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Passive House Performance Standards and Climate Considerations

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Abstract

Optimizing energy performance of buildings requires a multi-disciplinary team approach to integrating architecture with the systems that condition the environment inside the building. The popularized passive house design criteria have provided a road map to achieving lower energy use in buildings for almost two decades in Germany and for nearly a decade in the United States. Passive House standards have been formally utilized and documented in certification of buildings and informs the design of low-energy buildings through the use of scientific analysis of weather and climate data along with solar exposure of the site to inform the building's site orientation, shape, and envelope level of insulation and glazing to drive requirements for energy and electricity lower in buildings. There has been criticism in the past however, that the standards for passive houses were developed without regard to extreme climate conditions outside of temperate climate typically found in Germany. In recent years, with a wide variety of climate zones represented in the United States, the Passive House Institute of the United States (PHIUS) formed a Technical Committee in conjunction with Department of Energy (DOE) to study climate zones in relation to the established standards and propose variations appropriate for those locations that are better suited for optimized energy performance. The acknowledgement and study of Passive House Standards and climate zone application by the PHIUS Technical Committee and the DOE is a step in the right direction for inspiring design teams and owners in other regions to pursue nearly net zero and net zero designs.

Keywords: Passive House, Energy Efficiency, Superinsulation, Building Envelope, Airtightness, Climate

1. Introduction

Buildings in the United States account for almost 40% of energy consumption and 72% of electricity consumption, with the residential sector leading commercial sector in consumption [1]. After buildings are constructed and turned over for occupancy they are typically in operation and contribute to the national energy consumption rate for decades. With high consumption rates reported for buildings, responses to climate change, and increasing costs of natural resources, energy efficiency has become an industry focus following decades of varying levels of interest and attention toward improving our conservation of valuable natural resources.

Initial engineering design theories to achieve lower energy consumption first emerged in the 1970s as a reaction to the 1973 oil crisis. Over time, these design theories have been further developed and evolved with implementation and real world testing in construction driven by building regulations that support conservation of natural resources and promote use of renewable energy sources. Prior to the energy crisis, homes and buildings were designed and built with little concern for energy cost; single pane windows were common and insulation of walls and roof assemblies were considered adequate with R-13 and R-20 component values respectively ("R" represents thermal resistance of a building component). Through the advancement of building technology and passive house concepts implemented and proven, windows are now minimally double-pane rather than single pane; standard wall insulation is now a minimum of R-20 and roof insulation is R-32 [2].

Concepts of passive solar design were introduced to the public in the 1970s following the energy crisis as a response to the crippling economic affects this event had on the western world and its dependence on fuel consumption. Passive solar concepts scientifically informed building orientation and form optimization for energy efficiency of buildings by being responsive to the specific climate and site and controlling solar heat gain of the building. These design concepts were a first step towards energy optimization and were limited to architectural elements of a building. Ideas of increased insulation or "super insulation" of the envelope emerged later in the 1980s. Following the emergence of passive solar design and superinsulation was the development of Passivhaus standards formalized in Germany by Wolfgang Feist who formed the Passivhaus Institute in Darmstadt, Germany in 1996 with the goal of creating ultra-low energy buildings. In 2007 the German trained architect, Katrin Klingenberg advocated Passive House standards in the United States and is responsible for establishing the Passive House Institute of the United States (PHIUS) with standards resembling the licensed German Passivhaus standard [3].

While Passive House standards have been revered for their simplicity they have also been criticized for rigidity and limited application to buildings found in temperate, less extreme climates. It is acknowledged that the standards were created without much regard or study for application in extreme climate zones [4]. In recent years, with a wide variety of climate zones represented in the United States the Passive House Institute of the United States formed a Technical Committee in conjunction with Department of Energy to study climate zones in relation to the established standards and propose variations appropriate for those locations that are better suited for optimized energy performance [5].

2. Climate Specific Design for Energy Efficiency

2.1. *Passive House Standards by Climate Zone*

In late 2011, Passive House Institute of the United States (PHIUS) formed a Technical Committee to develop an adaptation of the standard and the committee introduced Climate-Specific Passive Building Standards for the United States Department of Energy (DOE) in March 2015 in an attempt to drive buildings closer to net zero utilizing passive measures. These are preferred measures that result in increased occupant comfort, durable construction, improved health and resiliency, and can be cost effective. To achieve net zero energy facilities it has been established that renewable energy systems are necessary to get there.

Passive design principles outlined in the previous section were first pioneered in North America following the oil crisis of the 1970s and later refined in the 1990s in Europe. The principles have been tested and proven to be generally effective in reducing heating and cooling loads on buildings significantly as compared to conventional construction. As a result, the Passivhaus system was developed in Germany with strict parameters shaped around the climate of the country rather than acknowledging diverse climate types found in other regions. When implementing Passivhaus standards as developed in Germany there were many cases where design decisions had negative results in thermal comfort and cost effectiveness for the end results. Therefore, the inclusion of these principles in building construction in the United States has been slow in adoption in many regions of the United States.

One of the main critiques of the German based Passivhaus standard's passive/conservation performance metric used as a guideline for developing the building envelope and systems for space conditioning criteria is not set up for responsiveness to a diverse climates and energy markets found across the United States. This standard was originally established for use in Germany, in a climate that has moderate heating and cooling requirements. Theoretically Passive House standards can be achieved in any climate zone however, attempting to do so in extreme climate conditions can be so prohibitively expensive that the costs to do so would not be justified over the life of the building[4]. These concerns along with the invested interest of encouraging designers and owners in all climate zones to work towards achieving near net zero results in buildings created this opportunity to study the standards and their cost effective application in the range of climate types found in the United States.

Since 2007, PHIUS has promoted the use of the European based energy metrics for buildings constructed in the U.S. and Canada with over 100 projects completed in various climates and meeting the criteria two main issues were identified: 1) Different cost structure implies a different economic optimum, and 2) Interaction or criteria and climate misled designers [5]. The first issue is related to the blanket standard building metric of 15kWh/m^{2}yr (4.75 kBtu/ft^{2}yr) annual heat demand that is derived from central Europe as there is a clear break point of cost-competitive economics however, in the U.S. there is not a clear cost-optimized metric for all climate zones and regions where it would be cost competitive to take costs out of heating and cooling systems to place in the envelope. The second issue is concerned with the relationship between degree-days and peak design temperature. These factors are weakly correlated and greatly vary by climate, especially in areas away from the coasts where peak conditions can be extreme when compared to degree-days. In the projects completed since 2007 it was found that designers for projects outside of marine climates used the annual-demand route for calculations 92% of the time whereas projects within marine climates used annual-demand 42% of the time. Annual demands can be lowered further in the U.S. than in Europe through over-glazed façade designs because of the greater solar resource [5].

The objective of the study conducted by the DOE and Technical Committee was to validate climate-specific passive house standards and criteria for space conditioning (limitations on heating and cooling loads) while preserving a high level for energy reduction targets and remaining economical feasibility within the region of construction. The three standard principles of focus in the study were:
Airtightness – criteria for superinsulation of building envelopes that assures prevention of moisture intrusion that can lead to failures of construction.
Source Energy – cost competitive levels for heating and cooling load limits with a focus on conservation.
Space Conditioning – requirements structured to guide designers toward passive measures.

2.2. *Airtightness*

The airtightness criteria standard was reviewed against climate data due to concerns about moisture intrusion and mold risks with an airtight building. The proposed change is from a limit of 0.6 ACH50 to 0.05 CFM50 per square foot of gross envelope area (or 0.08 CFM75). This allows the airtightness requirement to scale appropriately based on building size [5].

2.3. *Source Energy*

Limits on source energy were reviewed with consideration of global carbon dioxide emission budgets set by the Intergovernmental Panel on Climate Change (IPCC). Changes were proposed for accuracy and fairness in calculating energy limit factors such as:
Per-person limitation has been set as opposed to the previous square foot of floor area in residential projects.
Correction of the source energy factor to 3.16 for grid electricity in the calculation protocol for consistency with the United States national average.
Lighting and miscellaneous plug-load default of 80% of the Residential Energy Services Network standard has been adopted.
Source energy limit is set to 6200 kWh per person per year and the committee will be looking into tightening that requirement to 4200 kWh per person per year in a few years.
Allow for onsite photovoltaics or other renewable energy systems to be accounted for the same way as solar hot water by applying the limit on the source energy to the calculated net of the estimated fraction of onsite renewables [5].

2.4. *Space conditioning*

Space conditioning criteria was considered from an economic feasibility standpoint with changes proposed, such as:
A shift to climate-specific mandatory thresholds for annual heating and cooling demands and peak loads that help to target a "near-optimal sweet spot with slightly more energy savings than Building Energy Optimization (BEOpt) software's calculated optimum cost. This change and use of BEOpt will ensure efficiencies will be reasonably cost-competitive.

The reference floor area will be simplified, representing "an inclusive interior-dimension floor area" [5].

The results of studying these updated measures provides a performance-based, cost-effective standard that will reduce the national average energy consumption in buildings by approximately "86% for heating and 46% for cooling, with a peak load (systems size) reduction of 77% and a peak cooling load reduction of 69% as well as total source energy reductions for buildings consistent with limiting global temperatures from warming by more than 2 degrees Celsius" [5].

To achieve these savings, heating and cooling load limits calculations were restructured to be climate responsive. It is recommended that designers use Building Energy Optimization (BEopt) Software developed by National Renewable Energy Laboratory (NREL) for residential construction pursuing passive house and net zero. The tool assists designers in developing a climate specific energy saving design that is cost optimized using the National Residential Energy Efficiency Measures database embedded in the program. The software will provide the heating and cooling load performance data and will "curve fit that data to local climate parameters such as degree-days and design temperatures. The optimizations are constrained with strict requirements on air-tightness, and minimum window U-values, to ensure that building durability and winter comfort are not compromised in the search for energy savings" [5].

Formulas derived from the study for each climate type can be used in energy models to help set the criteria for heating and cooling as long as the climate information for the location is known. Previously set energy and airtightness standards were evaluated and changed to be scalable with the building envelope's surface area rather than volume of interior space and space conditioning criteria remains the same. Residential projects source energy calculation will be scaled per person and based on design occupancy.

PHIUS has published an online climate specific performance targets data tool for the United States as a result of the study. This tool is searchable on a map with more than 1000 locations identified with performance metrics calculated to help designers arrive at a climate specific design that is energy aggressive and cost effective (see Figure 1).

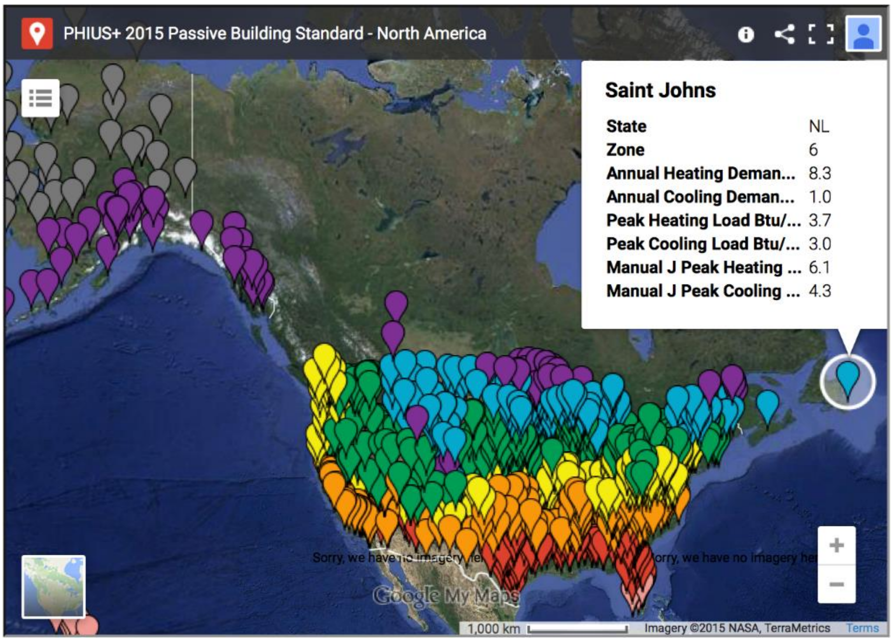

Figure 1: Passive House Institute of the United States – Passive Building Standard, climate specific targets data map [6].

As a result of this study DOE and PHIUS has provided a road map to design buildings for net zero that is better suited for specific climates found within the U.S. In designing a Passive House facility design teams take an integrated approach that will still focus first on passive means of improving the building through its envelope design then selecting mechanical equipment that will further target reductions in heating and cooling energy use [7].

3. Conclusions & Future Research

Without the oil crisis of 1973 prompting the need for energy independence and a focus on conservation of natural resources, the building sector would be contributing the higher energy consumption rates without concern for sustainability or resilience. Today Passive House Standards are in place as well as other stringent regulations and standards that are required by select municipalities and for government projects. Additionally, proactive owners who want to lower their consumption and save on energy costs are also demanding changes in the way buildings are designed, constructed, and operated.

This paper presents the Passive House Standards that have been utilized in the building sector largely for residential and smaller commercial construction for nearly two decades in Europe and one decade in the U.S. Much has been learned through the successes and failures of buildings entering the Passive House certification process throughout various climate zones. Successful achievement of certification in the past has been challenging for buildings in locations of extreme climate types. The acknowledgement and study of Passive House Standards and climate zone application by the PHIUS Technical Committee and the DOE is a step in the right direction for inspiring design teams and owners in other regions to pursue nearly net zero and net zero designs.

The recommended changes to the Passive House Standard as a result of the study is an area that could be studied further for application particularly in hot-humid climates and cold climates where relying on passive principles mainly with reduced mechanical assistance has been cost-prohibitive in many cases. Study of other energy efficient designs and experimental technologies implemented in buildings located in these climate zones were reviewed as a part of this research and would be valuable to study against a traditional passive house approach for comparison. Case studies in these regions could prove additional or alternative passive house principles are necessary for building design in these locations.

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