(e) Passive House Comfort

The origins of the Passive House standard began with passive solar design and superinsulation techniques during the 1970s in the United States and Canada. In the 1990s European scientists refined these concepts and design techniques to develop the Passive House standard tailored to the Central European climate zone. Although Passive House has its origins in energy efficiency, many of its design and quality-assurance requirements are squarely focused on the thermal comfort of building occupants.

The Passive House standard (technically a guideline) is a stringent, voluntary energy standard resulting in some of the most energy efficient, comfortable, durable, and resilient buildings in the world, while simultaneously establishing readiness for a net zero or net positive energy path. The German Passivhaus Institut (PHI) offers a quantifiable performance standard well-suited for the Central European and similar climate zones. However, the European standard and target metrics do not work well in most North American climate zones. The Passive House Institute U.S. (PHIUS) in cooperation with Building Science Corporation under a U.S. DOE Building America grant, developed passive building standards that account for the broad range of climate conditions, market conditions, and other variables in North American climate zones, resulting is the PHIUS+ 2015 Passive Building Standard—North America. The PHIUS+ 2015 Passive Building Standard accounts for a full range of variables including climate zone, source energy, and costs and includes a web-based clickable map bringing up target criteria for more than 1,000 locations in North America. PHIUS+ 2015 certified projects earn U.S. DOE Zero Energy Ready Home (ZERH) status and the U.S. EPA Indoor airPLUS label. PHIUS+2018, recently released, offers tighter source-energy criteria, space conditioning targets

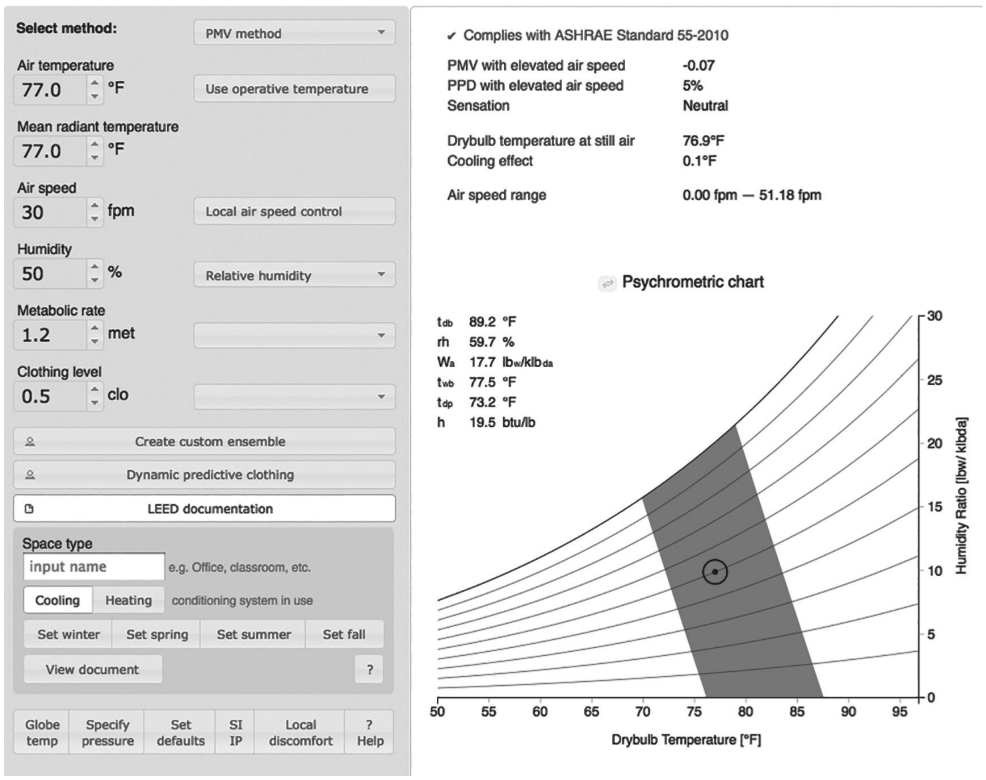


Fig. 4.23 *CBE Thermal Comfort Tool. Left side shows user input fields. Top-right section contains the results of the calculations. Bottom-right section contains a visualization of thermal comfort conditions as a psychrometric chart, temperature-humidity chart, or the adaptive comfort chart. (Hoyt Tyler, Schiavon Stefano, Piccioli Alberto, 2013, CBE Thermal Comfort Tool for ASHRAE-55. Center for the Built Environment, University of California Berkeley, http://cbe.berkeley.edu/comforttool/; used with permission.)*

that are less granular in terms of climate, and space conditioning requirements that adjust for a range of different building sizes and occupant densities.

The Passive House guidelines seek to improve occupant comfort while simultaneously minimizing building energy use. It is important to emphasize the suitability of the Passive House approach beyond single-family, residential construction. While most commonly applied to single-family dwellings, the principles have been successfully implemented across a range of project types and building scales.

As both an energy standard and set of design and construction principles, the Passive House concept promises superior comfort, can regularly achieve a 90% baseline energy reduction, and can typically achieve net-zero source energy with the integration of a relatively small supplementary renewable energy system. Certified buildings are superinsulated and very airtight, such that they can rely almost exclusively on internal and solar gains for heating. Per the standard, indoor air quality must be well maintained, typically through the use of a heat recovery ventilator (HRV) or energy recovery ventilator (ERV), which supplies a constant volume of fresh outdoor air. The design approach is a well-insulated, airtight building that is heated by solar gains, people, equipment, and lighting; heat losses are minimized by thermal-bridge-free construction.

A number of strategies help to increase thermal comfort and reduce energy use in passive buildings. Even though all the guiding principles must work in concert, the first three principles are critical in the schematic design phase of a project.

As the design progresses, thermal bridging and airtightness can be tested and the design optimized through use of the WUFI-Passive energy modeling and planning software.

Among the most notable characteristics of a passive building is its simultaneous simplicity and rigor of the building envelope. A passive building is designed and built in strict response to these five building-science principles:

1. Employs **continuous insulation** throughout the envelope without any thermal bridging.
2. Establishes an **airtight building envelope**, preventing infiltration of outside air and loss of conditioned air.
3. Uses high-performance windows (typically triple-paned) and doors.
4. Uses some form of **balanced heat- and moisture-recovery ventilation** and a small-capacity space conditioning system.
5. **Manages solar gains** to reduce the energy required for heating during the heating season and to minimize overheating during the cooling season.

The comfort criteria in Passive House building construction:

- The air velocity in the occupied zone must be less than 19.7 fpm (0.1 m/s). This criterion limits both the air permeability of a component as well as potential draftiness.
- Average room temperature compared to the average wall surface temperature should not differ by more than 7.56°F (4.2°C).
- Designers must also specify glazing elements and mechanical systems that meet minimum passive building performance criteria, and the project team must verify the building's airtightness on-site several times throughout the construction process—typically immediately after the envelope is finished, again before the interior walls are put in, and finally upon completion of the building.

References and Resources

Passivhaus Institut. http://passiv.de/

Passive House Alliance United States (PHAUS). http://www.phaus.org/

Passive House Institute United States (PHIUS). http://www.passivehouse.us/

9.10 CASE STUDY—HEAT FLOW AND ENVELOPE DESIGN

Orchards at Orenco

PROJECT BASICS

- Location: Hillsboro, Oregon, USA
- Latitude: 45.53 N; longitude: 122.94 W; elevation: 194 ft (60 m)
- Heating degree days: 4750 base 65°F (2639 base 18.3°C); 280 base 65°F (156 base 18.3°C); annual precipitation: 43.5 in. (1105 mm)
- Building type: Multifamily, affordable housing
- Floor area: Phase I: 42,584 ft^2 [3956 m^2] treated floor area, 57 units; Phase 2: 58 units

Fig. 9.17 *Orchards at Orenco, Phase 1, completed in 2015, opened as the largest certified passive house multifamily, affordable housing project in the US. (© Casey Braunger, Ankrom Moisan Architects, Inc.)*

Fig. 9.18 *Orchards at Orenco, Phase 2, completed in 2017, was precertified to the PHIUS+2105 Standard. (© Casey Braunger, Ankrom Moisan Architects, Inc.)*

- Completed: Phase I 2015; Phase II 2016
- Design team: Owner: REACH Community Development; Ankrom Moisan Architects, Inc. (architect of record); William Wilson Architects (Design Architect); Walsh Construction Company (contractor); Phase I: Greenhammer/ Dylan Lamar (Certified Passive House Consultant)

Background. This project demonstrates the successful implementation of affordable passive building strategies and their scalability to a large, multifamily, affordable housing project, comparing optimized envelope designs from two different passive housing certifications.

REACH Community Development, a nonprofit affordable housing provider sought to provide a comprehensive, sustainable model for affordable living and purchased a vacant, two-acre [8,094 m^2] site in Hillsboro, Oregon, to build 150 units. Affordability goals included low rents and close proximity to work, but also low monthly utility bills. The project is intended to be convenient, transit-oriented, and affordable. Completed in 2015, Phase I was certified with PHIUS as the largest multifamily Passive House development in the United States (Fig. 9.18). Phase II, completed in 2016 (Fig. 9.19) was precertified under the PHIUS+2015 Standard. Phase III, is currently under construction (Fig. 9.20). The buildings are predicted to achieve nearly 90% energy reduction for space heating and 60–70% for overall energy use compared to a comparable USGBC LEED building. REACH installed the ImagineEnergy monitoring system to track and improve upon tenants' energy usage habits.

Context. During Phase I of Orchards at Orenco, the architects, contractors, and passive house consultants embraced careful adherence and intent to meet the meet stringent Passive House requirements and criteria commonly achieved in Europe. The unique challenges for this phase were in the HVAC integration and minimization of the thermal bridging in the enclosure. There were many lessons learned by the design team in this first project of this scale in the U.S. Primary strategies used in this project included continuous insulation, no thermal bridging, airtight envelope, balanced heat recovery ventilation,

Fig. 9.19 *Orchards at Orenco plan showing three phases of development. (© Walker | Macy Landscape Architects.)*

(*a*) (*b*)

Fig. 9.20 *(a) Orchards at Orenco Phase 1 construction of foundation and (b) envelope assembly (© Walsh Construction Company)*

and optimized solar heat gains for heating during the heating season and minimize overheating during the cooling season. Just after completion of Phase I, the PHIUS+2015 climate-based North American Passive Building Standard was released and the Phase II project was designed and pre-certified to the criteria of this standard.

Design Criteria and Validation. The criteria used in Phases I and II are shown in Table 9.2. The PHIUS+2015 passive building standard adjusts annual heating and cooling demand and peak heating and cooling loads. The source energy demand is based on occupancy and air tightness takes into account area of the envelope rather than solely volumetrically.

Design Features

- **Superinsulation and Hygrothermal Performance**. Like the cutting-edge 1970s houses from which the Passive House standard was derived, certified buildings feature highly insulated envelopes, with typical wall assembly R-values ranging from 35 to 55 Btu/hr ft^2 °F (7–10 W/m^2 K) and roof assembly R-values ranging from 60 to 90 Btu/hr ft^2 °F

TABLE 9.2 Performance metrics and criteria for Orchards at Orenco Phase I using the single target metric and Phase II using the climate-based standard for location in Portland/Hillsboro, Oregon. (U.S. DOE, *Climate-Specific Passive Building Standards*.)

	Single Performance Target	PHIUS+2015 Passive Building Standard
Climate Zone	NA	ASHRAE Climate 4C; Portland/Hillsboro
Annual Heating Demand	≤4.75 kBtu/ft^2 yr (15 kWh/m^2 yr)	5.1 kBtu/ft^2-iCFA yr
Annual Cooling Demand		1 kBtu/ft^2-iCFA yr
Peak Heating Load	≤3.17 Btu/hr ft^2 or 0.93 W/ft^2 (10 W/m^2)	3.7 Btu/ft^2-iCFA yr
Peak Cooling Load		3.9 Btu/ft^2-iCFA yr
Source Energy Demand	≤38 kBtu/ft^2 yr (120 kWh/m^2 yr)	≤ 6200 kWh/yr/person
Airtightness	≤ 0.6 ACH_{50}	≤ 0.05 cfm_{50}/ft^2 or 0.08 cfm_{75}/ft^2

(10–17 W/m^2 K). Unlike their 1970s counterparts, however, modern enclosure assemblies are carefully analyzed for their hygrothermal performance to assess the degree of vapor diffusion through the assembly.

The Phase 1 roof has 12 in. (305 mm) of polyiso insulation, approximately three times the amount required by code. Light color reflects solar radiation and helps moderate the building's temperature. The foundation and envelope enclosure, shown under construction in Fig. 9.21a, b and in the construction detail (Fig. 9.22), show the reinforced concrete perimeter foundation is wrapped with 4 in. (102 mm) EPS insulation and the exterior wall enclosure using 1.5 in. (38 mm) exterior insulation and 2 x 10 in. (38 x 235 mm) wall framing filled with blown-in fiberglass insulation. In Phase 2, the exterior wall uses dramatically less material and insulation, 1 in. (25 mm) mineral wool exterior insulation and 2 x 8 in. (38 x 184 mm) wall framing, due to the newly, revised climate-specific PHIUS+2105 criteria, and careful cost-saving measures.

As the complexity of the assembly increases, so must the rigor of its hygrothermal analysis. Components must be thoughtfully organized to reduce the potential for vapor condensation and accumulation, which is a precursor to mold growth. At Orchards at Orenco, extensive hygrothermal modeling was used to verify the "vapor-open" nature of the assembly: While the assembly is both airtight and highly thermally resistive, moisture is allowed to dry to both sides.

- **Air Sealing.** One of many energy-saving measures required of certified passive buildings is a continuous air barrier. Great care (and much tape) is required to ensure that the "airtight layer," which includes floor, walls, and ceiling, remains free of both intentional and unintentional holes.

  Shown in Fig. 9.22, the primary layer for airtightness is formed by 0.5 in. (12 mm) plywood, carefully taped at its seams. This layer is placed between the 2 x 10 in. (38 × 235 mm) wall and the mineral wool. This strategic placement protects the airtight layer from weather and from occupant wear, and it minimizes necessary service punctures to the airtight layer, as the service cavity is placed in the innermost. Meticulous detailing is provided at the wall intersections, and at penetrations such as windows, to insure continuity of the air barrier system.
- **Shading Devices.** Shading devices that allow the winter sun in, but block it in the summer were placed on facades. This was a particularly important element at the west- and south-facing facades. Exterior shades are one of the most critical components of HVAC design and this very simple addition to the façade design, will be seen through low energy use and excellent thermal comfort.
- **Heat Recovery Ventilators.** In Phase I, three rooftop mechanical penthouses (Fig. 9.23) house the U.S.-made heat recovery ventilators each serving 18 to 20 apartments (typical duct layout for apartment, Fig. 9.24*a*, *b*) and supply to some of the common areas. Rather than designing a fully centralized system, or a decentralized system with individual HVAC units in each apartment, this grouped approach provides a high degree of efficiency

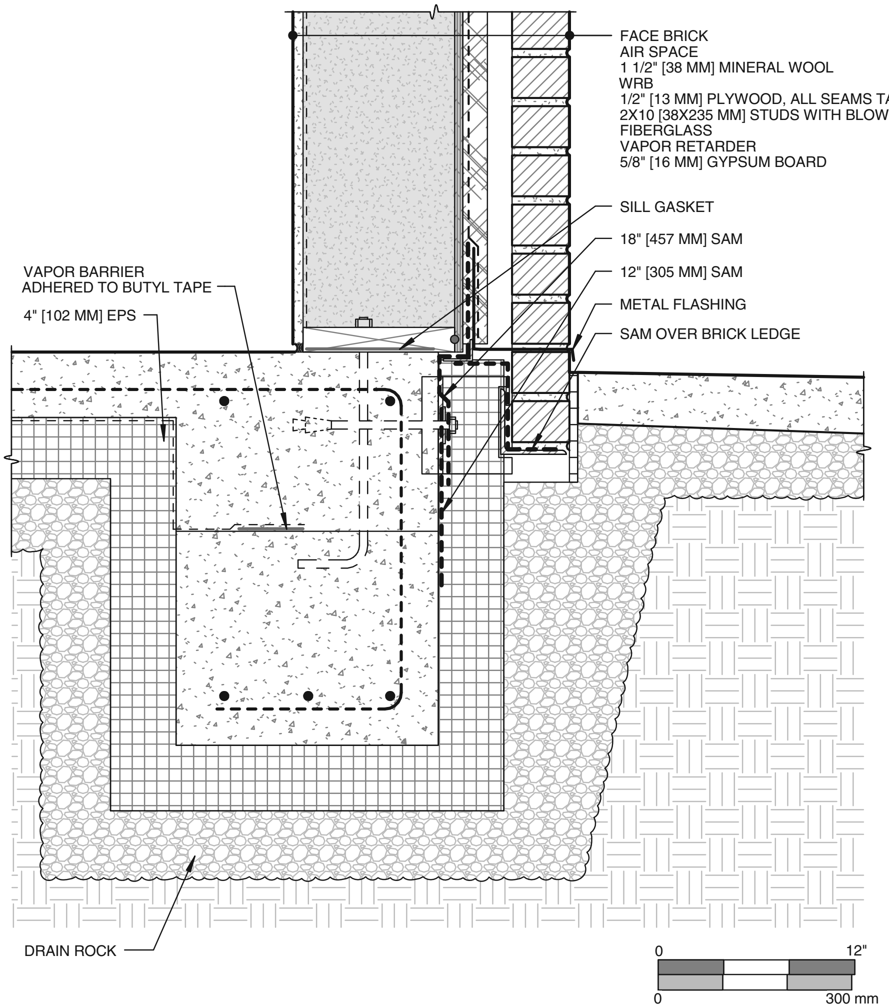
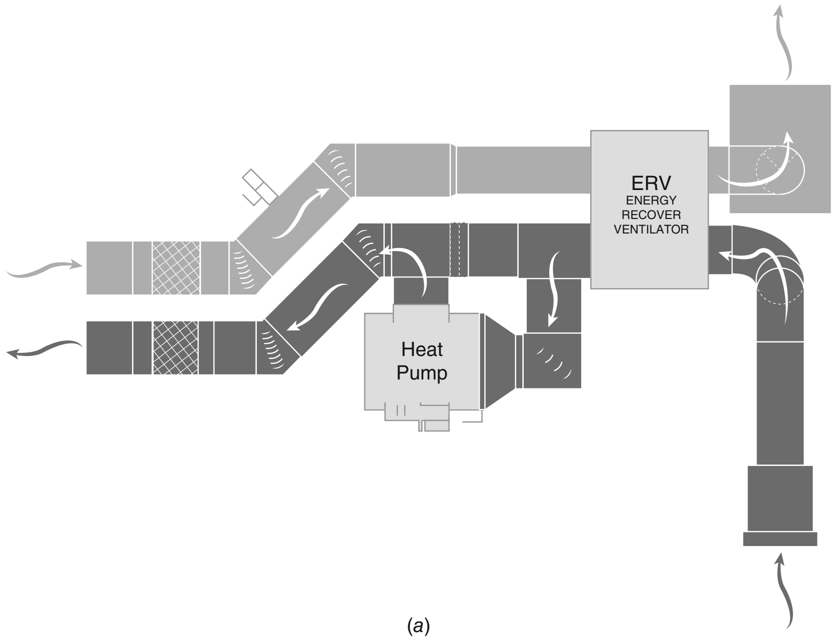
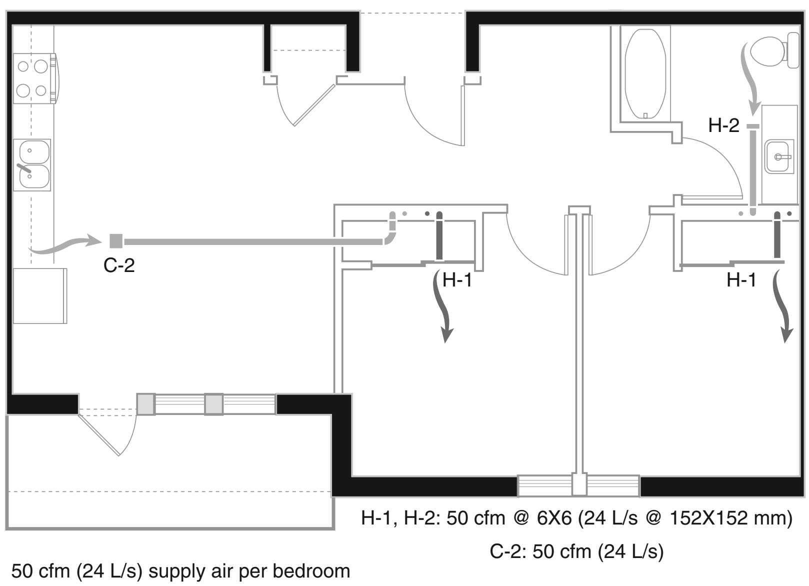


Fig. 9.21 An offset steel angle supports the brick wainscot with reduced thermal bridge effects. Wall construction with 10 in. (13 mm) deep studs and two types of cladding: fiber cement panels and brick veneer. (Ankrom Moisan Architects, Inc., redrawn © Passive House Details: Solutions for High Performance Design, Routledge, 2018.)

Fig. 9.22 Left: Penthouse location houses an ERV and heat pump inline with the supply air trunk line that carries fresh air to the apartments and common areas. Right: Ventilation air is routed through the space above the third-floor corridor. (© Walsh Construction Company)



(*a*)



(*b*)

Fig. 9.23 *(a) Heating and partial cooling using an energy recovery ventilator (ERV) and heat pump; (b) mechanical layout for supply to bedrooms and exhaust from the bathroom in a typical 2-bedroom apartment. (© PAE Consulting Engineers, Inc.)*

Fig. 9.24 *Display shows comparative energy use by unit and for the entire building, located near the mailboxes and lobby in the Orchards at Orenco, Phase I Project. (© Casey Braunger, Ankrom Moisan Architects, Inc.)*

while simplifying distribution and likely cutting down on maintenance needs. Heat recovery ventilators use the energy from kitchens and bathrooms exhaust air to warm the fresh incoming air, to be supplied to the bedrooms.

- **High Performance Windows**. The team chose to use equipment from the Loren Cook Company—a North American manufacturer—due in part to cost considerations, but also based to a significant degree on the mechanical contractor's prior experience with that manufacturer's products. The windows are PVC-fiberglass hybrid window frames with argon-filled triple pane glazing and operate with a tilt-turn, European-style movement.
- **Performance Data:** Precertification was applied for to the Passive House Institute US (PHIUS). The project used PHIUS+ Rater and Earth Advantage, to perform on-site inspections and blower door testing. Final certification occurred at the end of construction after the final blower door test and commissioning of the heat recovery ventilators. An energy tracking system records the performance of each unit and display the results in the lobby (Fig. 9.25). Building entry and common spaces (Fig.9.26) were oriented to respond to urban design cues such as the light rail. (PHIUS Case Study, Orchards at Orenco: Phase I).

Awards

- 2015 Oregon Opportunity Golden Hammer Award for Best Overall Project
- 2015 Passive House Institute U S (PHIUS) Building Project Competition – Best Overall Project and the Best Affordable Housing Project awards for Orchards at Orenco
- 2015 Portland Business Journal Better Bricks "Sustainable Project of the Year"
- 2015 World Architecture News (WAN) Sustainable Buildings
- Award of Merit Green Project: Orchards at Orenco, ENR Northwest, December 10, 2015
- People's Choice category–First Place; Private Buildings Category Honorable Mention; High Performance Building Award–Top Choice. Oregon Daily Journal of Commerce Top Projects, May 5, 2016

Fig. 9.25 *Common space and kitchen areas area spacious and designed to balance daylighting and electric lighting. (© Casey Braunger, Ankrom Moisan Architects, Inc.)*

FURTHER INFORMATION

Passive House Institute U.S. (PHIUS). http://www.phius.org/home-page

Passivehaus Institut (PHI). http://passivehouse.com

PHIUS Case Study, Orchards at Orenco: Phase I. http://www.phius.org/phius-certification-for-buildings-products/case-studies/orchards-at-orenco-phase-i

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7.10 CASE STUDY—HEAT FLOW AND ENVELOPE DESIGN

This section presents three case study projects, including a multifamily housing project, a school, and a commercial office retrofit. The projects demonstrate both the successful implementation of many Passive House strategies and their scalability and versatility across climate zones and beyond newly constructed, single-family detached dwellings.

Background. The Passive House standard is commonly regarded as one of the most stringent energy standards in the world. Applicable to both residential and commercial building types, the standard seeks to improve occupant comfort while simultaneously minimizing building energy use. Certified buildings regularly achieve a 90% baseline energy reduction and can typically achieve net-zero source energy with the integration of a relatively small supplementary renewable energy system. Certified buildings are superinsulated and very airtight, such that they can rely almost exclusively on internal and solar gains for heating. Per the standard, indoor air quality must be well maintained, typically through the use of a heat recovery ventilator (HRV) or energy recovery ventilator (ERV), which supplies a constant volume of fresh outdoor air.

It is important to emphasize the suitability of the Passive House approach beyond single-family, residential construction. While most commonly applied to single-family dwellings, the principles can be successfully implemented across a range of project types and building scales. To better reflect this versatility, "Passive House" may undergo a name change (time will tell). For the sake of clarity, projects are referred to as "Passive House buildings," to emphasize that the standard can be broadly applied.

Design Intent. Among the most notable characteristics of the Passive House standard is its simultaneous simplicity and rigor. The standard has four primary requirements:

- Heating energy use must be less than 4.75 kBtu/ft^2 per year (15 kWh/m^2 per year).
- The peak heat load must be less than 1 W/ft^2 per hour (10 W/m^2).
- Air leakage must be less than 0.6 air changes per hour (ACH), measured at 50 pascals.
- Total primary (source) energy use must be less than 38 kBtu/ft^2 per year (120 kWh/m^2 per year).

In addition to these energy criteria, designers must meet several equally challenging thermal comfort requirements. These aim to maintain a constant and comfortable ambient temperature throughout the building and to reduce radiant asymmetry by maintaining a minimum difference of 7.6F° (4.2C°) between all surface temperatures and the ambient air temperature.

Designers must also specify glazing elements and mechanical systems that meet minimum Passive House performance criteria, and the project team must verify the building's airtightness onsite several times throughout the construction process—typically immediately after the envelope is finished, again before the interior walls are put in, and finally upon completion of the building.

The Center for Energy Efficient Design (CEED)

Project Basics

- Location: Rocky Mount, Virginia, USA
- Latitude: 36.99 N; longitude: 79.89 W; elevation: 1232 ft (376 m)
- Heating degree days: 4228 base 65°F (2383 base 18.5°C); cooling degree days: 4158 base 50°F (2309 base 10°C); annual precipitation: 41 in. (1042 mm)
- Building type: K–12 educational facility
- Floor area: 3053 ft^2 (284 m^2)
- Completed: 2011
- Design team: Structures Design/Build (architects, contractor, Certified Passive House Consultant)

Context. As the first Passive House–certified public school in the U.S., the Center for Energy Efficient Design [CEED] was built to teach. Incorporated into a building-specific curriculum, CEED serves as a demonstration of environmental science and design principles for middle- and high-school students. Additionally, the building is open to interested designers, builders, and homeowners as a showcase of successfully integrated energy-efficient design strategies. Continuous, real-time building monitoring allows students to understand relationships between design, occupant behavior, and immediate environmental impact.

Key Design Features

Massing. A simple form both minimizes building footprint and reduces building surface area, thereby reducing heat transfer through the building envelope. In general, Passive House–certified buildings rely on low-surface-area forms to minimize envelope heat loss and infiltration. Any bump-outs and façade articulations are carefully considered and optimized for solar control. Depending on climate, building massing is optimized for passive solar heating.

Employing classic passive solar design principles, CEED's compact shape, strategic siting, and heavily glazed south façade capitalize on the heating benefits of the winter sun. Shown in Fig. 7.17, a permanent trellis system shades these south-facing windows from summer solar heat gain.

Fig. 7.17 *CEED's expanse of south-facing glazing takes advantage of winter solar heat gain. This and other passive strategies enabled this public school to reach net-zero-source energy through the addition of a small renewable energy system. (© Structures Design/Build LLC; used with permission.)*

Mechanical Systems. Mechanical systems in Passive House–certified buildings are characterized by their simplicity and efficiency. A small heat recovery ventilator (HRV) or energy recovery ventilator (ERV) is the most commonly used system to provide thermal comfort and a constant supply of fresh outdoor air. In residential buildings, air is typically supplied to living spaces and exhausted from kitchen and bathroom spaces; the ERV or HRV is centrally placed to minimize duct runs.

The mechanical systems at CEED address an interesting challenge common to nonresidential buildings: how to efficiently provide adequate air supply to variable-occupancy spaces. Challenged by limited U.S. equipment availability and Virginia's mixed humid climate, the design team implemented a two-stage variable speed ERV system. ERV intake air is first heated, cooled, or dehumidified using a water-to-air heat exchanger; this heat exchanger can circulate either solar hot water or brine from a passive ground loop. Stage two, a ground-source heat pump, is used for periods of higher occupancy, when additional cooling is required.

Validation. CEED is continuously monitored. Sensors measure wind speed, indoor and outdoor temperatures, relative humidity, solar panel and wind turbine performance, ground-source heat pump performance, CO_2 levels, and rainwater harvesting performance. The data, which are shown in Fig. 7.18, are shared publicly as a component of the school's mission in environmental education.

A thermal comfort survey, which was administered one year after occupancy, demonstrated overwhelming satisfaction with the building's indoor environmental quality: 0% of respondents reported dissatisfaction in all assessed categories, which included dry-bulb and radiant temperatures, humidity, air speed, and air and lighting quality.

Glasswood

Project Basics

- Location: Portland, Oregon, USA
- Latitude: 45.52 N; longitude: 122.78 W; elevation: 39 ft (12 m)

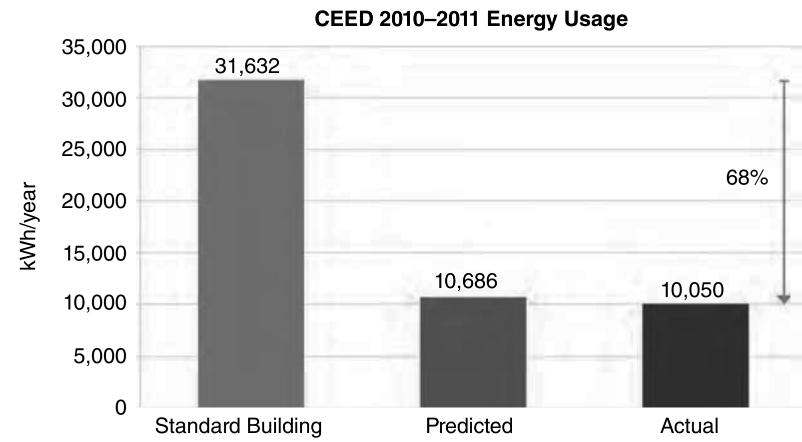

Fig. 7.18 *Post-occupancy energy monitoring data measured at the Center for Energy Efficient Design in Rocky Mount, VA. (© Structures Design/Build; used with permission.)*

- Heating degree days: 4428 base 65°F (2509 base 18.5°C); cooling degree days: 2790 base 50°F (1548 base 10°C); annual precipitation: 36 in. (914 mm)
- Building type: Commercial
- Floor area: 1397 ft^2 (130 m^2)
- Completed: 2012
- Design team: Scott Edwards Architecture (architects); Hammer & Hand (contractor, Certified Passive House Consultant)

Context. Glasswood, the first Passive House commercial retrofit project in the United States, brings energy performance to a 1916 building on the east side of Portland. The project's Passive House potential was clear from the start, as the framing was essentially the only usable component of the existing building. Through reconstruction of the building's envelope, the design team sought to preserve the historic aesthetic of the building while providing a modern, high-performance update to the materials and construction. The two-story building houses offices on the upper floor and a restaurant on the first. While the thermal comfort and energy efficiency of both floors of the building were drastically upgraded, only the top floor pursued Passive House certification.

(*a*) (*b*)

Fig. 7.19 *A comparison of before (a) and after (b). Glasswood's Passive House retrofit shows the preservation of the façade design and historic aesthetic. (© Hammer & Hand; used with permission.)*

Key Design Features

Superinsulation and Hygrothermal Performance. Like the cutting-edge 1970s houses from which the Passive House standard was derived, certified buildings feature highly insulated envelopes, with typical wall assembly R-values ranging from 35 to 55 Btu/hr ft^2 °F (7–10 W/m^2 K) and roof assembly R-values ranging from 60 to 90 Btu/hr ft^2 °F (10–17 W/m^2 K). Unlike their 1970s counterparts, however, modern enclosure assemblies are carefully analyzed for their hygrothermal performance to assess the degree of vapor diffusion through the assembly.

Shown under construction in Fig. 7.20, Glasswood's existing 2×4 (50 × 100 mm) wood stud wall was upgraded to a 12-inch (305 mm) double-stud framing system. The second stud wall was built inboard of the existing framing and serves as a service cavity. A 2-inch (50 mm) layer of EPS foam outboard of the existing framing supplements the thermal resistance achieved by the cellulose in the two wall cavities.

As the complexity of the assembly increases, so must the rigor of its hygrothermal analysis. Components must be thoughtfully organized to reduce the potential for vapor condensation and accumulation, which is a precursor to mold growth. In Glasswood, extensive hygrothermal modeling was used to verify the "vapor-open" nature of the assembly: While the assembly is both airtight and highly thermally resistive, moisture is allowed to dry to both sides.

Air Sealing. One of many energy-saving measures required of Passive House–certified buildings is a continuous air barrier. Great care (and much tape) is required to ensure that the "airtight layer," which includes floor, walls, and ceiling, remains free of both intentional and unintentional holes.

Shown in Fig. 7.21, Glasswood's airtight layer is formed by 0.5 in. (12 mm) OSB, which is carefully taped at its seams. This layer is placed between the two 2×4 (50 × 100 mm) stud walls. This strategic placement protects the airtight layer from weather and from occupant wear, and it minimizes necessary service punctures to the airtight layer, as the service cavity is placed in the innermost stud wall.

Energy monitoring in Glasswood reveals the importance of controlling plug loads. A circuit-by-circuit energy monitor was installed; the real-time feedback allowed occupants to keep wasteful loads in check and remain below their targeted annual energy use.

Thermal comfort studies were equally revealing. The original design did not include external sunshades, which resulted in excessive solar heat gain during the shoulder seasons. Rather than relying on the mechanical system to maintain comfortable temperatures, as the original design prescribed, the occupants installed external shades on the south-facing façade. The experience proved educational for the office occupants, who are building science professionals themselves; one occupant reports, "I think exterior shades are one of the most critical components of HVAC design."

Fig. 7.20 *A construction phase photo of Glasswood reveals the outermost 2×4 (50 × 100 mm), cellulose-filled stud wall before construction of the airtight layer. (© Hammer & Hand; used with permission.)*

Fig. 7.21 *Glasswood's airtight layer is made of 0.5-in. (12 mm) tiled OSB sheets, whose seams are carefully sealed with tape. The airtight layer was placed between the two stud walls for protection. (© Hammer & Hand; used with permission.)*

After this very simple modification to the initial façade design, occupants report very high persistence of thermal comfort with a low energy use.

Stellar Apartments

Project Basics

- Location: Eugene, Oregon, USA
- Latitude: 44.12 N; longitude: 123.22 W; elevation: 357 ft (109 m)
- Heating degree days: 4913 base 65°F (2781 base 18.5°C); cooling degree days: 2519 base 50°F (1402 base 10°C); annual precipitation: 46 in. (1168 mm)
- Building type: Multifamily housing
- Floor area for building type (6 units/building): 5626 ft^2 (523 m^2); 5069 ft^2 (471 m^2) conditioned floor area for Passive House building type
- Completed: August 2013
- Client: St. Vincent de Paul Society of Lane County
- Design team: Bergsund Delaney Architecture (architects), Meili Construction (contractor), SOLARC (energy consulting), Ecobuilding Collaborative of Oregon (energy consulting)

Context. The Stellar Apartments, a 54-unit affordable housing complex just west of downtown Eugene, Oregon, seeks to provide occupant thermal comfort and energy performance without the commonly associated rent premiums. Each of the complex's 12 buildings complies with the Earth Advantage Certification, but one building reaches further, targeting Passive House certification. Though the ambitious energy targets required by each of the standards raised the project's first cost, the choice to proceed was fairly easy for the client. Utility costs are rising faster than rental costs for consumers; thus, enhanced energy performance

__Fig. 7.22__ The front elevation of the Stellar Apartments, a portion of an affordable housing project that was built to the Passive House standard, features strategically placed and responsibly shaded windows. (© Bergsund Delaney Architecture and Planning; used with permission.)

reduces the monthly financial burden for low-income tenants.

Key Design Features

High-Performance Components. Envelope components in a Passive House building must meet minimum performance thresholds; these are informed both by energy considerations and by thermal comfort criteria, which limit the allowable U-values of glazed components.

The Stellar Apartments Passive House building envelope components are no exception. The U-values of the European tilt-turn windows are considerably lower than those of the glazing systems specified in the Earth Advantage buildings in the complex (and at a price). The higher performance reduces conductive/convective heat loss and radiant temperature asymmetry caused by cold glazing surfaces. While high-quality components typically have higher first costs, the payback periods are often relatively short. Furthermore, increased adoption of more rigorous building practices will only reduce prices and increase domestic availability of higher-performance components.

Thermal-Bridge-Free Detailing. More so than perhaps any other standard, Passive House design and construction require meticulous attention to detail. Careful detailing and construction of joints and attachment points minimize both thermal bridging and air infiltration. Figures 7.23 and 7.24 show window details from different buildings in the Stellar Apartment complex. The comparison illustrates the rigor of the Passive House approach relative to a somewhat-better-than-business-as-usual construction. The thermal breaks and layers of tape found in the Passive House detail are common, relatively inexpensive detailing modifications that improve thermal resistance and airtightness of connection points, as in the example shown.

Validation. Energy performance information was unavailable at the time of publication, as construction was just reaching completion. The local utility has provided \$20,000 to St. Vincent de Paul to support post-occupancy energy monitoring of two of the buildings in the Stellar complex (one Passive House building and one Earth Advantage building). The buildings will be monitored for a minimum of one year.

At the time of publication, the project team was performing the requisite post-construction blower door test. Results showed an airtightness of 0.50 ACH_{50}, below the 0.6 ACH_{50} required of the Passive House standard. Tests of the Earth Advantage comparison building showed substantially higher air leakage.

Each of these projects relied on extensive energy modeling to meet certification criteria. Feedback from the Passive House Planning

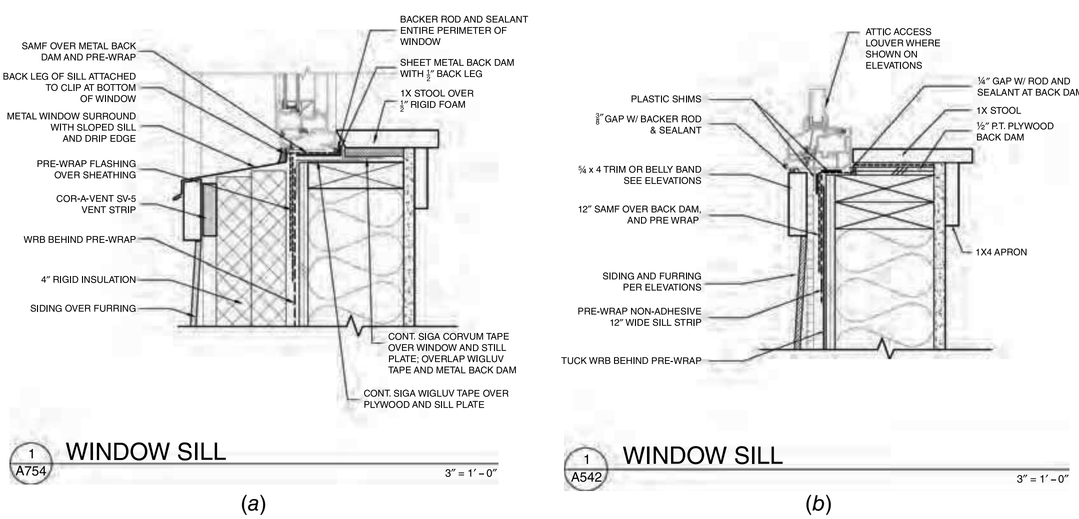

__Fig. 7.23__ A comparison of the windowsill details of the Passive House building (a) and the Earth Advantage building (b) at the Stellar Apartments. (© Bergsund Delaney Architecture and Planning; used with permission.)

(a) *(b)*

Fig. 7.24 *A comparison of window assemblies of the Stellar Apartments' Passive House–certified building (a) to those of a noncertified building in the same complex (b) reveals the significantly thicker walls and advanced window assemblies typical of Passive Houses. (© Alison Kwok, all rights reserved.)*

Package [PHPP], an Excel-based energy modeler, is often used as a design driver in Passive House design development, allowing project teams to understand the energy (and certification) implications of various design iterations. PHPP's accuracy has been verified by corroborating field measurements across a range of climate zones and building types.

Many Passive House design teams will supplement the PHPP with WUFI, a dynamic hygrothermal-modeling tool, and with THERM, which analyzes two-dimensional heat transfer through building details. In 2013, the developers of WUFI created WUFI Passive, an integrated energy modeler designed specifically for the Passive House standard, which combines the capabilities of the static PHPP model with those of the dynamic WUFI model to create a streamlined and more convenient Passive House modeling tool.

FOR FURTHER INFORMATION

Stellar Apartments [Bergsund/Delaney Architecture]: http://www.bdarch.net

Glasswood [Hammer and Hand]: http://hammerandhand.com/glasswood-passive-house-retrofit

Center for Energy Efficient Design [Structures Design/Build]: http://ceed.frco.k12.va.us/

Passive House Alliance U.S.: http://www.phaus.org

Passive House Institute U.S.: www.passivehouse.us

Passive House Institute: http://www.passivehouse.com

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Gordon, J. 2009. "The Aggressive Standard of a Passive House," *Dwell*, November 2009. http://www.dwell.com/green/article/passive-acceptance/