Passive House informed: The next level of energy efficiency in affordable housing

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ABSTRACT: In 2012, Bergsund DeLaney Architecture and Planning (BDA) designed an affordable housing community for St. Vincent DePaul Society of Lane County (SVdP) that included two six-unit buildings with identical floor plans and orientation, each constructed to a different sustainability standard: Passive House and Earth Advantage. Research groups from the University of Oregon School of Architecture (UO) conducted two studies, one that analyzed life cycle decisions made in the early design process and another that monitored and analyzed energy use post-occupancy. All of the research conducted by the UO was made available to the project team for review and use. The research has proved valuable not only to validate and support the decisions made during the design and construction of the Passive House, but also to inform future building design. This paper presents a framework to review the strategies used in the two case study buildings and determine recommendations for Passive House informed construction.

KEYWORDS: Passive House, Affordable Housing, Energy Efficient Design, Research Collaboration

INTRODUCTION

Affordable housing programs exist to subsidize tenant rent and assist low-income individuals and families from becoming house poor, but tenants are typically responsible for the cost of their utilities. As energy costs continue to increase, energy efficient design in affordable housing has become a high priority for owners looking to pass utility saving onto tenants. Over the past decade, funding for affordable housing has required participation in green building certification programs as a way to confirm a commitment to energy efficient design. As funding for affordable housing becomes more competitive, developers are willing to commit to higher levels of energy efficiency in order to stand out in applications for funding. In the Oregon, the most commonly used certification program is Earth Advantage.

In 2012, during the design process for a multi-unit affordable housing project Bergsund DeLaney Architecture and Planning (BDA) and St. Vincent DePaul Society of Lane County (SVdP) were approached to consider certifying one building in a multi-building project to Passive House standards. Due to a higher than expected return on awarded tax credits, the team was able to conduct a pilot project comparing two six-unit buildings with identical floor plans and orientation constructed to two different sustainability standards: Passive House and Earth Advantage. The Owner, Architect and General Contractor (Meili Construction) worked closely with a team of Passive House consultants to determine what strategies would be utilized for the Passive House building. The strategies proposed by the Passive House consultants and the Architect were weighed against constructability concerns brought forth by the General Contractor and operations and maintenance concerns represented by the Owner. The intent with the construction methods for the Passive House was to be as similar as possible, to typical multi-family affordable housing construction practices utilized in the Pacific Northwest.

1.0 RESEARCH RELATIONSHIP

Multiple research groups from the University of Oregon School of Architecture (UO) approached the project team about conducting studies to analyze life cycle decisions made in the early design process as well as monitor and analyze energy use once construction was complete. All of the research conducted by the UO teams has been made available to the project team for review and use. The research has proved valuable not only to validate and support the design and construction of the Passive House, but also to inform future building design.

This unique relationship between the University, a small architecture firm and a non-profit client results in a mutually beneficial research feedback loop. The UO research groups benefit from the ability to collect and analyze data from a tangible project while the architecture firm and the client benefit from research the team would not be able to otherwise afford to conduct or commission. The research collected and shared has increased the rigor with which the owner-architect team questions energy efficiency strategies and provides a basis to compare potential strategies against for Passive House Informed construction.

The first research study was a Life Cycle Assessment (LCA) commissioned by the City of Eugene with Eugene Water and Electric Board (EWEB), the local utility provider, in an advisory role. Both the City and EWEB financially supported the Passive House case study in various ways, including a financial contribution to the energy monitoring equipment installed in both case study buildings. The LCA was conducted shortly after the schematic design phase. The intent was to determine the environmental life cycle impact of the additional materials added to the building to meet the Passive House standard and

> to ensure that improved construction (such as increased insulation) can be 'paid back' in increased building efficiency instead of inadvertently shifting the environmental burden from the use phase to the construction phase with no overall lifecycle environmental savings (Moore 2011, 2).

The results of the study showed that,

> even though there are significant environmental impacts associated with the additional construction materials for a Passive House upgrade, these impacts would be offset by the increased building efficiency (Moore 2011, 1).

The second study conducted is in progress and is a two-year data collection and analysis comparing the energy usage between the constructed Earth Advantage and the Passive House buildings. A report of the energy lessons from the first year has been recently prepared and issued to the Owner. In the first year, the data collected has shown that the

> Passive House units used 59% less *heating* energy than the Earth Advantage units; we assume that this translates into approximately 63% better than (the Oregon Energy Efficiency Specialty) code (Kwok 2014, 6).

An interesting result from the first year lessons is that the Passive House uses 36% less *total* energy than the Earth Advantage building. The target savings anticipated for the Passive House is 60% better than Earth Advantage. The conductors of the study feel that "occupant behavior is a strong factor in the energy usage" (Kwok 2014, 13). During the second year of the study they hope to ascertain if "occupant knowledge and awareness of how Passive House and Earth Advantage buildings function and their specific goals may help to further lower energy consumption of the high performance buildings" (Kwok 2014, 13).

2.0 LESSONS LEARNED

The Owner, General Contractor, Architect and Passive House consultants met for a debriefing session six months after project completion. The purpose of the meeting was to determine if the Passive House standard was appropriate for affordable housing. While acknowledging the utility cost savings to the tenants, the team also discussed the 30% difference in initial construction cost between the Passive House case study building and the Earth Advantage case study building. When faced with the choice of developing more units of housing to a level of efficiency still exceeding code or building fewer units of housing that are Passive House certified, the Owner decided that they cannot justify the added construction cost of Passive House. This reality, that meeting Passive House standards is not financially feasible on future projects, has inspired the establishment of a framework to review the strategies most applicable for Passive House *informed* construction.

The data collection and analysis has shown that the energy savings for Passive House construction is real and that it is significant. The project team recognized increased affordability for tenants via lower utility bills was a primary reason for participating in the Passive House case study. With this information at hand, the Owner plans to commit to many Passive House design and building techniques going forward. For example, the team benefitted from the opportunity to learn how to work with continuous exterior insulation, anticipating that it will eventually be a code requirement (as of the release of the 2014 Oregon Energy Efficiency Specialty Code (OEESC), it is still not required) and will include this insulation in future projects. The team also agreed to continue pursuing enhanced air sealing on future projects. While the General Contractor admitted that the enhanced air sealing measures, especially around the windows, was one of the biggest challenges with a steep learning curve, they feel that they could anticipate a significant labor savings if the process was repeated in the future because of what was learned on the case study project. The General Contractor identified HVAC as the biggest cost challenge to the project. The ERV system used came with increased complexity to meet the Passive House certification requirements, which was a disincentive to the Owner and the General Contractor for using an ERV system in the future.

3.0 PASSIVE HOUSE INFORMED FRAMEWORK

The analysis of the strategies used in the Passive House case study building (PH) and Earth Advantage case study building (EA) case study building (Fig. 1) guided the Passive House Informed Framework (PHIF). The case study experience impressed upon the team that the passive elements of high performance building are the most beneficial in multi-unit affordable housing and this principle influenced the creation of the Passive House Informed Framework. It is organized in a manner similar to the Passive House Institute's principles. The categories include: insulation and reduced thermal bridging; air sealing; air exchange; high performance windows and solar gain.

Figure 1: Passive House case study building (left), Earth Advantage case study building (right).

3.1. Insulation and thermal bridging

The insulation specified at the Earth Advantage (EA) case study building (Table 1) included blown-in blanket insulation in 2x6 stud walls at 24” (60.96 cm) on center (R-23), 16” (40.64 cm) of glass fiber loose fill insulation in the ceiling (R-49) and the 11-7/8” (30.48 cm) truss joists at 24” (60.96 cm) on center filled with batt insulation (R-38). Rim joists and headers were insulated with 2-1/2” (6.35 cm) of EPS - Expanded Polystyrene insulation (R-11).

At the Passive House (PH) case study building (Table 1), the same blown-in blanket insulation was used in the 2x6 stud walls at 24” (60.96 cm) on center (R-23) and the rim joists and headers were insulated with 2-1/2” (6.35 cm) of EPS (R-11). These were the only areas with the same insulation levels at the case study buildings. The ceiling was insulated with 27” (68.58 cm) of glass fiber loose fill insulation (R-84), the 11-7/8” (30.48 cm) truss joists at 24” (60.96 cm) on center were filled with glass fiber loose fill insulation (R-50) and the entire building was covered with 4” (10.16 cm) of Exterior Rigid Polyisocyanurate continuous insulation (R-27) (Fig. 2). Additionally, the concrete stem wall foundation was insulated from the exterior with 4” (10.16 cm) of EPS (R-18) and from the interior with 3” (7.62 cm) of EPS (R-13.5).

Figure 2: Continuous insulation over WRB on PH (left), siding directly over WRB on EA (right).

The value of super insulating buildings is clear from the energy monitoring information collected from the case study buildings. The Passive House Informed (PHIF) buildings currently under construction have increased insulation. The insulation values are scaled back from the Passive House standards in some areas and in some areas remain the same as in the Earth Advantage case study building (i.e. the crawl space).

Blown-in blanket insulation is used in the PHIF 2x6 stud walls at 24” (60.96cm) on center (R-23). Continuous insulation has been added to the exterior of the building to reduce thermal bridging (Fig. 3). An advanced framing strategy takes advantage of the rim joists at the edge of the floor framing for window and door headers; this allows the full wall thickness of insulation above windows and doors. Smegal and Straube provide further justification for this assembly.

> The use of 1” thick insulation at the exterior side… does not significantly alter the constructability of the wall. The use of thicker layers of exterior insulation… (i.e. thickness > 1”) tends to increase the complexity of detailing around windows, doors and other penetrations through the wall (Smegal and Straube 2010, 35.)

During the preparation of construction documents, the team determined 1” (2.54 cm) of rock wool continuous insulation would work without modification to the firm’s standard window detail. Rock wool insulation was recommended by Walsh Construction Co., a Pacific Northwest based general contractor with significant green building experience in the region, because 1” (2.54 cm) thickness the is still breathable in the event that moisture gets into the wall. While on site for the PHIF window mock-up, the window and door detail was modified in such a way that it could grow to accommodate additional inches of continuous insulation for future projects.

Figure 3: Continuous insulation over WRB on PHIF.

The PHIF roof/ceiling assembly is composed of roof trusses at 24” (60.96 cm) on center with 5/8” (1.58 cm) Type X gypsum board attached to the bottom of the roof trusses. In the Passive House (PH) case study building, a layer of 1/2” (1.27 cm) plywood was added between the roof trusses and the gypsum board to support the additional weight of the R-80 glass fiber loose fill insulation. The project Structural Engineer determined that 19-1/2” (49.53 cm) of loose fill insulation (R-60) can be supported by the gypsum board ceiling without adding an additional layer of plywood, creating a PHIF assembly that is sufficiently insulative without adding extraneous material (Table 1).

Table 1: Insulation R-values.

	PH	*EA*	*PHIF*	*OEESC*
Attic (Flat Ceiling)	R-84	R-49	R-60	R-38
Walls (Cavity)	-	R-23	-	R-21
Walls (Continuous)	R-23+R-27ci	-	R-23+R-4ci	R-13+R-3.8ci
Raised Floor	R-50	R-38	R-38	R-30
Exterior Stem Wall	R-18	-	-	-
Interior Stem Wall	R-13.5	-	-	-

3.2. Air sealing

At the Earth Advantage (EA) case study building, a weather resistive barrier system was used over the plywood and an air sealing checklist was developed in house to meet the requirements of the Energy Star Thermal Bypass checklist required for Earth Advantage certification. The blower door test was conducted for the whole EA building and resulted in 3.5 air changes per hour (ACH) when tested at 50 pascals, exceeding the required 6 ACH. Foam and caulk were the most frequently used materials to fill any gaps around penetrations in the EA building shell. The Passive House (PH) case study building functioned as a six-sided box with plywood at the walls, ceiling and crawl space taped at the seams to serve as the air barrier (Fig. 4). The PH building exceeded the required 0.6 ACH and tested at 0.5 ACH @ 50 pascals for the whole building. Tape was used most frequently to address any penetrations in the PH building shell.

Figure 4: Taped plywood seams throughout PH.

The General Contractor self performed all of the air sealing at the Passive House and the Earth Advantage case study buildings. Air sealing has been handled in various ways on different sites throughout the years. The article *Air-Sealing Tips and Tricks* states “you can’t count on crew members or subs to do their own air-sealing as the job moves along. There has to be someone on the job who oversees all of the trades to make sure the air-sealing gets done, and who is willing to give this role the focus and attention to detail it requires” (Nordbye 2012, 25). At the case study building, the effectiveness of air sealing was related to the control the GC took over the measures. Since this is a means and methods item, the most beneficial thing an Architect can do is devote a pre-construction meeting to the importance of air sealing.

In the Passive House Informed Framework (PHIF) buildings currently under construction, an air barrier house wrap system is used as the WRB. The seams of the house wrap are taped to serve as an air barrier at the exterior walls with a tape from the air barrier manufacturer (Fig. 5). The plywood seams could be taped to meet the same goal. At the Passive House (PH) case study building, the tape recommended by the Passive House consultants was a high quality imported tape. It was very expensive for the quantity used and therefore is not being used on the buildings currently under construction.

Figure 5: Air barrier house wrap with taped seams at PHIF.

In the Passive House (PH) case study building all penetrations through the roof/ceiling assembly were eliminated and all light fixtures, fire sprinklers and smoke detectors were moved onto the interior walls. This presented multiple challenges related to conventional construction methods and trade experience with typical roof/ceiling penetrations. The next big challenge anticipated is to address treating the ceiling as an air barrier.

During the debrief after the case study was complete, the General Contractor informed the team that conducting the blower door test for the whole building after drywall was installed was very difficult with the extremely low target for air changes. The General Contractor felt that air sealing at the party walls and testing unit by unit would've made the process easier. To meet the Passive House certification standard, a larger box is a more efficient box and therefore the party walls received no additional air sealing. At a project concurrent with the case study buildings by the same architects, the seams at the plywood sheathing were taped on the exterior walls and foam and caulk was used at each party wall in a multi-unit building to treat each unit as a small box. Though the project had no continuous insulation, the resulting blower door test results ranged from 2.9-3.5 ACH50. The team anticipates even better test results from the PHIF buildings currently under construction.

3.3. Air exchange

The result of building tighter buildings is that fresh air needs to be introduced and stale air exhausted. At the Earth Advantage case study building, trickle vents in windows were used to introduce fresh air paired with a continuous running exhaust fan in the bathroom to exhaust stale air. At the Passive House case study building, an energy recovery ventilator (ERV) was used to bring in fresh, filtered air and exhaust stale air with 96% heat recovery efficiency (Fig. 6). For the Passive House case study building, there were only two approved ventilation units available in the country. To use anything else would have incurred a 15% devaluation from the manufacturer's claimed efficiency and put certification out of reach. Once installed, balancing the ERV proved complicated because factory pre-sets needed to be overridden so that the equipment ran at lower rates than the lowest available setting.

Figure 6: ERV at PH (left), examples of passive air inlets (center), trickle vent at window head at EA (left: Kwok 2014, center and right: Author 2013).

In the past, the problem seen with trickle vents at windows is that tenants will tape over the vents to prohibit the 'draft' at the window and therefore override the fresh air coming into the unit. Given the cost and complexity that came with balancing the particular ERV to meet the Passive House standard, the Owner is prejudiced against using this additional piece of mechanical equipment in the immediate future. The Passive House Informed Framework (PHIF) buildings are using two passive air inlets (Fig 6) per dwelling unit paired with trickle vents in bedroom windows to supply fresh air and rely on the continuous running bathroom fan for exhaust.

It is important to note that in the Oregon climate heat recovery ventilators (HRV) could effectively be used but that for the Passive House (PH) case study building an ERV was required based on model inputs and trade-offs. The Architect is investigating the use of HRVs and ERVs at upcoming projects.

3.4. High performance windows and solar gain

At the Earth Advantage case study building, a double glazed vinyl window was used throughout. The windows were either single hung or fixed and had an average u-value of 0.29 and a solar heat gain coefficient (SHGC) of 0.29. At the Passive House building, a triple glazed fiberglass window was used throughout. The windows were either casement or fixed and had an average u-value of 0.21 and a SHGC of

0.50. Sunshades over the windows on the south and east facades provide shade in the summer and allow for passive solar to enter the building in the colder winter months. The windows in both of the case study buildings were from Pacific Northwest based manufacturers.

As part of the debriefing session with the General Contractor, the team learned that the windows were one of the top three areas for increased cost and difficulty in the Passive House building. The first year results at the Passive House (PH) case study building show that the Earth Advantage case study apartments are kept approximately 2˚F warmer than the Passive House units. The study speculates that less thermal stratification in the Passive House units and less air leakage resulting in less draft are factors in the difference (Kwok 2014). The triple-glazed casement windows would likely contribute to the improvement in both cases. The Architect feels that money spent on better windows is in line with the concept of focusing on the passive elements of high performance buildings but our owners and contractors are not ready to make the change to triple glazed windows. The Passive House informed buildings currently under construction will have single hung, double-glazed, vinyl windows and a u-value of 0.25.

Joe Lstubrick advises against passive solar, instead “you should do very, very low SHGC’s, around 0.2, in your glazing” (Lstubrick 2014, 2). The SHGC’s in the windows used at the Passive House Informed Framework buildings are 0.29, even with the improved u-value. As this region is not a cooling climate, there is not a great benefit from super low solar heat gain coefficient glazing.

CONCLUSION

In 2014, Stellar Passive House Apartment Building in Eugene, Oregon became the first multi-unit affordable housing project to be certified by Passive House Institute US and the entire project team was excited to learn from this unique opportunity. The experience has changed the way that all of the parties look at energy efficiency in affordable housing. In response to the question of whether it makes financial sense to build to the Passive House standard for affordable housing, the team has concluded that it does not. The team agrees that it is important to continue building increasing energy efficiency in a cost and material efficient manner.

One of the most important aspects of this experience is that data is being collected from the case study buildings, analyzed by a third party and shared with the project team so that all parties benefit from the application of research and applied knowledge. The first Passive House Informed Framework project is under construction by Meili Construction for St. Vincent de Paul in Eugene, Oregon and includes a building type with a similar design to the Stellar Apartments case study buildings. It is the hope of the Architect that the same energy monitoring equipment will be installed in the first PHIF buildings so that the impacts these measures have on energy savings can be compared across like projects and further inform future strategies.

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