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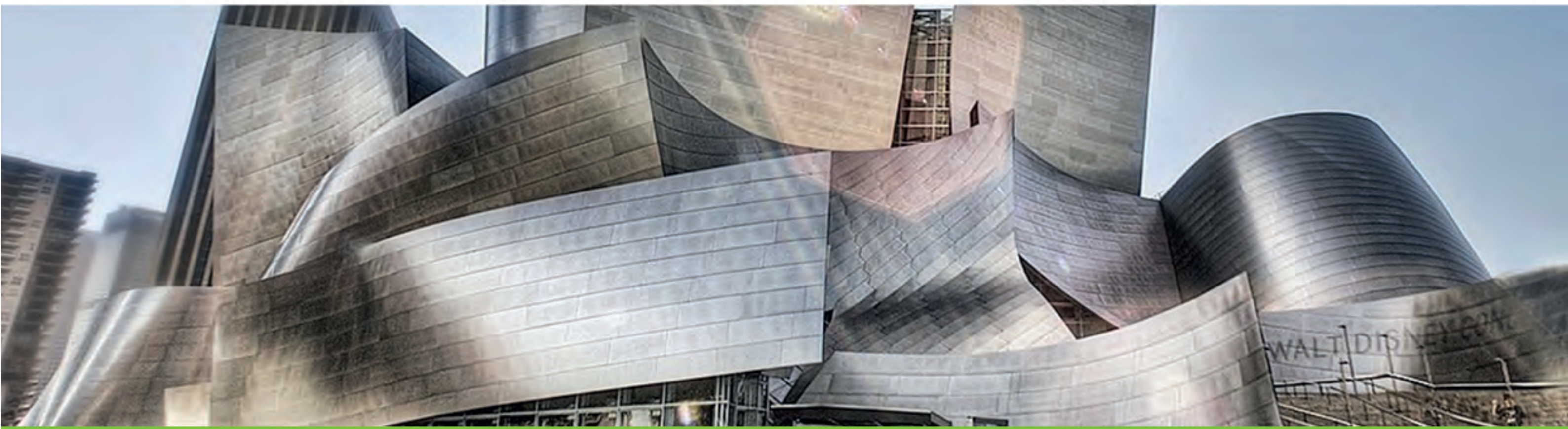

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CONTENT

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Affordable and cost-effective high-performance housing – the field of dreams eco community

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Abstract

This paper deliberates on the development and design of a 20-unit, affordable residential development for the Northern Utah Cold Climate Zone. Located in Kearns, Utah, it is named the **Field of Dreams Eco Community**. A holistic, collaborative, and interdisciplinary approach to building led to a carefully designed, highly energy-efficient, sustainable and cost-effective development, where the focus is on Genius Loci oriented, integrated passive energy design. The interdisciplinary design process included energy modeling and simulation as a design tool and a close collaboration between the author as the architect/researcher, contractor, jurisdiction (planning department) and structural and mechanical engineers delivering a context-based and regionally rooted architecture. The emerging buildings minimize the common dependence on fossil fuels and are expected to be 55% more efficient over the Utah-applicable IECC 2015 residential energy code built-to-code benchmark building. Among others, the following paragraphs will focus on the envelope development, which contributes to the explicit combination of high performance and affordability.

Keywords: Affordable Housing, High Performance Housing, Structural Insulated Panels, Strategic Design Approach, Collaborative Design Process, High Performance Building Envelope

1. Introduction

The collaborative and interdisciplinary community research project Field of Dreams Eco-Community (FoD) in Kearns, Utah came into life when the author approached Salt Lake Valley Habitat for Humanity (SLVHFH) with the proposal to develop and design better performing buildings for Habitat's clientele, who come from a low-income demographic background. According to SLVHFH, 60% of its clientele are single women with an average of two children, with the mothers working full-time to ensure the family's survival. Most dollars saved by such families are redirected into educational support for their children, to provide them with better future opportunities in their future lives. To be eligible for the SLVHFH housing program, each low-income applicant must complete a minimum of 225 'sweat equity' hours with the non-profit organization, working alongside other volunteers from the community that supports SLVHFH's mission. Each applicant must also participate in homeowner education classes and workshops to prepare for homeownership, before a Habitat house is then purchased through an interest-free, 30-year Habitat for Humanity loan [1]. This enables families to disengage from rental dependencies (with moving frequencies as high as twice a year due to the rules of the rental market), and to advance into a mortgage ownership situation. Monthly mortgage rates are often considerably lower than the previously paid monthly rental fees, and the families can now take pride, ownership and responsibility for their very own building and communities, which certainly stabilizes the lives of the entire family and especially those of the children.

To date, the typical SLVHFH house supported these families with code standard buildings that provided sufficient shelter for their inhabitants. Their layouts followed outdated, single-story design guidelines, with an emphasis on fast and inexpensive construction, and therefore a lack of *efficiency, resilience and sustainability*. In 2014, SLVHFH was able to purchase the former *Kearns American League Western Boys Baseball training field* in the township of Kearns within the Salt Lake Valley, which had been falling into disrepair over many years. The applicable R-1-6000 zoning allowed for the subdivision of the land into ten, 560 m^2 / 6,000 square feet (sq.ft.) parcels, which legally allowed for a maximum density of ten single-family detached residences on said premises.

2. Methods

2.1 Project goals

From an urban density standpoint, but particularly from a space-to-person ratio for affordable housing, it appears questionable to offer single-family detached residential buildings with up to 185 m^2 / 2,000 sq.ft. living space to a 3 to 4-person household on the affordable market, all this being constructed on 560 m^2 suburban parcels. As a result thereof, and based on previous research and construction experiences, in which the author proved that high-performance residential buildings can be locally constructed at or below market rate cost, the goals for the Field of Dreams Eco-Community were defined very ambitiously:

1. Exploration possibilities of higher than recent-zoning density in an existing part of the township of Kearns.
2. Development of a resilient, sustainable and affordable micro-neighborhood.
3. Each unit to be designed to a three-bedroom, 1½ bathroom, 139 m^2 / **1,500 sq.ft.** house.
4. Maximum purchase cost to not exceed **$150,000** including cost of land for the future homeowner.
5. Daily energy consumption to heat and cool the house and to provide domestic hot water (DHW) must be equal or less than **$1.50** (this does not include metering and general utility fees).
6. Design and construct the buildings to the U.S. Office of Energy Efficiency & Renewable Energy **Solar Ready** standard, which requires a building to be designed and built with integrated electrical and mechanical features that will streamline a future integration of photovoltaic panels [2].
7. Use of robust and durable construction and construction materials, to protect low-income homeowners from increased maintenance cost during the lifetime of the building.

As a result thereof, the author decided to design the buildings as close to the Passive House standard as budget would allow.

Figure 1: An aerial overview of the Field of Dreams Eco-Development in the township of Kearns, Utah, USA

2.2 Interdisciplinary, collaborative team approach

In the affordable residential market segment, correct pricing is essential to significantly influence the market and develop a successful case study; end users are simply not able to pay a larger premium for high performance buildings. To reach the challenging project goals of energy-efficiency, resilience *and* affordability, the early composition of the team was critical to the entire process. With SLVHFH acting as client and general contractor (GE), an excellent fit for an important position within the development team was already filled. Based on SLVHFH's experience in the very specific affordable housing market, some of their long-term subcontractors such as the civil engineer and landscape architect could instantly be tied into the process. Due to SLVHFH being new to the field of energy-efficiency building, and the considerably higher performance requirements for the FoD case study buildings, the team had to identify new structural and mechanical engineers that were familiar with the chosen building material and the author-driven development of specific HVAC systems. Another important player in the collaborative and interdisciplinary effort turned out to be Salt Lake County Development Services (SLCDS), which is the legal jurisdiction that manages zoning changes and is responsible for zoning and building permits in Kearns.

Figure 2: Typical pre-FoD SLVHFH single-story home

Led by the author as the design and project architect (DPA), the team met frequently on demand during the entire planning and design phase. Major non-standard design steps were checked for code-conformity with SLCDS. Team members were present in accordance with their respective tasks. DPA was responsible for the Passive House design and Sefaira energy modeling and simulation, which were used to evaluate and control major design steps. SLVHFH was the direct consultant to DPA and provided support in best practice construction methods and cost efficiency. In their function as contractor, SLVHFH's collaboration was essential to define and alter standard construction methods and standard materials and components at affordable cost, which promises high market-transferability for future projects of the case study. For this reason, DPA also emphasized the application of available U.S. market systems and components to ensure further adaptability. All components specified are available on the marketplace, but need to be combined and configured in new ways, since passive, low-tech strategies are still relatively new to the Utah residential building market.

2.3 Design philosophy

Albert Einstein once said: *"Everything should be made as simple as possible, but not simpler."* In today's world, we have lost this kind of approach in many regards, including the ability to concentrate on the essence of things. This applies to architecture too and, with few exceptions, is well documented in the built environment with which we surround ourselves. Especially in the field of residential design and construction in the U.S., architectural design is repeatedly confused with the functional organization of large quantities of spaces, which, at their best, conform to code, but lack spatial and architectural quality. Often, the results are pricey, poorly performing buildings with a low spatial quality and an expected lifetime of less than 30 years. To find a way back to the essence of good architectural design, the author has based his design philosophy on the following four pillars, which have been applied to the extend possible to the FoD case study project:

1. *Simplicity* is the key to successful design, sustainability, and high performance in architecture and urban design;
2. A *holistic*, interdisciplinary approach leads to superior architectural design;
3. The *quality* of the detail and its execution determines the level of quality of the overall work;
4. Successful architecture and urban design include aspects of both *regional and global* contexts.

2.4 Design process

2.4.1 Site and site development, building placement

The former *Kearns American League Western Boys Baseball training field* project site is located in the township of Kearns, about 18 km south of downtown Salt Lake City. It was purchased by SLVHFH in 2014 for $400,000 and is surrounded by typical, semi-suburban, 1.5 story tall single-family residential buildings. The neighborhood consists of a mixed White (60.2%) and Hispanic or Latino (31.7%) population with an average age of 29.5 years [3] – it therefore represents an ideal community for simple, affordable starter homes for first time home buyers, even though the target group for the typical Habitat house differs from that described above. The parcel is about 87,000 sq.ft. / 8,100 m^2 or 0.81 hectare in size. Originally zoned to R-1-6000, it allowed for a maximum density of ten single-family detached residences, which would have provided a perfect setting for the typical single-story, outdated SLVHFH homes. However, to reach the cost goal of a maximum purchase price of $150,000 per home for the project alone, the 'business-as-usual' strategy would have cut $40,000 out of the already tight budget, leaving $110,000 for site development, infrastructure and the actual building itself.

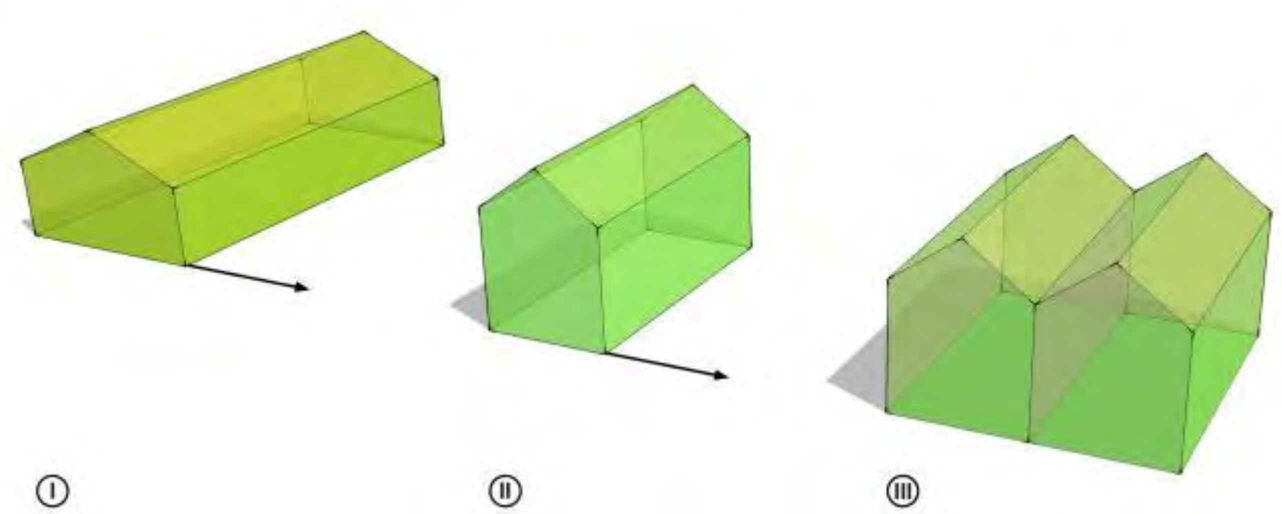

Figure 3: Conceptual approach for building densification

By proposing a 100% higher density in two-story buildings that are organized in duplexes, property-related cost could be cut by 50%, leaving $130,000 for land development and building, an amount that appears to be much more realistic to reach the project goals. In working closely with SLCDS and the civil engineers, the team was able to rezone the land to an R-1-3000, which now allows 20 units on 3,000 sq.ft. or 280 m^2 individual parcels. With Utah anticipating the fastest population growth of all states in the U.S., the Salt Lake metropolitan area along the Wasatch Front is under enormous pressure to provide more affordable housing over the next decades. By providing homes for twice as many families, the FoD strategy will make a small contribution to reducing the stress on the market, and, more importantly, will provide a research-based case study project that documents the (rather difficult and time-consuming) process of rezoning and urban densification for affordable housing.

With SLCDS requiring project documentation down to the duplex construction document level, the rezoning process alone took two years. However, the team was able to utilize project hurdles in the said process to the project's advantage. Instead of developing the land into standard 3,000 sq.ft. parcels owned by each individual future homebuyer, an ownership model was developed in which each of the 20 units is individually owned only to the exterior walls. The space in direct adjacency around the buildings, which include the front and back yards and the driveway, are defined as a *Limited Common Area*. These areas are still under direct ownership responsibility of each individual owner, but also under the influence of the Future Home Owner Association's (HOA) rules, the so called Covenants, Conditions & Restrictions (CC&Rs), which will be established by SLVHFH as the project developer towards the finalization of the first units in fall 2017. The same applies to the access loop road on the outer edges of the development, which is also part of each individual 3,000 sq.ft. parcel, but is established as a legal, binding easement to ensure continuous access to all buildings in the future, also under the legal rules of the CC&Rs.

This rather complex ownership model strategy is justified through a large, FoD community-owned central green space located between the north and the south row of duplex buildings. The space will provide a 1,100 m^2 / 12,000 sq.ft. open playing field for sports, recreating and community activities, two bocce courts, a picnic area with pavilion, and two playgrounds for toddlers and children. The central green area will be open to people beyond the FoD community, thus also providing a neighborhood recreational space to people in the immediate surroundings of the site.

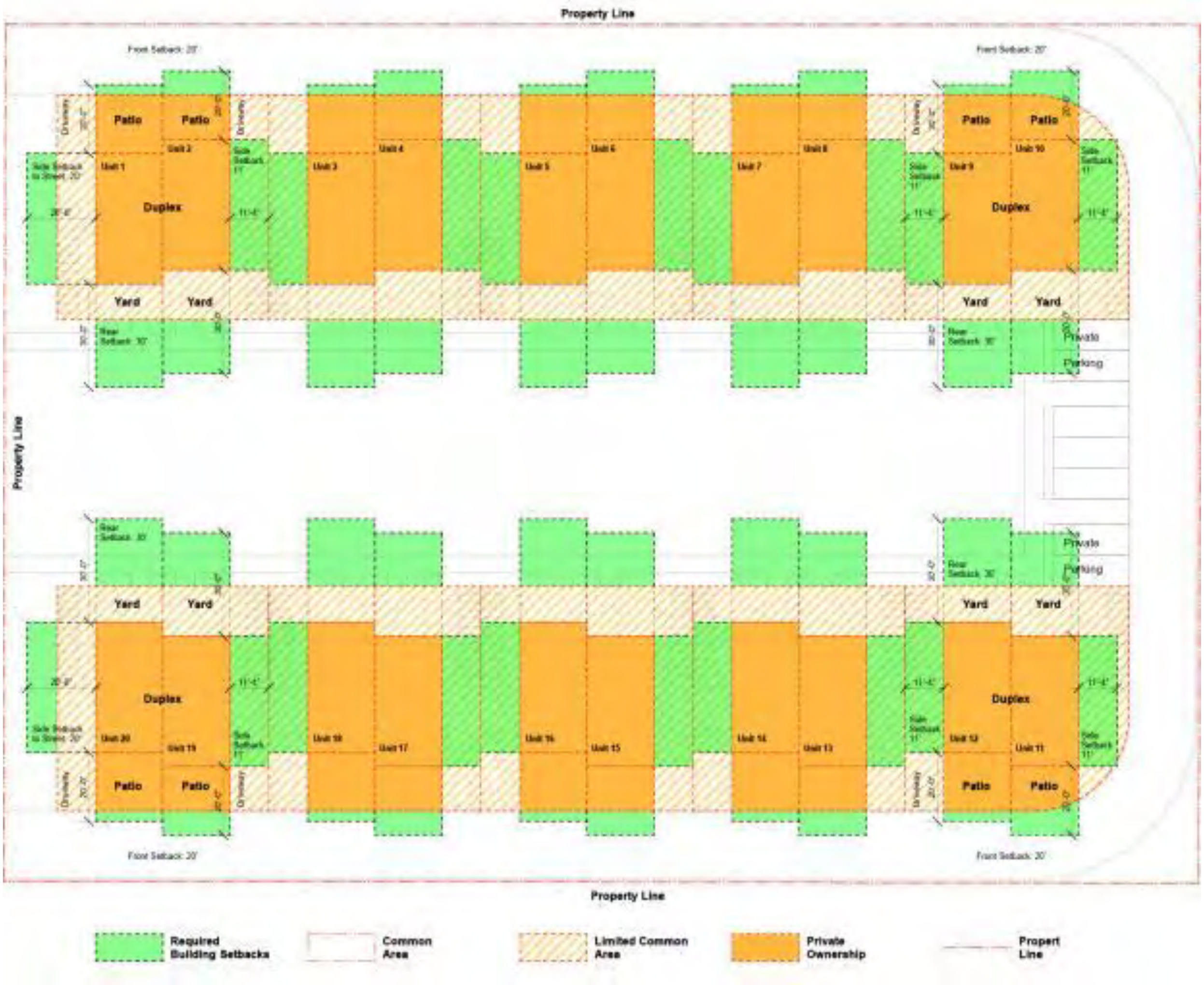

Figure 4: Different areas as defined by specific ownership model

2.4.2 Envelope assembly methods and performance

As part of the passive design approach towards higher energy-performance in each unit, common construction methods on the Utah residential market were analyzed for their feasibility to achieve Passive House standard. This paper focuses on the structural envelope components, but the overall process incorporated passive design measures for a specific building orientation on site (a simple measure that is still persistently ignored by most residential builders in the U.S.), functional optimization, windows, roof and other component analysis. The predominant residential construction method in the southwestern states of the U.S. is wooden balloon framing, with building heights up to 7 stories, where the first one to two stories are commonly made from cast-in-place concrete. With Kearns being located in the ASHRAE [4] climate zone 5 (which is similar to ASHRAE's international climate zone 5, to which Zurich and many German cities are assigned), the minimum code requirement for wood-framed exterior walls is a 2x4 wood stud, with actual dimensions of 1.5" x 3.5", or 3.8 cm x 7.6 cm. These wooden stud walls are usually sandwiched between a ½" / 12 mm OSB board on the outside, which is covered with a moisture barrier (building paper) and exterior siding, and a ½" / 12 mm drywall board on the inside, with a moisture barrier between the drywall and the stud. This minimal threshold between the conditioned inside of a building and the elements on the outside allows for 3.5” or 7.6 cm insulation material between the studs, which are usually spaced 24” / 60 cm on center. The R-Value for a 3.5” batt insulation as the common insulation material is rated at R-13 Btu/(hr ºF sq.ft.), which equals a metric U-value of 0.48 W/(m^{2}K), but quickly degrades to less than the R-6 or U 0.95 overall wall value if air penetrates the envelope assembly due to the many gaps that are usually unavoidable in standard U.S. construction. In addition, each wood stud acts as a thermal bridge every 24” / 60 cm, therefore the R-value of the general overall assembly might be as low as an R-9 or a U 0.63. For a high performance building, these values need to be compared to Passive House qualified wall assemblies for the Salt Lake Valley location of about R-42 or U 0.14.

Structural wood framing offers a variety of advantages, among which cost-effectiveness, speed of construction, and knowledge among trades weigh most. However, energy-performance and air-tightness – two of the most important criteria to construct a high-performance building – are not among the advantages of wood-framed buildings. Insulation value inefficiencies can be overcome by doubling up wooden stud walls, e.g. using a structural 2x6 on the exterior side of the wall assembly, with a non-load-bearing 2x4 offset to the inside by a distance that allows for a desired insulation value in the wall. Offsetting the studs minimizes thermal bridging, and using blown-in blanket (BIB) fiberglass or cellulose insulation eliminates the problem of air pockets in the assembly, thus contributing to a considerably better component performance. Due to the number of seams, gaps, nail holes and other construction inefficiencies of wood-framed walls, it is much more challenging though to achieve superior air infiltration rates towards a Passive House performance of at least 0.6 ACH50. Therefore, the author decided to push for Structural Insulated Panels (SIPs) as the predominant envelope material.

2.4.3 Structural Insulated Panels

Figure 5: 6” wall and 12” roof Structural Insulated Panels for the Snow Creek Project on-site in Park City, Utah, 2011

Structural Insulated Panels, or SIPs, are relatively new to the Utah market, even though their application originally dates back to the 1930s, when the U.S. Forest Products Laboratory started research and testing of such stressed-skin panels, resulting in the assembly of a first, small SIPs building in Madison, Wisconsin. Garnering enough attention to bring in First Lady Eleanor Roosevelt to dedicate the house at that time, the structure became a testament of durability for SIPs panels, withstanding Wisconsin’s severe climate until 1998, when the house was demolished for a larger structure on the University of Wisconsin campus [5].

Between the 1930s and 1950s, architect Frank Lloyd Wright and one of his students, Alden B. Dow, further experimented with the specific material assembly, contributing to further research and later dissemination of the panels onto the U.S. construction market. Negative experiences with SIPs in very cold climates such as Canada or Alaska led to criticism of the material in the 1970s, when the panels were used to construct very airtight building envelopes, in which a necessary fresh-air exchange did not happen due to the lack of heat recovery systems, resulting in severe mold problems and component disintegration. With the latest, widespread availability of effective Heat and Energy Recovery Ventilation systems (HRV or ERV) on the U.S. market, stressed-skin panels such as SIPs present a perfect, cost-effective building material for high performance buildings.

Common SIPs are manufactured from an insulated EPS foam core, which is sandwiched between two structural OSB facings. Load bearing and shear forces are taken over by the OSB boards, which are laminated into a structurally sound assembly with the foam. The foam core takes over the function of insulation, and since the panels are manufactured under factory-controlled conditions, they can be manufactured to nearly any building design and requirement. SIPs panels have no solid structural components inside the assembly, thus thermal bridging is minimized if the right splice method is being applied, using foam splices or similar as shown in Figure 06. Because SIPs panels are glued and nailed when assembled on-site, their construction seams are airtight, with additional airtightness to be achieved by taping all exterior or interior seams after assemblage of the panels. SIPs come in standard thicknesses that echo the thickness of standard wood-framed walls to allow for compatibility – often, a standard application combines SIPs for exterior walls and roofs coupled with interior regular wood framing walls. SIPs can be manufactured to thicknesses up to 14 ¼" or 36.8 cm, with standard EPS performance of up to R-53, or a U-value of 0.10. Using BASF Neopor, a graphite-enhanced EPS foam in which the graphite coating of each EPS cell reflects heat back into or to the outside of the building, performance can be enhanced from an average R-value of 3.85 per inch to R-4.7 per inch, which, in the case of the FoD project, results in a SIPs panel value of R-36 or U 0.15 with a 8 ¼" thick panel, and a roof value of R-54 or U 0.10 with a 12 ¾" panel combination. Additional R-value is added through finish materials such as drywall on the inside and a cement board rain screen facade on the outside. According to Passive House Planning Package (PHPP) software, the final component performances, which include interior and exterior surface film resistances, are as listed below:

- Wall assembly: R-40.3 Btu /(hr ºF sq.ft.) / U 0.14 W/(m^2K)
- Roof assembly: R-57.6 Btu /(hr ºF sq.ft.) / U 0.1 W/(m^2K)
- Slab-on grade concrete floor on 8" EPS: R-30.7 Btu /(hr ºF sq.ft.) / U 0.185 W/(m^2K)
- Windows (see below under 2.4.4): U-value of 0.23 Btu /(hr ºF sq.ft.)

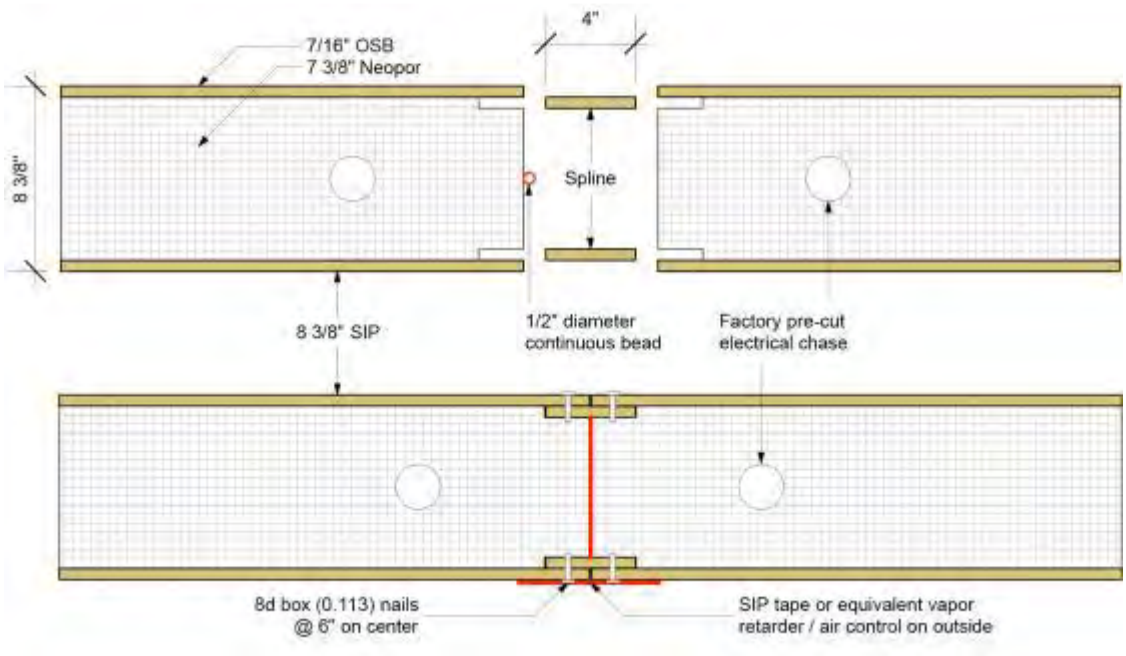

Figure 6: Thermal-bridge free splice method to connect SIPs panels

2.4.4 Windows

High-performance building envelopes require a balanced choice of components that include wall, floor and roof assemblies and windows and doors with high-performance frames. To maximize energy performance and interior comfort, openings have to be precisely adjusted to site-specific light conditions, orientation, passive solar winter heat gain, and predominant wind direction. Glass quantities *and* qualities should be adjusted to orientation wherever possible, providing larger glazed areas with a high solar heat gain coefficient (SHGC) to catch as much solar energy as possible during the cold winter months. These windows need to be shaded with additional external sunshades during the summer months, to avoid overheating and lessen energy consumption on the mini split cooling system. Windows oriented towards the north, east and west should receive an effective low-emissivity coating with a high SHGC, to reflect heat from the inside of the building back inside during the winter months and to keep the sun radiation out during the summer months. To achieve Passive House standard at the location, combined window-frame U-factors have to be within the range of 0.12 to 0.18 Btu/(hr ºF sq.ft.). Opportunities to utilize European double or triple pane tilt-turn windows with wooden or UPVC frame were researched during the design development phase, but turned out to be way above the limits of the given budget. As a compromise, a U.S. brand of double pane, argon-filled casement and awning units with UPVC frames were chosen, with an average U-value of 0.23 Btu/(hr ºF sq.ft.), and SHGC according to their specific orientation.

2.4.5 Energy modeling

Located in the Utah Cold Climate Zone, or ASHREA climate zone 5, Kearns within Salt Lake Valley is elevated to 1,410 m / 4,625 feet above sea level. Weather data shows an average low temperature of -3.3ºC in January, and an average high temperature of 32ºC during summer months. Typical minimum winter nighttime temperatures drop as low as -15ºC in January, and raise to 38ºC during mid-summer days, with summer nighttime temperatures only dropping a few degrees due to the city's high desert location. Humidity values range from daily averages of 74% in the winter months to 22% during the summertime [6], which represents a dry high desert climate that makes the higher summer temperatures relatively acceptable to the Valley's inhabitants. With an average of 3,059 annual sun hours [7], Salt Lake Valley is sun-soaked even during the winter months, thus representing perfect conditions for additional winter solar heat gain. Overall, these values characterize the range in which a building in the location has to perform – a heating-dominated climate with a cooling component during the hot and dry summer months.

To predict the building's performance regarding the defined energy goal of no more than $1.50 a day for heating, cooling and domestic hot water energy use, the Sefaira energy modeling and simulation tool [8] was utilized throughout the design process. Sefaira is a real-time building performance and daylighting tool that comes as a plug-in for architectural 3D modeling software such as SketchUp and Revit. The energy modeling explorations for FoD were conducted in SketchUp as the architectural 3D-software, and were combined with the author's sustainable design classes at the University of Utah, to extensively explore the building seeking the highest performance at the given budget.

Beginning with the component performance data of the typical, build-to-code standard building, the building used 74,244 kBtu/sq.ft./yr for heating, 31,384 kBtu/sq.ft./yr for cooling, and, among others, 71,838 kBtu/sq.ft./yr for equipment such as the standard, tank-based water heater, standard forced-air furnace, and air conditioning system and standard appliances. Even though some of this equipment is rated to pass the Energy Star performance benchmark, its performance is well below what could be achieved with a better choice of and smarter combination of systems – as was done for the FoD units. As an example, earlier research in a similar test house within the Salt Lake Valley showed that a standard, Energy Star rated, 67% efficient gas hot water tank performs to this efficiency only when being used in the wintertime and in combination with radiant floor heating, which requires constant production and use of hot water. During summer time, when hot water is required only a few times during the day for showers or other DHW usage, these poorly insulated tanks keep the water constantly at 50-60ºC, which is when their actual performance drop to 33% or less. With DHW being one of the larger energy consumers in a residential building, this issue can be overcome by using 98% efficient condensing on-demand gas hot water heaters, preferably in combination with radiant heating, as they will be built into each FoD unit.

Sefaira energy modeling showed that the code-standard building with 2x4 walls and energy star windows (U-value of 0.32 Btu/(hr ºF sq.ft)) requires a daily energy cost of $7.20, which adds up to $216 per month, presenting a serious financial challenge for a low-income family to heat and cool a house.

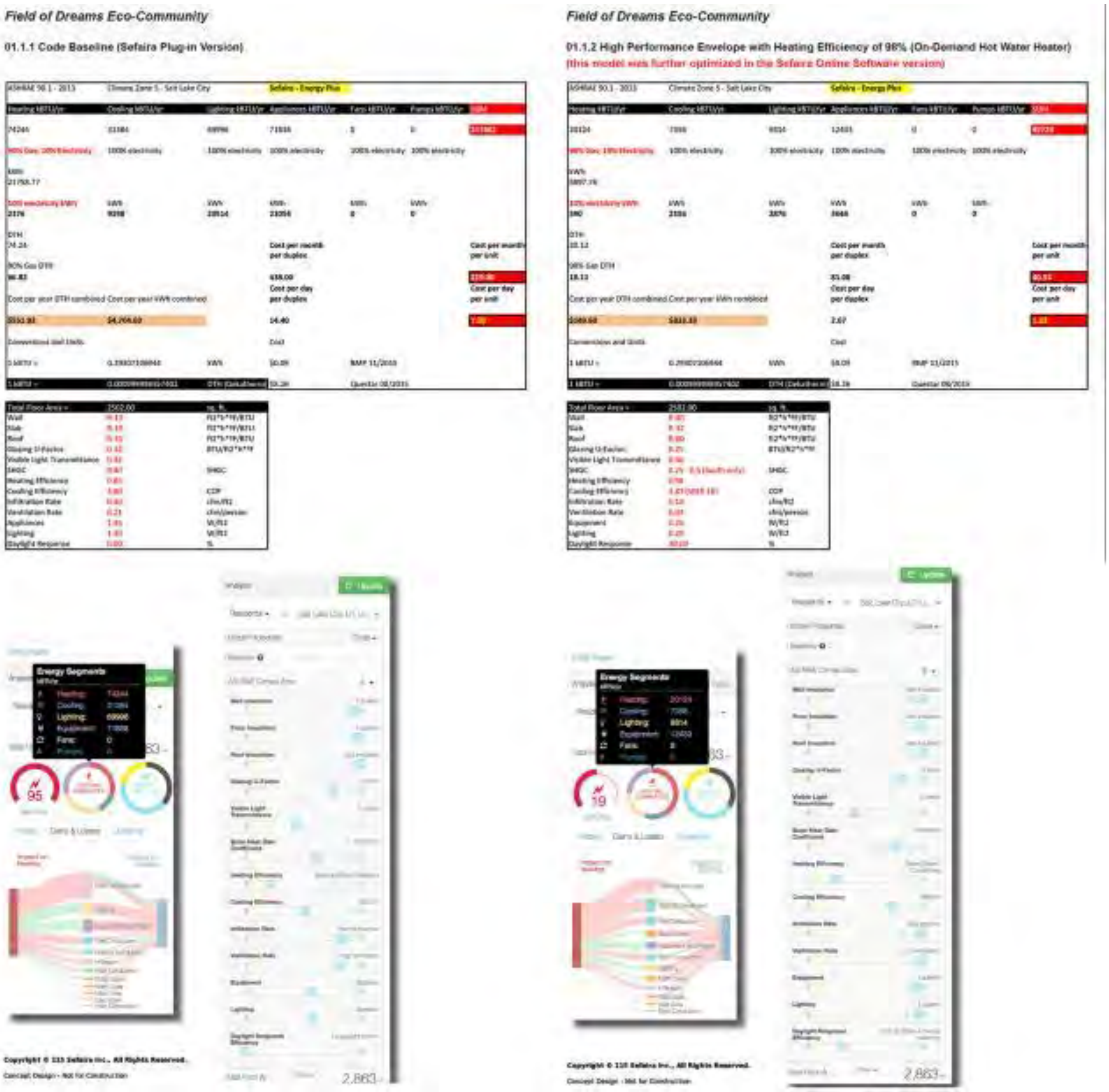

Figure 7: Sefaira energy modeling and simulation results

With close-to-Passive House performance measures implemented in the FoD units, energy demand for heating was cut to 20,124 kBtu/sq.ft/yr (27% of the original value), cooling was lowered to 7,358 kBtu/sq.ft./yr (23%), and equipment to 12,433 kBtu/sq.ft./yr (17%). Even though the latter included much better performing equipment and appliances, it is also important to note that with a better passive performance, thus higher energy performance of the envelope, the heating and cooling load requirements for the system components dropped considerably. As a result, the expected daily average cost for heating, cooling and DHW dropped to $1.33 or roughly $40 per month, which is a much more realistic energy cost for a low-income family that has to survive on as little as $10,000 a year in some cases.

To ensure long-term durability of the exterior building components, the team also explored the humidity behavior of all wall and roof assemblies and compared the different behaviors of a SIP wall versus a wooden stick frame wall. WUFI Pro 5.2 results showed that for all assemblies, the moisture content would perform within the range of a durable building component, even over a long-term perspective of several decades. Figure 08 below shows results for the north wall assemblies alone, which is the most critical orientation in

Salt Lake's climate. The SIPs walls will have a slightly lower initial moisture level than the stick-framed walls (0.5 lb/sq.ft. compared to 0.6 lb/sq.ft.), but within one year, both wall systems will perform very similar, range between 0.2-0.35 lb/sq.ft, which represents healthy data for a durable, moisture-free assembly.

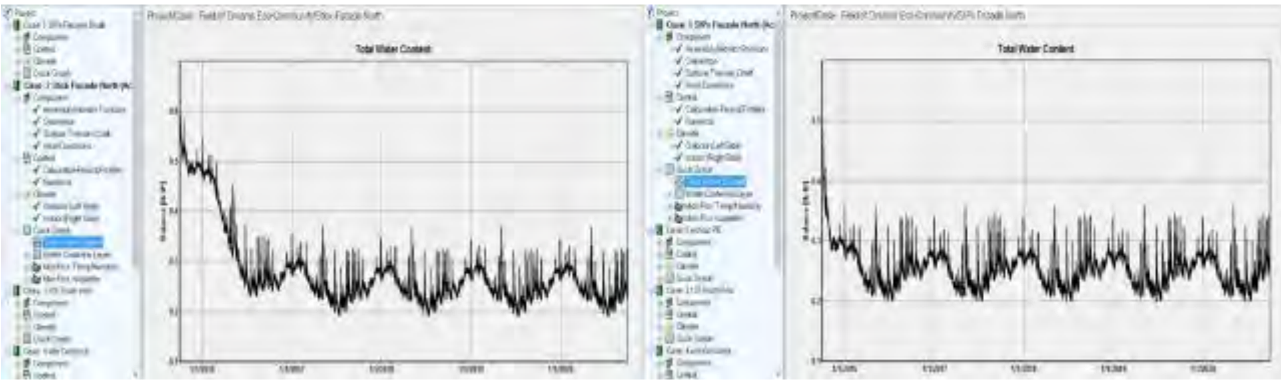

Figure 8: WUFI Pro 5.2 results for moisture content in a 12" stick-framed wall (left) and a 12" SIPs (right) over 5 years

3. Conclusion

As proven in previous projects, the most powerful tool to reach the project goals for FoD is its highly collaborative, integrated design and development process, which, in tandem with energy modeling and a close collaboration between architect, contractor, and structural and mechanical engineers, delivers a context-based and regionally rooted architecture. Due to the number of 20 units developed and constructed successively, FoD project duration is anticipated to last for several years, with each project phase finalized acting as a pilot for the subsequent project phase. With performance values only representing simulations at this point in time, Post-Occupancy monitoring will show the actual performance of each unit, which will also include user behavior as a difficultly predictable unit. Realizing FoD duplex by duplex will allow for the analysis of each project phase, to influence the subsequent building to the point where the author hopes to document a best-practices model for highly efficient and affordable homes for families in need. The project has already caught large media attention on the regional scale, leading to additional, research-based case study projects with the City of Salt Lake City and other stakeholders to push the envelope of affordable, well-performing buildings even further. This paper represents the first documentation of a series with to follow, in which the further process, construction experiences, findings, and actual performance will be discussed. With the first units expected to be finalized in fall 2017, the author expects that the Field of Dreams Eco-Community will help to move the residential market in the Intermountain West and beyond towards high-performing, affordable homes.

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