Applications Handbook

Residential Usage Profile Dependent on Project Demographics		Baseline Residential SWH Usage per Person
Low	All occupants working, seniors, middle income, and higher population density.	12 gallons/day
Medium	Mixture of working / non-working occupants, mixture of age groups, medium population densities.	25 gallons/day
High	High percentages of children, low income, public assistance, or no occupants working.	44 gallons/day

Service water heating is an impactful end use in residential occupancies, with the usage strongly dependent on occupant demographics!

Baseline Hot Water Flow Rates

- Not prescribed in ASHRAE 90.1
- Federal Energy Policy Act (EPAct) of 1992 establishes water efficiency standards for showerheads and faucets manufactured after January 1994.
  - Lavatory faucet 2.5 GPM
  - Kitchen faucet 2.5 GPM
  - Showerheads 2.5 GPM

Hot Water Demand Savings Due to Low Flow Fixtures

ProposedHWD = BaseHWD*(0.36+0.54*LFS/BSF+0.1*LFF/BFF)

LFS [GPM] – rated flow rate of the specified low-flow showerheads
BSF [GPS] – flow rate of the baseline showerheads
LFF[GPM] – rated flow rate of the specified low-flow faucets
BFF [GPM] – flow rate of the baseline faucets

From a study by Hwang et al http://enduse.lbl.gov/Info/LBNL-34046.pdf for multifamily buildings.

Needs adjustment when used for different building types.

Changes in 90.1 2019

- Clarified that SWH piping losses should not be modeled.
- Set baseline hot water demand based on the maximum allowed by the applicable code, which is often more stringent than the EPACT 1992!

Quiz 20

Apartments in the case study have low flow faucets and shower-heads with the design flow rates below the maximum set in the applicable plumbing code.

Can water heating energy use be based on lower volume of hot water consumed in the proposed design compared to the baseline?

Miscellaneous Other Loads

Elevators

- Where the *proposed design* includes elevators, the elevator motor, *ventilation* fan, and light load must be modeled.
- The cab *ventilation* fan and lights must be modeled with the same schedule as the elevator motor.
- The baseline elevator peak motor power:

Same as proposed

bhp = (Weight of Car + Rated Load – Counterweight) × Speed of Car/(33,000 × *hmechanical*)

Pm = bhp × 746/*hmotor*

Table G3.9.2 ***Performance Rating Method*** **Baseline Elevator Motor**

Number of Stories (Including Basement)	Motor Type	Counterweight	Mechanical *Efficiency*	Motor Efficiency[a]
≤4	Hydraulic	None	58%	Table G3.9.3
>4	Traction	*Proposed design* counterweight, if not specified use weight of the car plus 40% of the rated load	64%	Table G3.9.1

a. Use the *efficiency* for the next motor size greater than the calculated bhp.

Refrigeration Systems

- The *proposed design* shall be modeled using the actual *equipment* capacities and efficiencies.

  90.1 2019: clarified that the proposed refrigeration systems rated in accordance with AHRI 1200 must be modeled with the rated energy use

- Where refrigeration *equipment* is specified in the *proposed design* and listed in Tables G3.10.1 and G3.10.2, the *baseline building design* must be modeled as specified in Tables G3.10.1 and G3.10.2 using the actual *equipment* capacities.
- If the refrigeration *equipment* is not listed in Tables G3.10.1 and G3.10.2, the *baseline building design* must be modeled the same as the *proposed design*.

Equipment Type					
Equipment Class[a]	Family Code	Operating Mode	Rating Temperature	*Energy* Use Limits,[b,c] kWh/day	Test Procedure
VOP.RC.M	Vertical open	Remote condensing	Medium temperature	1.01 × TDA + 4.07	AHRI 1200
SVO.RC.M	Semivertical open	Remote condensing	Medium temperature	1.01 × TDA + 3.18	
HZO.RC.M	Horizontal open	Remote condensing	Medium temperature	0.51 × TDA + 2.88	

Motors

Non-HVAC motors 1HP and larger must be modeled based on Table G3.9.1 in the baseline, and as specified in the proposed design

Table G3.9.1 ***Performance Rating Method*** **Motor** ***Efficiency*** **Requirements**

Motor Horsepower	Minimum Nominal Full-Load *Efficiency*, %
1.0	82.5
1.5	84.0
2.0	84.0
3.0	87.5
5.0	87.5
7.5	89.5
10.0	89.5
15.0	91.0
20.0	91.0
25.0	92.4

Receptacle and Process Loads (Table G3.1 No 12)

Energy use associated with receptacle and process loads, such as office equipment and residential appliances, must be estimated based on the building type or space type category and modeled identically in the *proposed* and *baseline designs.*

Exceptions: When quantifying performance that exceeds the requirements of Standard 90.1 and approved by the rating authority, the power, schedules, or control sequences of the equipment modeled in the baseline building design may vary from the proposed design based on documentation that the equipment installed in the proposed design represents a significant verifiable departure from documented current conventional practice

Documenting Plug Load Credit for Above-code Programs

Table 4.7. Plug Load Calculation for the Advanced Case without Additional Controls

	Baseline			Advanced		
Plug Load Equipment Inventory	Quantity	Plug load, each (W)	Plug load (W)	Quantity	Plug load, each (W)	Plug load (W)
Office Equipment						
Computers – servers	8	65	520	8	54	432
Computers – desktop[(a)]	134	65	8,710	89	54	4,806
Computers – laptop[(a)]	134	19	2,546	179	17	3,043
Monitors – server – LCD	8	35	280	8	24	192
Monitors – desktop – LCD	268	35	9,380	268	24	6,432
Laser printer – network	8	215	1,720	8	180	1,440
Copy machine	4	1,100	4,400	4	500	2,000
Fax machine	8	35	280	8	17	136
Water cooler	8	350	2,800	8	193	1,544
Refrigerator	8	76	608	8	65	520
Vending machine	4	770	3,080	4	770	3,080
Coffee maker	4	1,050	4,200	4	1,050	4,200
Portable HVAC (heaters, fans)	30	30	900	30	30	900
Other small appliances, chargers	250	4	1,000	250	4	1,000
Total plug load (W)			40,424			29,725
Plug load density, W/ft^2 (W/m^2)			**0.75 (8.07)**			**0.55 (5.92)**

(a) Assumes shift towards higher proportion of laptops instead of desktop computers in advanced from earlier equipment power density.

From "Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings" (published in 2009 by PNNL)

EnergyStar® Appliances

- Performance credit may be claimed for above-code programs such as LEED and EPA ENERGY STAR Multifamily High-rise.
- Performance credit for Energy Star ® appliances based on the www.energystar.gov

Quiz 21

Apartments in the case study have ENERGY STAR refrigerators. Can lower appliance loads be modeled in the proposed design compared to the baseline?

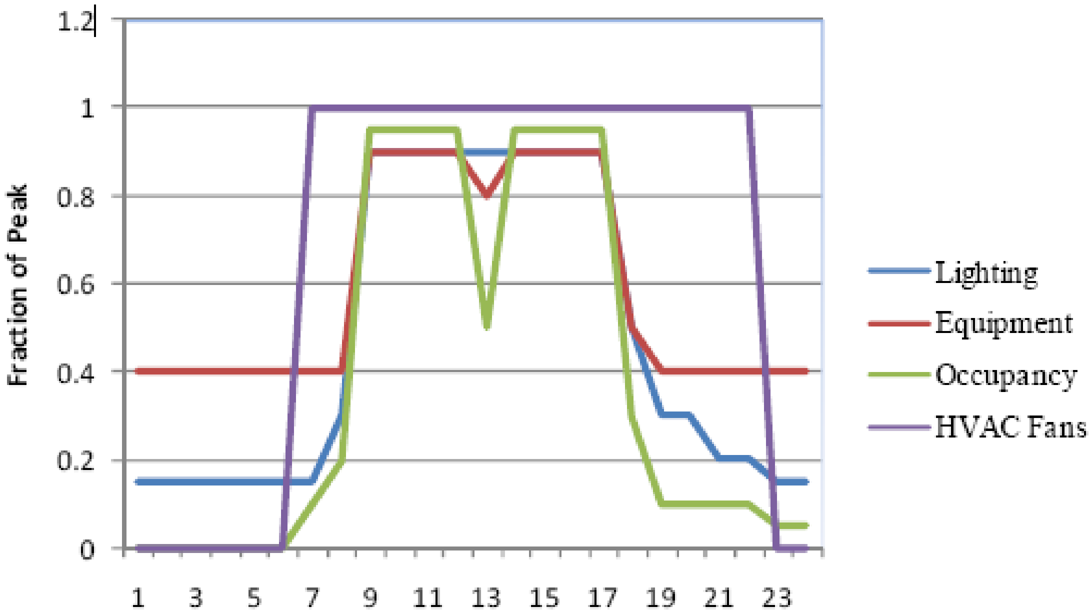
Default Schedules (90.1 User Manual)

Table G-I—Office Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
2 (1-2 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
3 (2-3 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
4 (3-4 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
5 (4-5 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
6 (5-6 am)	0	0	0	10	5	5	Off	Off	Off	8	8	7	0	0	0
7 (6-7 am)	10	10	5	10	10	5	On	On	Off	7	7	4	0	0	0
8 (7-8 am)	20	10	5	30	10	5	On	On	Off	19	11	4	35	16	0
9 (8-9 am)	95	30	5	90	30	5	On	On	Off	35	15	4	69	14	0
10 (9-10 am)	95	30	5	90	30	5	On	On	Off	38	21	4	43	21	0
11 (10-11 am)	95	30	5	90	30	5	On	On	Off	39	19	4	37	18	0
12 (11-12 pm)	95	30	5	90	30	5	On	On	Off	47	23	6	43	25	0
13 (12-1 pm)	50	10	5	80	15	5	On	On	Off	57	20	6	58	21	0
14 (1-2 pm)	95	10	5	90	15	5	On	On	Off	54	19	9	48	13	0
15 (2-3 pm)	95	10	5	90	15	5	On	On	Off	34	15	6	37	8	0
16 (3-4 pm)	95	10	5	90	15	5	On	On	Off	33	12	4	37	4	0
17 (4-5 pm)	95	10	5	90	15	5	On	On	Off	44	14	4	46	5	0
18 (5-6 pm)	30	5	5	50	5	5	On	On	Off	26	7	4	62	6	0
19 (6-7 pm)	10	5	0	30	5	5	On	Off	Off	21	7	4	20	0	0
20 (7-8 pm)	10	0	0	30	5	5	On	Off	Off	15	7	4	12	0	0
21 (8-9 pm)	10	0	0	20	5	5	On	Off	Off	17	7	4	4	0	0
22 (9-10 pm)	10	0	0	20	5	5	On	Off	Off	8	9	7	4	0	0
23 (10-11 pm)	5	0	0	10	5	5	Off	Off	Off	5	5	4	0	0	0
24 (11-12 am)	5	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
Total/Day	920	200	60	1040	280	120	1600	1200	0	537	256	113	555	151	0
Total/Week	48.60 hours			56.00 hours			92.00 hours			30.54 hours			29.26 hours		
Total/Year	2534 hours			2920 hours			4797 hours			1592 hours			1526 hours		

Wk = Weekday

Schedules from DOE/PNNL Technical Support Document



Schedules from "Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings" (published in 2009 by PNNL). This document also estimates baseline plug loads as 0.75 W/Sq Ft.

Typical Plug and Process Loads Site EUI

	Process & Plug Loads	Total
Hospital	49	127
Large Hotel	35	90
Small Hotel	21	63
Large Office	42	74
Medium Office	14	36
Primary School	20	57
Secondary School	14	40

PNNL 2013EndUseTables_2014jun20.xls

http://www.energycodes.gov/commercial-prototype-building-models

Receptacle and Process Loads

- Default assumptions are included in 90.1 User's Manual

I-P Version	
Building Type	Receptacle Power Density[3] W/ ft^2 (Btu/h·ft^2)
Assembly	0.25 (0.85)
Health/Institutional	1.00 (3.41)
Hotel/Motel	0.25 (0.85)
Light Manufacturing	0.20 (0.68)
Office	0.75 (2.56)
Parking Garage	n.a.
Restaurant	0.10 (0.34)
Retail	0.25 (0.85)
School	0.50 (1.71)
Warehouse	0.10 (0.34)

90.1 2019 Appendix G

- When receptacle controls installed in *spaces* where not required by Section 8.4.2 are included in the *proposed building design*, the hourly schedule of such controlled receptacles may be reduced by 10%

- Background: Section 8.4.2 requires automatic receptacle controls in at least 50% of all 125 V, 15 and 20 amp receptacles in all private offices, conference rooms, rooms used primarily for printing and/or copying functions, break rooms, classrooms, and individual workstations;

Reporting Requirements

Documentation (G1.3.2)

Simulated performance shall be documented, and doc[...]entation shall be submitted to the *rating authority*. The informat[...]e submitted in a report and shall include the following:

Extensive Reporting Requirements!

a. A brief description of the project, the key *energy efficiency* improvements com-pared with the requirements in Sections 5 through 10, the *simulation pr*[...] used, the version of the *simulation program*, and the results of the *en*[...] sis. This summary shall contain the calculated values for the *b*[...] *performance*, the *proposed building performance*, and th[...] ment.

b. An overview of the project that includes the n[...] *grade*), the typical *floor* size, the uses [...] retail, parking, etc.), the gross are[...] *tioned space*.

c. A list of the *energy*-re[...] the performance rat[...] that differ between the m[...] and *pro-posed building perform*[...]

d. A list showing complian[...] the requirements of Sections 5.4, 6.4, 7.4, 8.4,[...] provisions).

e. A list identifying those aspe[...] *design* that are less stringent than the requirements of Sections [...], 9.5, and 9.6 (prescriptive provisions).

f. A table with a summary by en[...]se of the *energy* cost savings in the *proposed building performance*.

g. A site plan showing all adjacent *buildings* and topography that may shade the proposed *building* (with estimated height or number of stories).

[...]ptable).

[...] the computer simulation.

[...]ing assumptions.

[...]al to support data inputs (e.g., *U-factors* for [...]es, NFRC ratings for *fenestration*, end-uses identified [...]sign Model," paragraph [a]).

[...]ut reports from the *simulation program* or compliance software, [...] a breakdown of *energy* use by at least the following components: [...]ts, internal *equipment* loads, *service water-heating equipment*, *space*-heating *equipment*, *space*-cooling and heat rejection *equipment*, fans, and other HVAC *equipment* (such as pumps). The output reports shall also show the amount of *unmet load hours* for both the *proposed design* and *baseline building design*.

m. *Purchased energy rates* used in the simulations.

n. An explanation of any error messages noted in the *simulation program* output.

o. For any exceptional calculation methods employed, document the predicted *energy* savings by *energy* type, the *energy* cost savings, a narrative explaining the exceptional calculation method performed, and theoretical or empirical information supporting the accuracy of the method.

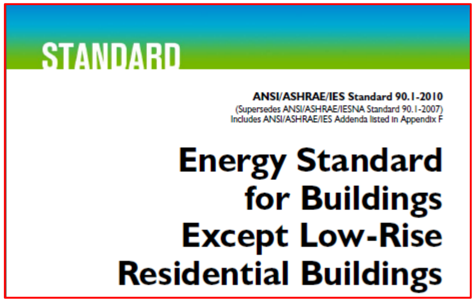
p. The reduction in *proposed building performance* associated with *on-site renewable energy*.

q. The version of the software and the link to the website that contains the ASHRAE Standard 140 results for the version used in accordance with Section G2.2.4.

COMPLIANCE FORM DEMO

INTERPRETING SIMULATION RESULTS

NYSERDA Research Study



New York State Energy Research and Development Authority funded a study to examine equivalency of ASHRAE Standard 90.1 Appendix G, PHIUS+, and PHI modeling protocols to inform technical requirements of the multifamily program.

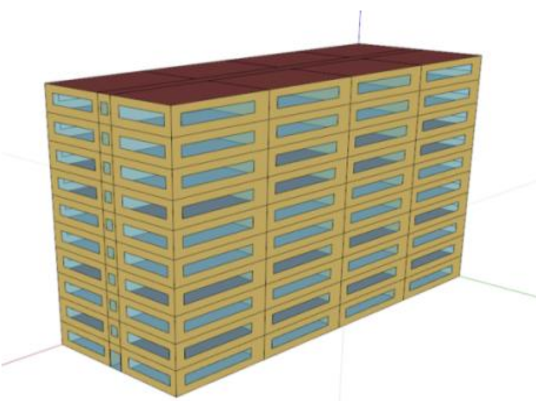
Study Methodology

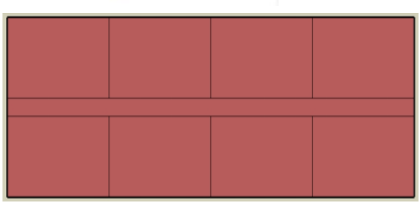
- Model the same building designs in the three protocols
- Compare projected performance
- If projections differ, understand sources of the difference
- Develop an approximate mapping between protocols

Standard 90.1 Performance Rating Method

Case Study Description

Building shape and floor plan based on the Pacific Northwest National Lab (PNNL) high-rise apartment multifamily progress indicator model





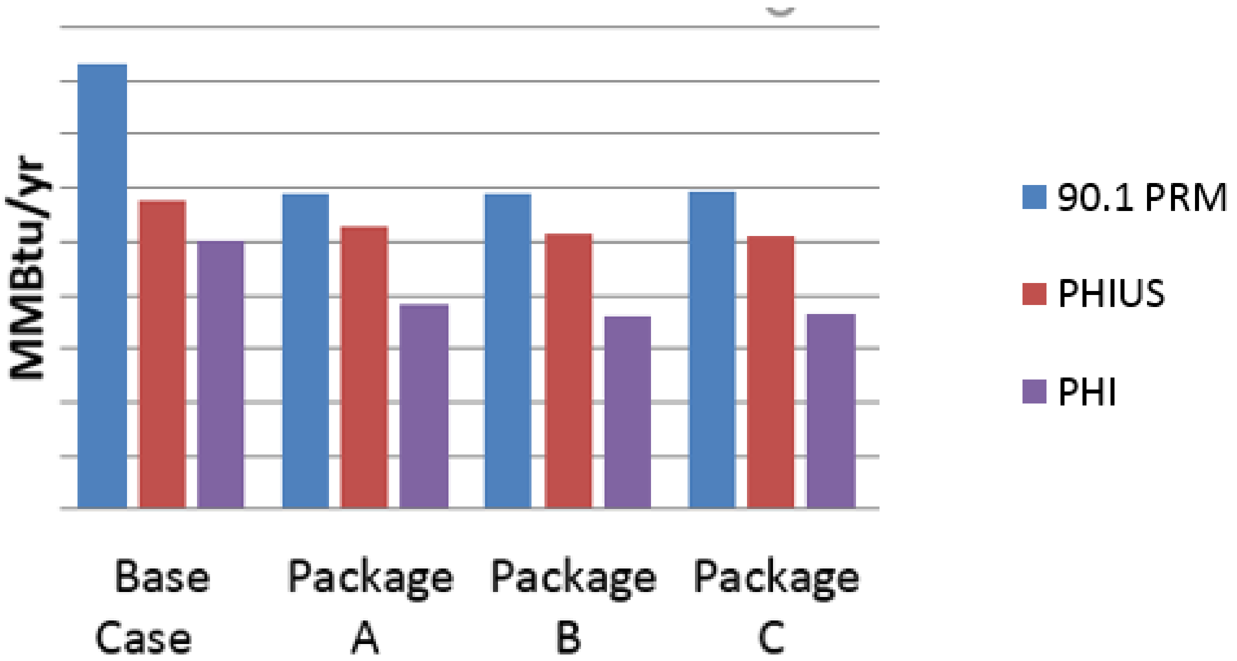
- 84,360 sf^2 10-story
- 79 apartments
- Windows account for 30% of gross exterior wall on each exposure
- Slab-on-grade foundation
- Modeled alternative designs from minimum code compliant to exceeding passive house requirements

Modeling Protocols and the Teams

	Guiding Documents	Simulation Tool
90.1 PRM	ASHRAE Standard 90.1 2010 Appendix G; EPA Energy Star MFHR Simulation Guidelines	eQUEST v3.65
PHIUS	PHIUS+ 2015 Certification Guide Book V1.01	WUFI V.3.0.3.0
PHI	PHPP v9.5 – PH Classic	PHPP v9.5

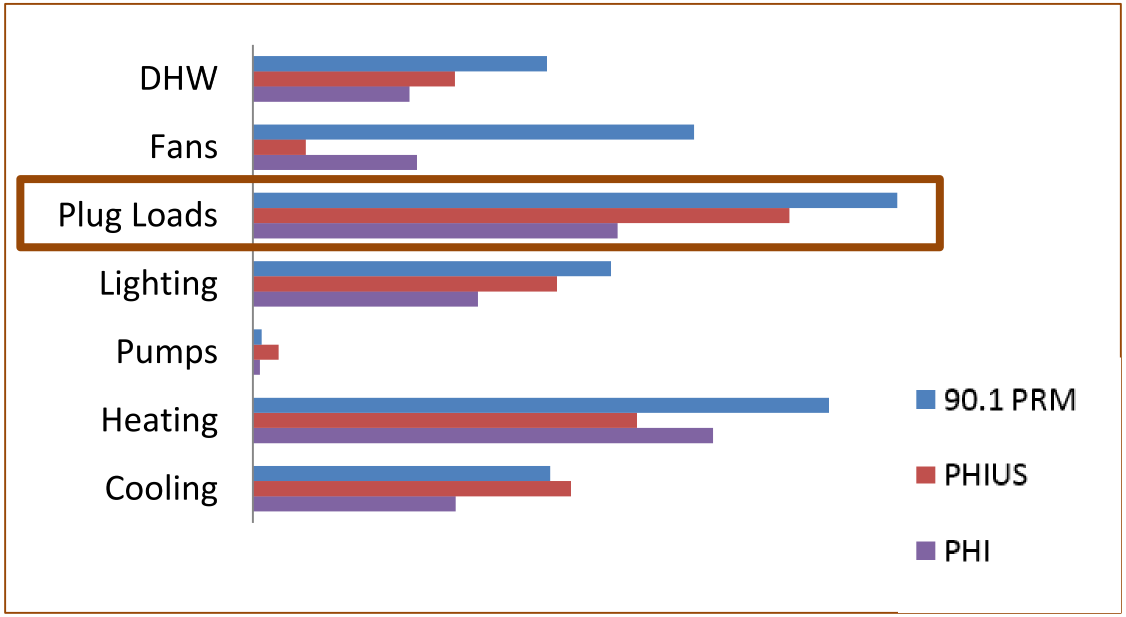
All materials including the models and analysis were shared between the teams to enable peer review.

Modeled Annual Source Energy Use

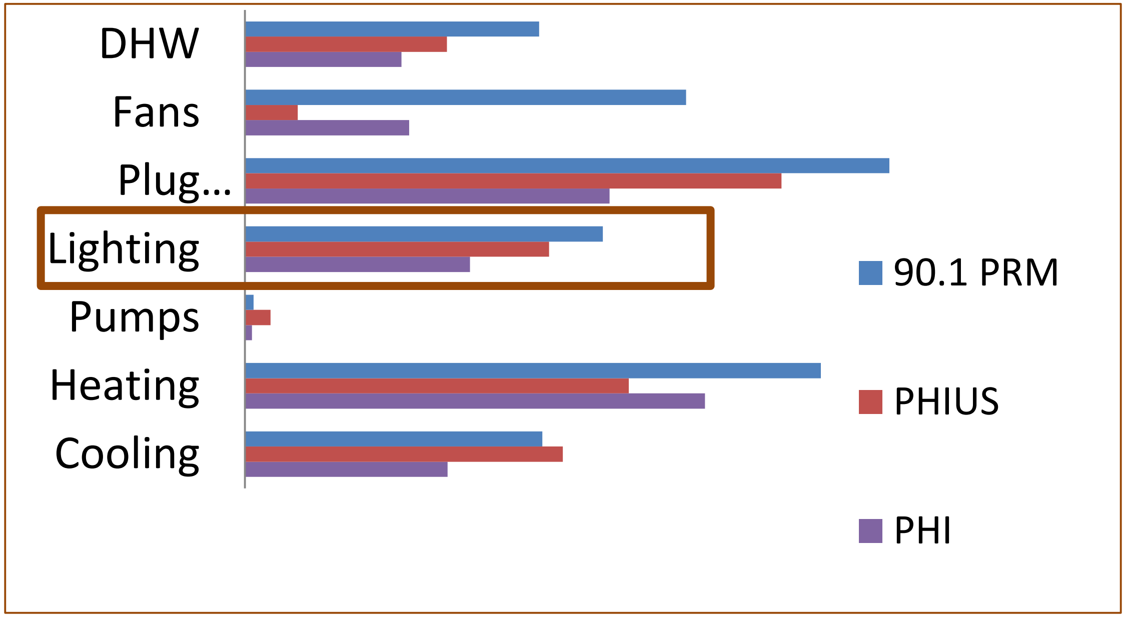


* Site-to-source energy conversions on all graphs are based on the EPA Portfolio Manager

Base Case Source Energy: Plug Loads

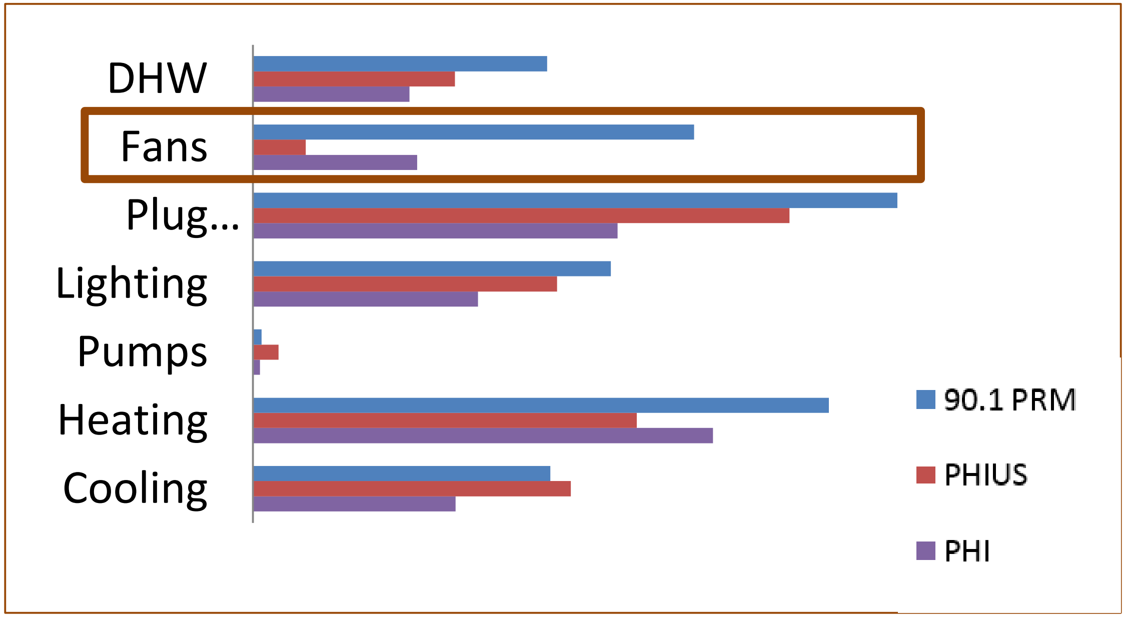


Base Case Source Energy: Lighting



* Site-to-source energy conversions based on the EPA Portfolio Manager

Base Case Source Energy: Fans



Key Reasons for the Difference: Modeling Assumptions and Rules

PH protocols have significantly more optimistic assumptions for systems and operating conditions not inherent in design compared to EPA MFHR. Examples include …

- in-unit lighting
- plug loads
- hot water use
- credit for the manual controls (90.1 credits automatic controls only)

Key Reasons for the Difference: Simulation Tools Capabilities

- WUFI and PHPP were designed to model high performing buildings with relatively simple mechanical systems, and do not meet many of the simulation tool capabilities required by ASHRAE Standard 90.1.
- Sample limitations that affected the case study:
  - could not explicitly model different mechanical systems serving common corridors (e.g. gas-fired RTU) versus apartments (e.g. VRF heat pumps)
  - continuously running heating & cooling system fans (e.g. in PTACs in the Base Case) were not captured

So Which Protocol Got it Right?

The actual performance of the proposed design will differ from the modeled performance due to the following…

- variations in schedule of operation and occupancy

- building operation and maintenance

- weather
  10 year historical weather average ≠ 2020 weather

- changes in energy rates
  2017 electricity and gas cost ≠ 2020 costs

- tenant equipment
- the precision of the calculation tool

THIS FACTORS AFFECT ALL PROTOCOLS

If Modeled Performance Cannot Pinpoint Actual Performance, then Why Bother?