

Compact or Dispersed? Examining the Effectiveness of Low Surface-to-Volume Ratios

Karlla Dreser¹ and Tim Frank¹

¹Kennesaw State University, Atlanta, GA

ABSTRACT: In a United Nations 2013 survey tracking World Sustainable Development Challenges, a global 'one size fits all' approach to sustainable development was distinguished and precluded from policy frameworks as regional priorities, objectives and paths toward sustainable development were notably diverse. Regional specificity is particularly evident in the formal and spatial disposition of vernacular buildings that respond directly to climate zone characteristics in that area. Today, despite the proven effectiveness of these past approaches, sustainable building guidelines have embraced the belief that buildings are more efficient through the widespread adoption of system building technologies, compact building forms and the subsequent reduction of surface to volume (S/V) ratios. This trajectory relies heavily upon interior building systems and exterior envelope technology, endowing much of a building's performance to the integrity of these components to ensure thermal comfort. However, in some climates, like temperate profiles with hot and humid summers, this approach may not produce the most energy efficient solutions.

To test the validity of this direction, this paper systematically explores two structures in the Southern U.S., a distinctly temperate climate with hot and humid summers, to ascertain whether designing compact structures is an appropriate strategy for energy savings, especially when this approach contradicts lessons offered by vernacular structures built in the same region centuries prior. This comparative analysis examines the Sadler House, a 19th century modified dogtrot located in McCalla, Alabama with a S/V ratio of 0.41 and the LEED Platinum RainShine House, a 21st century house located in Decatur, Georgia with a S/V ratio of 0.24. The results indicate the spatial disposition of the 19th century house outperforms that of its 21st century successor when inheriting the same interior and exterior system characteristics. The outcomes of this analysis reexamine vernacular strategies and stimulate the conversation pertaining to widely accepted sustainable design principles.

KEYWORDS: southern building performance, surface to volume (S/V) ratio, mixed mode systems, spatial disposition

INTRODUCTION

Sustainable architecture seeks to design buildings that are less harmful to the environment during construction and life span operations. The building industry's patterns of energy consumption and greenhouse gas emissions make its impact on today's environmental crisis clear, requiring reconsideration regarding how buildings are designed, constructed and managed (Berardi, 2015). Today's sustainable design practice incentivizes the use of compact building forms, reducing the building surface area relative to the spatial volume enclosed in order to facilitate thermal control over indoor environments. The surface to volume (S/V) ratio measures the area of a building envelope defining the conditioned spatial volume. The lower the ratio, the more compact the form and the less exterior envelope used to enclose a given unit of interior space. This strategy focuses on the continuity of hermetically sealed thermal envelopes and mechanical systems that provide steady-state interior environments, many times overlooking how passive building strategies can exploit rapidly renewable energy sources (Lechner, 2014). Approaches toward building permeability such as dispersed volumes and mixed mode spatial dispositions are frequent in vernacular structures in the Southeast but are often abandoned in contemporary construction. Therefore, this paper aims to examine these seemingly oblique approaches in search of the best way forward for sustainable development in the Southern U.S..

In recent decades, the pursuit of sustainable design outcomes has generated new interest in vernacular structures because of their performance characteristics. These buildings are able to address their environmental context and climatic needs without advanced technologies and materials (Fathy, 1973). The use of building performance simulation (BPS) tools has allowed researchers to learn from their pre-industrial predecessors by extracting valuable information from vernacular structures through the systematic observation of boundary-state observations in a shared domain. These tools allow building scientists to measure a building's reliance on high-tech systems and to assess low-tech opportunities when offsetting the use of high-grade energy sources in providing occupant comfort. Therefore, the desire to realize the full potential of these emerging toolsets motivates the work and is best situated through the following questions.

Primarily, can we utilize a universal one-size-fits-all approach in contemporary development even when the basic premise runs oblique to vernacular practices? In addition, are the advancements in the post-industrial world being used to their fullest capacity while acknowledging valuable lessons offered by our pre-industrial predecessors? A few rebuttals to the questions, examined through the lens of the sustainable development in the Southern U.S., are taken up in this paper.

The overarching goal of the research is to enhance the discussion of sustainable strategies by examining whether compact building forms and sealed envelopes can work in the context of ever-advanced systems in the spectrum of building technology. The long-term objective of the work is to offer BPS enhanced methodologies that can be used by researchers to extract engrained knowledge from vernacular structures and to test those lessons with state-of-the-art analysis tools to enhance thermal comfort without using high-grade energy sources. This paper examines the reduction of S/V ratio in Southern U.S. structures, testing its impact on building performance through simulation tools. It does this through the comparison of two southern residential structures, the pre-industrial Sadler House and the contemporary RainShine House. Implanted within both structures are aspects of the southern dogtrot typology that is tailored to passively moderate the temperate southern climate with hot-humid summers. The Sadler House is recognized in the National Register of Historic Places, while the RainShine House is one of the first LEED-platinum certified single-family residences in the southeast.

1.0 BACKGROUND

Through the study of vernacular architecture, it is possible to recognize generalizable characteristics about how builders used first-principles building strategies to moderate climatic conditions around the world (Fitch 1990). Lacking technological resources, climate-specific passive building techniques were developed over time by early societies, dictated by constraints of climate, these approaches lead to innovated low tech building models in order to achieve thermal comfort (Zhai and Previtali, 2010). In the Southern U.S., the humid temperate climate presents unique comfort challenges including enhanced cooling and dehumidification due to intense summer heat, heavy rains and humid air. Responsive design strategies are present in examples of vernacular architecture of the South. Pre-industrial southern building typologies such as the dogtrot and the bungalow provide comfort to inhabitants through basic architectural solutions like maximized protection from intense radiation through shading and ventilation to dissipate heat and humidity from indoor spaces (Kemp, 1990). Characteristics such as spatial dispersion and permeability of the building envelope are also commonplace in vernacular southern building systems to enhance the comfort of interior spaces (Coch, 1998). Together, these strategies aim to make buildings thin and permeable, thus increasing envelope area to enhance thermal comfort without the use of mechanical or technological means such as air conditioning and dehumidification systems.

Currently, the use of mechanical cooling systems has become ever more commonplace in the building industry (Addington, 2003). With the technological advancements of industrial building systems like heating, ventilation and air conditioning (HVAC) equipment, a noticeable shift has occurred in the design of buildings. Strategies for promoting interior comfort now emphasize hermetically sealed and tightly controlled indoor environments, forgetting the lessons offered by vernacular structures (Singh et al., 2009). Today, in the "Sustainability Era", even though approaches may vary, many recommendations tend to prioritize innovative mechanical systems, super insulation of the envelope and reduction of S/V ratios (Ionescu et al., 2015; Ching and Shapiro, 2014). Envelope technology and building systems have become attractive solutions for building performance due to the possibility of increasing control over thermal characteristics of indoor environments. Furthermore, high performance "green building" rating systems like LEED typify and support those approaches as the most sustainable in order to create measurable results that can be compared through a systematic metric-based structure (Altomonte et al., 2015). Returning to an earlier postulation, can universal sustainable design solutions be the best fit for all climate profiles? Buildings located in the Southern U.S. stand to challenge the narrow benchmarks assigned by metrics-based rating systems and BPS tools are well equipped to examine the plausibility of universal approaches in the context of contradictory historical patterns of passive climatization.

2.0. METHODOLOGY

Simulation tools offer researchers the capability to replicate building configurations and observe their modulation of environmental states in specific time and climate contexts. Central to the simulation workflow is the domain comprised of a digital model representing building boundaries, input states culled from climate datasets and mathematical equations used to approximate state behavior relative to architectural contexts. While these tools are often used to predict how new buildings will perform in the future they can also be used to extract valuable knowledge from pre-industrial structures to inform how those geometries were attuned to local climates. This research leverages BPS tools to comprehend gaps in development patterns, from pre to post industrial, and proposes new trajectories that aim to close these gaps. The work does not intend to focus

on simulation tools themselves but instead seeks to generate further comprehension between vernacular and contemporary building systems to identify forward trajectories, advancing sustainable building design by integrating vernacular strategies that exhibit mastery in response to environmental imperatives.

In order to analyze the performance of building systems, both new and old, measurable and quantifiable results are required for assessment against established comfort criteria. SketchUp, developed by @last Software with Brad Schell and Rhinoceros 3D, by Robert McNeel and Associates are the interoperable modeling domains used in the analysis. Simulation plugins used in tandem with these modeling platforms include Sefaira Architecture, DIVA-for Rhino and Autodesk® CFD that examine energy consumption, solar radiation and fluid dynamics respectively, all critical elements to ascertain building behavior. Sefaira, an energy analysis program developed by the Trimble Company uses analysis engines in compliance with EnergyPlus. This software analyzes passive and active strategies of a building to optimize performance and design. While Sefaira's functionality is limited in terms of its range of input factors and HVAC configurations, this study focuses on the program's ability to exchange assembly parameters to highlight the relative proximity of outcomes in lieu of obtaining absolute values. DIVA-for-Rhino is a solar raytracing tool developed at the Graduate School of Design at Harvard University used to understand daylighting and radiant heat gain in buildings with reliable engines including Radiance and Daysim. Lastly, Autodesk® CFD is a computational fluid dynamics program developed by the Autodesk® CFD Engineers used to replicate the fluid flow behavior of air in buildings using Navier-Stokes equations validated through test models with known results. Together, these simulation tools are used in concert to circumscribe the performance characteristics of each case study to disclose how the boundary configurations of each contribute to the modulation of environmental forces.

3.0. CASE STUDIES

In the Southern U.S., buildings moderate a humid temperate climate challenged by intense radiation and high humidity levels. Vernacular southern structures, developed incrementally over the course of centuries, exhibit hallmark characteristics including large overhangs to provide maximum solar shading, dispersed spatial volumes and intermediary space types that together enhance ventilation in order to minimize the effects of humidity (Banham, 1966). Alabama and Georgia in the Southern U.S. are home to some of the finest examples of southern vernacular architecture including residential typologies such as the dogtrot, the bungalow, and the antebellum mansion. The two houses analyzed in this paper, the Sadler House and the RainShine House, exhibit continuities and shifts in the building tradition across the two centuries that separate them. While they both implement characteristics of the southern dogtrot, they are built with very different envelope characteristics, materials and construction processes. They are each true reflections of their time and available building technologies. The extent of time between them provides an interesting basis for comparison pertaining to energy efficiency and strategies for passive climatization due to the advances in building technologies. Analysis of each structure using the aforementioned method follows to highlight how vernacular traditions progress from the 19th to the 21st centuries while understanding the value emerging building technologies offer regional development.

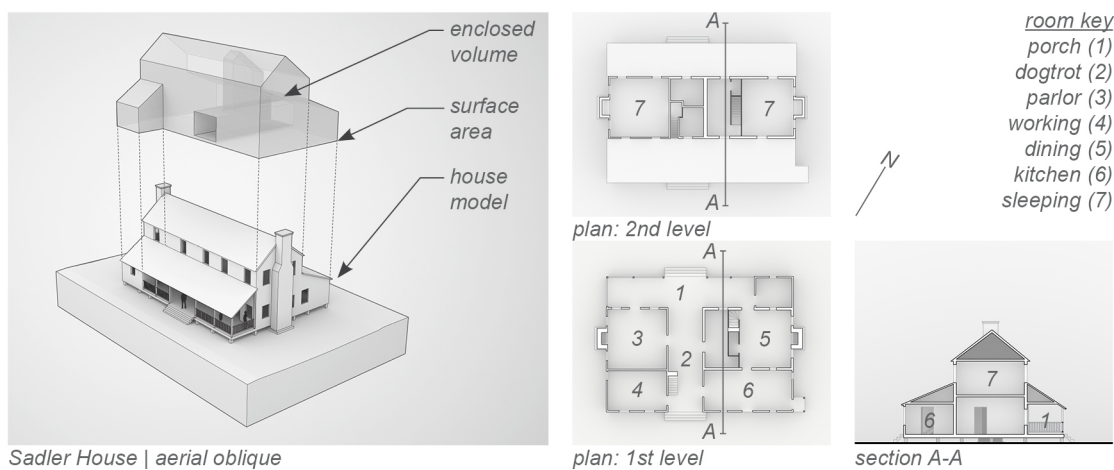


Figure 1: Sadler House reconstruction after Ford. Source: (Dreser and Frank 2017)

3.1. Sadler House

The Sadler House, built in the early 19th century, served as a plantation home in McCalla, Alabama. During the period, settlers to the Southern U.S. began to develop a building type called the dogtrot, or "single-pen" log house. These structures are built using load bearing wood logs and cedar shake roofs (Ford, 2014). While there are variations to this style as it propagates the Southern U.S., they all adapt to the hot and humid southern climate through strategies such as elevated floor plates, shaded intermediary spaces including porches and, perhaps the most identifiable characteristic, the presence of a dogtrot or open breezeway that bifurcates the structure's mass. The S/V ratio of the Sadler House structure is calculated at .41, reflecting its thin floor plate on the second level and its intermediary space types central to its composition (FIG. 1). These construction strategies modulate the climate by allowing the house to breath and dissipate humidity through its floor, enhance ventilation in the interior rooms and protect the house from incident solar gains through shaded porches. Together, intermediary spaces like the breezeway and the porch, not only provide thermal comfort to the interior of the house, but also extend the enclosed living areas to the exterior that are often used as places to sit, interact with others and even sleep during the summer months. Given that the comfort standards in the early 19th century were likely less severe than we find today, they were attained by passive strategies to dissipate heat and humidity, and also through the migration of activities across the interior and exterior areas of the house.

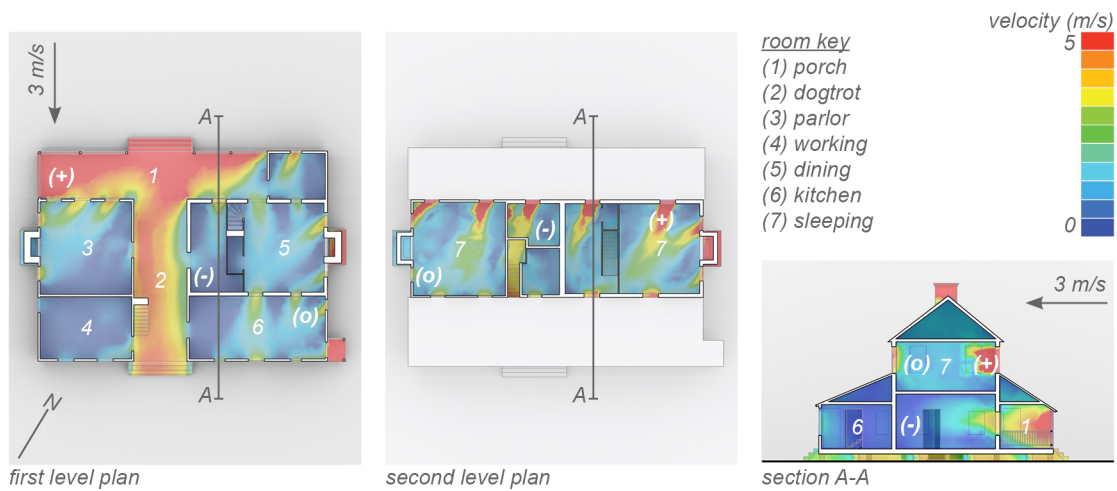


Figure 2: Sadler House CFD Analysis. Source: (Dreser and Frank 2017)

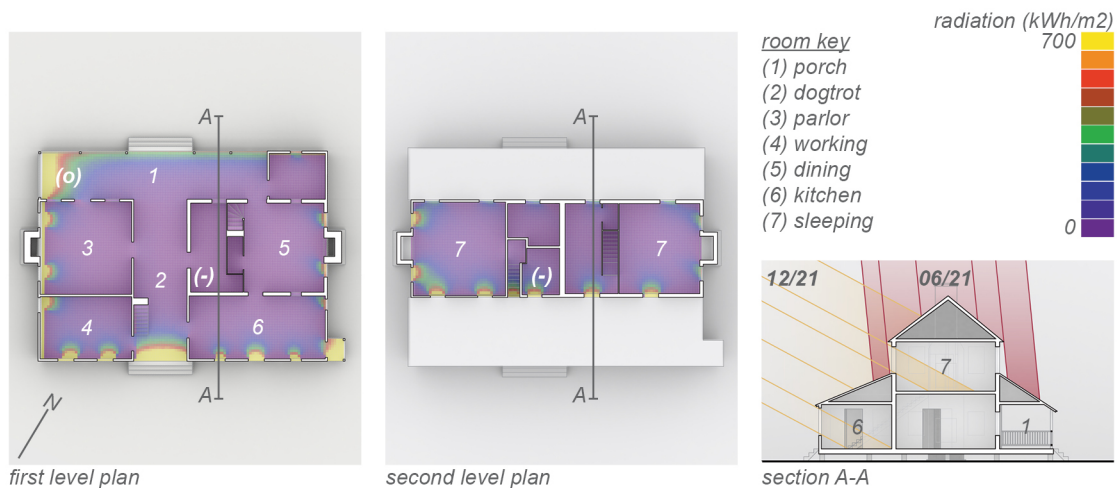


Figure 3: Sadler House Solar Raytracing Analysis. Source: (Dreser and Frank 2017)

CFD tests are run on the house, using the prevailing north-northwesterly 3 m/s summer wind as the velocity input to better understand the flow behavior within the structure. These results highlight the effectiveness of the breezeway in enhancing even moderate prevailing wind rates. Aligned apertures on the first level promote

cross ventilation in the dining and kitchen spaces while corner openings in the parlor increase air changes within the space. The thin footprint combined with the aligned openings on the second level generate ample ventilation rates for warm summer nights (FIG. 2).

Solar ray tracing simulations are also conducted to ascertain the levels of direct incident gains that are present within the house annually. The radiation maps reveal that most areas of the house are protected from direct solar gain due to the overhanging roof planes and intermediary space types. Areas where over 700 kWh/m² gains are noted annually include the northern porch and the southern edge of the central breezeway, two spaces with moderate degrees of enclosure and therefore ample ventilation rates to offset the potential for overheating. (FIG. 3).

The structure's energy use is also modeled, assigning pre-industrial building properties to building elements such as walls, roofs and floors without insulation and uninsulated single pane glass windows. The resulting EUI from the analysis resides at 64 KBtu/sq.ft./yr (FIG. 7). This outcome highlights the loose envelope construction and the low-tech systems employed in the early 19th century. Because these structures lack insulation and continuous thermal barriers, their quantitative performance outcomes sit below contemporary benchmarks that average 42 KBtu/sq.ft./yr for single-family detached houses in the same region (Architecture 2030, 2017). However, it should be noted that the resulting EUI should not be considered an absolute outcome since the properties assigned to the building's structure have not been validated. This is due to the prioritization of relative values between the two case studies in lieu of pursuing the unconditional results of a singular building.

3.2. RainShine House

Robert M. Cain's RainShine House was built in 2008 for a couple living in Decatur, a small suburb located just outside Atlanta, Georgia. The home is comprised of quadrants with the western-most units conjoined to form the public areas of the main house, the northeast unit used privately as the main bedroom suite and the southeastern unit used as an exterior southern porch. The S/V ratio of the structure is calculated at .24, much lower than the former example. This low S/V ratio echoes the compact composition of the home with most of its volume contained within the western block of the structure. The house was the first modernist residence to receive platinum certification by LEED Homes in the Southeastern U.S. (Jetson Green, 2009). A few of the more celebrated characteristics of the home include its high-efficiency envelope characteristics and on-site renewable energy systems with roof-mounted photovoltaic panels and geothermal heat pump system (Flannery and Smith, 2011). The RainShine House highlights a shift in climatization in the south, indicated by a smaller envelope area while creating a tight boundary that can be sealed and conditioned through its state-of-the-art mechanical system. While the RainShine House implements several modern technologies, it also explores traditional strategies through an operable edge condition that includes passive ventilation providing further evidence of its exemplary design (FIG. 4).

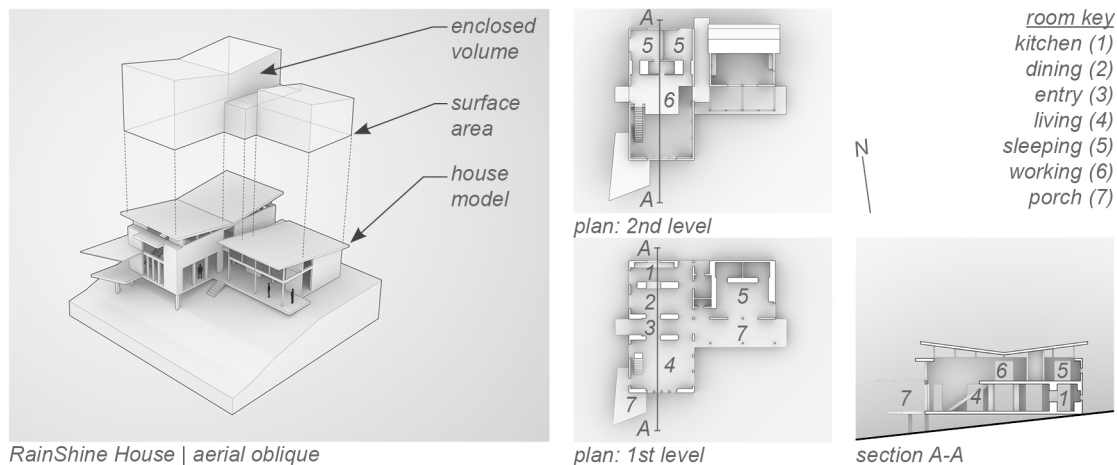


Figure 4: RainShine House reconstruction after Cain. Source: (Dresler and Frank 2017)

As indicated during the CFD analysis of the structure, the deep floor plates present within the compact building form reduces the rate of cross ventilation even with aligned apertures across its large mass. While stack ventilation rates are present from the ground floor to the upper volume of the house, low level velocities are noted with the limited operability of the upper level glazing that holds the potential to exhaust

buoyant hot air. Furthermore, air stagnation is present in areas of the plan where clear ventilation paths are obstructed by internal partitions or inoperable windows that are likely designed to minimize the level of heat transfer occurring through the exterior building envelope (FIG. 5).

Results from the solar ray tracing analysis indicate ample shading for many areas of the building plan, especially on the second level where inhabitable spaces are situated to the north of the building mass and in close proximity to the butterfly roof plane. However, areas of the first level show evidence of overexposure to solar gains, especially in the open living area encased in southward oriented glazing. While solar screens protect some areas of glazing, the orientation of the roof slope exposes areas of the southern envelope to direct solar gains. Other areas of the plan receiving over 700 kWh/m² gains over the year are located in open-air spaces including the southern porches and the entryway (FIG. 6).

When modeling the energy use of the structure, modern-day properties are assigned to building entities that include high insulation for walls, floor and roof in addition to high-performance glazing systems. These assignments result in an EUI of 28 KBtu/sq.ft./yr for the building, much improved relative to its pre-industrial predecessor and modern contemporaries as evidenced by its LEED Platinum certification (FIG. 7). These results highlight the value of advances in envelope and system technology that together allow a compact building form to perform well in a region where dispersed spatial volumes were historically adopted. Also worth noting is the fact that vegetal and on-site renewable energy systems were not factored into the calculations to facilitate comparison of S/V differences between its 19th century predecessor.

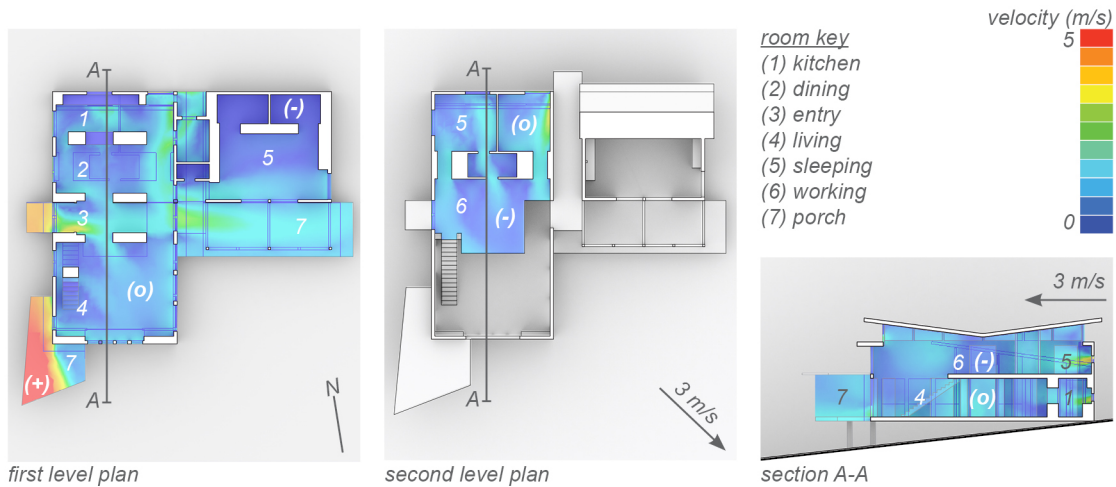


Figure 5: RainShine House CFD Analysis. Source: (Dreser and Frank 2017)

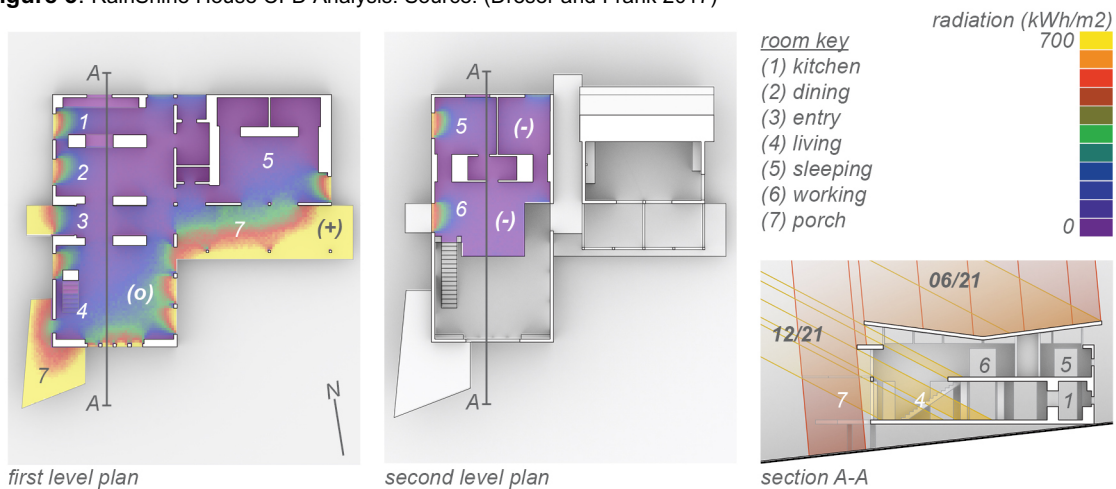


Figure 6: RainShine House Solar Raytracing Analysis. Source: (Dreser and Frank 2017)

4.0. SYNTHESIS

To gauge the relative effectiveness of massing strategies and corresponding S/V ratios for each structure, the energy models are reiterated to exchange building properties between case studies. When the Sadler House is assigned the properties of the modern RainShine House, its EUI shifts to 23 KBtu/sq.ft./yr. Likewise, when the vernacular properties of the Sadler House are applied to the RainShine House, its EUI increases to 69 KBtu/sq.ft./yr. (FIG. 7). The results from this exchange support the working hypothesis of the study highlighting the superior performance of dispersed building forms in temperate climates with hot-humid summers even when inheriting state-of-the-art building system specifications. To help rationalize the outcomes from this energy comparison, the CFD and solar ray tracing observations are further corroborated. The CFD results from the two projects indicate that thin building forms and intermediary space types break up the building mass and provide better opportunities for cross ventilation within inhabitable areas. Furthermore, aligning apertures throughout the structure strengthens ventilation paths but obstructions internal to the building composition interrupts flow networks along with wide floor plates that place significant distances between air inlets and outlets. Outcomes from solar raytracing show that thick building plans aid in shading interior spaces but access to natural daylight is inhibited without permeating interior partitions. However, thin footprints demonstrate adequate access to illuminance when shading devices such as overhangs protect the glazing. Without shading elements, spaces become susceptible to overheating and contrast glare. Results from CFD and raytracing studies both highlight the impact of intermediary space types like porches and breezeways. These spaces add to the room inventory, extending occupiable areas to the exterior where additional exposure to wind or sunlight may add direct benefit to the user group depending upon their desired activity type.

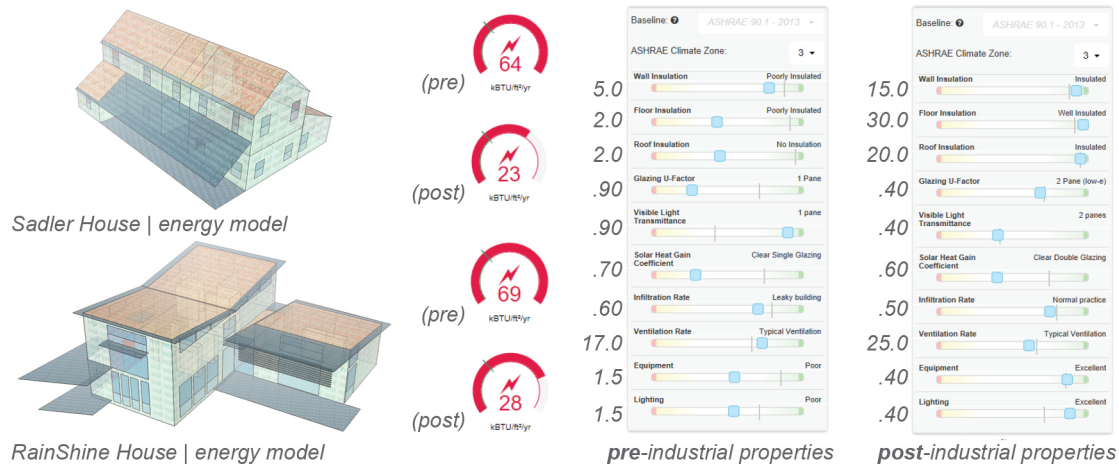


Figure 7: Energy Analysis. Source: (Dreser and Frank 2017)

CONCLUSION

While the outcomes from this study do not produce extraordinarily dissimilar results, they do demonstrate that despite 'one size fits all' recommendations made by some sustainable design guides today, decreasing S/V ratios in southern structures do not necessarily produce the most energy efficient results. These results underpin our research objective that aims to advance the conversation about the universal legitimacy of compact building forms, the espousal of lower envelope areas and highly insulated boundaries in all climate regimes. The work also serves to recall the sagacity of vernacular systems, tested with trial and error methods over centuries of development. The case study analysis presented here offers an initial glimpse into an alternative way forward that propagates important lessons from vernacular architecture, implements those lessons in contemporary development and uses post-industrial technologies to optimize building performance characteristics. We can elicit a number of lessons from this study for use in future research. While highly insulated enclosure systems minimize heat transfer in mechanically conditioned areas of a building, actively acclimatizing all interior spaces should be carefully considered to give occupants greater control over connections between inside and out. Furthermore, introducing a range of thermal zones should be prioritized in order to give occupants a variety of spatial alternatives while offsetting HVAC cost through the use of rapidly renewable sources for comfort. Finally, anticipating the migratory patterns of the building user group through the introduction of intermediary space types, extending activities to the outside of the building where moderate occupant protection can be provided. Based upon these lessons, the next steps in the research include the parametric flexing of domain models to increase the case study sample size for an improved boundary-state understanding. The examination of additional factors including outer envelope operability, building orientation

and interior disposition to build upon the S/V ratio findings herein. Finally, next steps also include expanding the selection set of case studies in the Southern U.S.; incorporating additional vernacular structures and their post-industrial successors for further analysis using state-based simulation platforms.

REFERENCES

- "The 2030 Challenge." *Architecture 2030*. Accessed October 27, 2017. <http://architecture2030.org/>
- Addington, M. D. (2003). "Your Breath is Your Worst Enemy." In A. Lightman, D. Sarewitz, and C. Desser (Eds.) *Living with the Genie: Essays on Technology and the Quest for Human Mastery*. Washington D.C.: Island Press.
- Altomonte, S., P. Rutherford, and R. Wilson. (2015). "Human Factors in the Design of Sustainable Built Environments." *Intelligent Buildings International* 7 (4): pp. 224-241.
- Banham, R. (1969). "Environmental Management." In *Architecture of the Well-Tempered Environment*. Chicago: The University of Chicago Press.
- Berardi, U. (2015). "Building Energy Consumption in US, EU, and BRIC Countries." *Procedia Engineering* 118: pp. 128 – 136
- Ching, F.D.K. and I. M. Shapiro. (2014). *Green Building Illustrated*. Hoboken: John Wiley & Sons Inc.
- Coch, H. (1998). "Bioclimatism in Vernacular Architecture." *Renewable and Sustainable Energy Reviews* 2 (1): pp. 67-87.
- Fathy, H. (1973). *Architecture for the poor: an experiment in rural Egypt*. Chicago: The University of Chicago Press.
- Fitch, J. M. (1990). Vernacular Paradigms for Post-Industrial Architecture. In M. Turan (Ed.) *Vernacular Architecture: Paradigms of Environmental Response*. Belfast: Aldershot Avebury.
- Flannery, J. A. and J. M. Smith. (2011). "The RainShine House." *Eco-Urban Design*. Netherlands: Springer.
- Ford, C. (2014). *Sadler House: Historic American Buildings Survey*. Illustration. National Park Survey. From the Library of Congress, Historic American Buildings Survey. <http://www.loc.gov/pictures/item/al1358/> (accessed January 15, 2017).
- Ionescu, C., T. Baracu, G. E. Vlad, H. Necla, and A. Badea. (2015). "The Historical Evolution of the Energy Efficient Buildings." *Renewable and Sustainable Energy Reviews* 49: pp. 243-253.
- "LEED Platinum Georgia RainShine House" *Jetson Green*. Last modified May 1, 2009. <http://www.jetsongreen.com/2009/05/rainshine-house-leed-platinum-decatur-georgia.html>
- Kemp, J. (1990). *American Vernacular: Regional Influences in Architecture and Interior Design*. Washington D.C: American Institute of Architects Press.
- Lechner, N. (2014). *Heating, Cooling, Lighting: Sustainable Design Methods for Architects, 4th Edition*. Hoboken: John Wiley & Sons Inc.
- Singh, M., S. Mahapatra, and S. K. Atreya. (2009). "Bioclimatism and Vernacular Architecture of North-East India." *Building and Environment* 44 (5): pp. 878-888.
- Zhai, Z. J., and J. M. Previtali. (2010). Ancient Vernacular Architecture: Characteristics Categorization and Energy Performance Evaluation. *Energy and Buildings* 42: pp. 357-365.