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Recapturing the Breeze: Computational Simulation of Natural Ventilation in a Raised Creole Cottage

Evan Oskierko-Jeznacki
University of Pennsylvania

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Abstract
This research investigates the environmental behavior of naturally ventilated historic, vernacular architecture in hot-humid climates using a computational simulation and analysis methodology to better understand the role of historic adaptive comfort strategies within the contemporary context of sustainable and energy efficient preservation design. The Pitot House, a raised Creole cottage, located in New Orleans, LA that has been heavily modified from its original environmental configuration will be studied in depth to highlight the importance of this approach in its ability to recreate historic configurations, visualize past levels of human thermal comfort, and use this information to make informed, sustainable decisions in the design of preservation strategies.

Keywords
CFD, thermal comfort, Pitot House, vernacular, sustainable preservation

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RECAPTURING THE BREEZE:
COMPUTATIONAL SIMULATION OF NATURAL VENTILATION
IN A RAISED CREOLE COTTAGE

Evan Oskierko-Jeznacki

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Advisor	Program Chair
Michael C. Henry, PE, AIA	Randall F. Mason, PhD
Adjunct Professor of Architecture	Associate Professor

Dedication

To my parents, George and Ewa, for their unyielding encouragement and unwavering support.

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Chapter 1: Introduction

Mechanical upgrades to historic structures are often considered to be the most challenging and costly aspect of historic rehabilitation projects nationwide and around the globe (Park 1999, 82-89). The increasing availability and affordability of climate control during the last century has reached a technological apex today, but the significance of adaptive comfort has been relegated solely to the discussion of sustainable, new construction, with little effort made to apply this methodology to historic structures. The definition of thermal comfort is a thus a dynamic one as it is a function of available technology and demand. Quite simply, the redefinition of indoor comfort is Jevon's Paradox of environmental design.[1] Additionally, the effects of global climate change on the perception of comfort in historic buildings will inevitably increase the reliance on mechanical systems if no effort is made to understand how these structures behave in their regional contexts and how comfort could be optimized by taking advantage of their inbuilt environmental features. By focusing on a building typology that has thrived prior to the advent of mechanical heating and cooling, specifically the raised Creole cottage, which is located in a climate region that experiences both significant moisture and heating loads, it will be possible to demonstrate and visualize the systematic behavior of a building type designed explicitly

[1] The phenomenon that occurs when technological progress increases the efficiency with which a resource is used while also increasing its rate of consumption and demand.

to take advantage of its climatic context. Critical to the understanding of this behavior is the understanding of its construction, use, and operation. This can be achieved by historical research to illustrate the particular management regimes in response to exterior environmental conditions. For instance, the manipulation of shutters and blinds, in coordination with the opening and closing of doors and windows are all dynamic inputs made by the occupant to regulate comfort in the pre-HVAC era.

It is important for this study to note, then, that even passive behavior, is predicated on active input. By understanding both the climate and the historic operation of the building it is then possible to apply the use of computational fluid dynamics (CFD) software as well as other performance simulation methods to model, simulate, and visualize indoor thermal comfort. The goal of this study is ultimately to illustrate the benefits of a passive 'operating manual' for historical building typologies that can achieve the same level of thermal comfort that would otherwise be provided only by invasive and destructive retrofitting techniques to accommodate mechanical systems.

Hypothesis

Through the use of simulation, it will be possible to not only recreate the case study building to its initial typological form but also reinstate the historical operation of the building as an integrated component of progressive preservation design. If successful, the outcome will inform not only an annual interior thermal comfort index for the spaces, represented as a percentage of thermally comfortable days per year, but more importantly give an empirical context for the integration of a hybrid conditioning methodology for application to building reuse and restoration today that will invariably require supplemental heating systems. By relying on a well-informed and calibrated simulation methodology, the sizing of these systems can then be minimized for the building, saving energy and preserving historical fabric.

Objectives for the Application of Computational Simulation Methodologies

1. Recreate and visualize historic environmental behavior of a building that has been modified from its original environmental configuration; demonstrate that it provided sufficient levels of thermal comfort. While this methodology can be seen as an to resource intensive, high resolution spatial monitoring for virtually any structure, particular emphasis is placed on the ability to recreate conditions of structures that have been modified from their initial configuration, such as the Pitot House.

2. Emphasize the significance of recreating historical environmental quality as an interpretive value.

3. Circumvent otherwise invasive and damaging retrofits of historic buildings; especially with respect to altering hysteresis cycles of building fabric that have reached a steady state with their environment. The environmental shock placed can be catastrophic in the long term.

Justification

The option to take advantage of passive, inbuilt environmental features of buildings is often discussed as a footnote in widely circulated literature, such as the *Technical Preservation Guidelines: HVAC Upgrades in Historic Buildings* published by the GSA. Nonetheless, this approach is seldom explained or accurately demonstrated (Alderson 2009). In the restoration, rehabilitation, and reuse of historic structures priority is oftentimes given to immediate and visible concerns for stabilization in the short term, while considerations for thermal comfort and regulating mechanical systems are demoted to a series of compromises. Without careful consideration by a well-coordinated team of engineers, architects, and environmental engineers, these compromises result in heavy disfigurement or modification of the historic fabric due to the misplacement of ducts or equipment. What is lost is the understanding that the thermal function of a building was just as an effective element of the initial architectural design and operation as it can be for its preservation design and operation today (Heschong 1979, vii).

The same approach that is applied today to sustainable new construction can and should be applied to the design of preservation strategies of historic buildings, with one distinct advantage: it is possible to recreate, through documentary research, the initial architectural configuration and thus operational behavior of the structure—an impossibility for new design. Often historic structures today have been forced to betray their intended thermal function due to code and regulatory modifications or simply due to a change in use—from a residence to an interpreted museum, for instance. By using computational fluid dynamics and other simulation methods it is possible to model the interior airflow and temperature fields in response to the dynamic operation of the building and to exterior climatic conditions to create and visualize the thermal comfort index. As mentioned, often these historic structures were designed without mechanical systems and yet still provided acceptable levels of thermal comfort, which when defined as a function of the *Secretary of the Interior's Standards for the Treatment of Historic*

Properties can and should result in the decision to *not* install *new* mechanical HVAC. Drayton Hall, located near Charleston, South Carolina, has set a precedent in such a decision, and illustrates that even in a warm-humid climate zone[2] landmark historic buildings are capable of performing sufficiently without modern climate control systems (Park 1999, 82). Other examples include the Aiken-Rhett house, also located in South Carolina, which help to underscore an emerging trend in the interpretation of historic buildings as originally built and without invasive mechanical retrofits. This being said, even passive systems require active participation of the occupant, and as such the hypothesis is that given such an 'operating manual' it is possible to reduce the reliance on air-conditioning. It is the goal of this study to use simulation to recreate the initial conditions of the case study building and to illustrate that it in fact functioned and could continue to function to provide a comfortable interior microclimate in an otherwise uncomfortable hot-humid climate without invasive retrofits.

[2] Charleston, South Carolina is located in IECC climate zone 3A, which is characterized as a warm-humid climate. See *2006 International Energy Conservation Code* for more information and details.

Chapter 2: Review of Relevant Literature

Naturally Ventilated Creole Cottage Building Typology

The raised Creole cottage typology is a unique building type for its climate, and is a combination of various features and architectural elements, the origins of which are still debated (Fricker 1984, 7). A popular theory relies on the importation of vernacular and provincial architectural traditions from France in the late 18th century. The medieval architectural roots of the raised Creole cottage are evident in its construction and uniquely heavy constructional quality. Edward Cazayoux relies on this reason to explain the choice of materials, constructional methods, and spatial organization of early Creole architecture, from which the raised cottage evolved (Cazayoux 2007, 1-2). These traditions, given the wide range in French climate between its northern and southern regions, were climatically pre-adapted to a full spectrum of environmental conditions. Edwards discusses this point at length, particularly the need for the French to constantly modify their dwellings as necessitated by regional differences in climate in the new world:

> The relative *preadaptation* of previously extant French vernacular traditions in Nordic, temperate, and tropical American environments played a role in the selection of different kinds of architectural patterns in the Americas. Northern houses would appear more like those of similar latitudes in Europe, while tropical adaptations might reveal profoundly non-Gallic modifications following the period of initial occupance and experimentation. (Edwards 2006, 244-245)

Following a period of initial occupance, Edwards goes on to discuss, outside influence from West Indian Creole, African-American, and Anglo-American traditions allowed the initial French vernacular design to evolve. This greatly streamlined their application in a new setting.

Other theories regarding the origin of the raised Creole cottage in New Orleans exist, however. In support of Edwards, Jonathan Fricker discusses the possibility that the appearance of the unique loggia configuration and use of the *cabinets* (small, cross-ventilated rooms that flanked the rear loggia) are due to an Italian influence. The Italian double-loggia house in particular, Fricker points out, bears a strong resemblance to the raised cottage, not only in appearance but in functionality as well (Fricker 1984, 7). Both theories rely on the exposure of early provincial French architecture to external influence, principally during the settlement of the West Indies. Malcom L. Comeaux even argues that the architecture of the first Cajun settlers in Louisiana may have been influenced by Germans living along the Mississippi River, remnants of the Company of the Indies; the impression is distinctly noted in the detailing of Cajun barns from this period (Comeaux 1989, 53).

The Pitot House

The Pitot House will be the case-study building used in this research to demonstrate the effectiveness of its inbuilt environmental features in a hot-humid climate. The basic premise for this thesis investigation arises from claims made about the Pitot House, and similar raised Creole cottages, regarding their performance in the

New Orleans climate. According to documentation compiled in 1991, the Historic American Building Survey posits that, "The design of the [Pitot] house is based primarily on climate control to promote maximum cross ventilation and provide comfort in the hot, humid, swampy Louisiana environment" (Pitot House 1991). At the macro scale, it is argued that the house was sited along the adjacent bayou, taking advantage of predominant wind patterns. Furthermore, diagrams illustrate generally how the house was ventilated, both in plan on both floors and in section (See Figure 11). The documentation illustrates that the combination of dense, thermal mass construction and the placement of adequate openings was able to ventilate the house both throughout the day and at night during the hottest months of the year. The use of slate tiles on the roof, for instance, acted as its own thermal mass, which during the evening provided a heat source for driving vertical convective ventilation for the bedrooms and cabinets on the second floor. However, it should be noted that this element, crucial to providing a means to exhaust heat during the evening, is challenged by conflicting documentary information. The HABS documentation posits that the original roofing material was constructed of cypress shingles, which would have been in line with imported French traditions given the abundancy of that particular species of wood in certain areas of Northern France, as well as its ease of procurement, moreover repair (Chapelot 1985, 316). However, the same HABS documentation also argues that slate tile was used, which would have caused the house to behave environmentally in an entirely different way.

Although the wood, particularly cypress, has a relatively high specific heat capacity, between 2.0-2.5 kJ/kgK, it has a relatively low density, of approximately 510kg/m^3. This causes wood, when part of an envelope assembly, particularly one that is in direct exposure to solar gain such as in a roof, to behave more like an insulative material when compared to slate. Slate has a much lower specific heat value, fifteen times less than wood, however is significantly more dense, with a density of between 2600 – 3300 kg/m^3.[3] An efficient thermal mass will have a high density, first and foremost, and the time-lag in re-radiating stored heat energy will be a function of its specific heat value (Olgyay and Olgyay 1963, 115-117). And for these reasons, slate behaves in an entirely contrary manner to wood. Fortunately, Barbara SoRelle Bacot and Jessie Poesch offer a reasoning for resolving this discrepancy by emphasizing the influence of city-wide fire prevention regulation in New Orleans in the early 19th and late 18th century (Poesch and Bacot 1997). The influence of factors other than environmental are indeed the key to understanding the choice of roofing material at the Pitot House.

A trend visible in the construction of the Pitot House and other similarly styled buildings in New Orleans from the early 19th and late 18th centuries is the choice in non-combustible constructional materials. Two significant fires decimated great portions of New Orleans in 1788 and 1794, events that directly influenced the shift away from

[3] For information regarding these material properties consult the Engineering Toolbox, found at www.engineeringtoolbox.com.

timber and wood elements wherever possible. Given the ability for fire to jump from roof to roof, the distinct possibility exists that slate would have been a more robust roof cladding material. Specifically, one year after the great fire of 1794 the Spanish enacted strict building regulations specifying the use of fireproof materials for walls and roofs (Poesch and Bacot 1997, 35-36). Furthermore, the lower pitch of the hip roof and Norman truss supporting structure speak to a response in bearing the additional weight that the slate would have imposed compared to wooden shingles. This being said, regardless of material choice, the significant environmental detail, which is at the core of the environmental function of the roof at the Pitot House is that the cladding elements are gap spaced and permit the free flow of air vertically from the spaces below. The primary difference between the behaviors of the two materials would have been the ability of the slate to provide its function as a convective engine well into the evening, due to the thermal lag involved.

Furthermore, as the premise of this thesis rests on the accurate reconfiguration of the case study structure, the issue of scrutinizing the various periods of the modification is a significant one. Thanks to the work of historians such as Fred Daspit and Samuel Wilson Jr., it is possible to accurately authenticate the original construction and configuration of the house, which will be discussed at length in a subsequent chapter. Samuel Wilson Jr., a prominent Louisiana architectural historian, has devoted a book to the topic of the Pitot House, which concisely documents the various periods of ownership, and catalogs the various modifications made to the structure throughout its history (Wilson 2011). Wilson has also published a translated and annotated version of the will of Hilaire Boutté, the assumed architect and designer of the Pitot House (Wilson 1982). The will is helpful in identifying other architectural projects designed by Boutté in New Orleans, particularly those that were designed in the wake of the fires of 1794; cross-referencing material and constructional choices made at the Pitot House with other buildings in the city from the same period offer a way to validate choices made in the simulation model.

CFD Simulation & Architectural Implications

Computational fluid dynamic simulation, or as it is commonly referred—"CFD," and the methodologies that have developed alongside it, are at present the most powerful tools available for the analysis of fluid distribution, and behavior across a number of industries and fields. CFD as it is used today represents over 40 years of development and evolution in simulation methods, the genesis of which can be traced to the surge in interests in such capabilities between the 1950 and 1970s by the aerospace and meteorological industries (Li and Nielsen, 443). Although historically relegated to the study of complex fluid behavior, geometries, and boundary conditions, such as the analysis of expansion gases in combustion engines, today the increased availability and streamlined operability of CFD has allowed the use of this tool to expand into fields such as ventilation engineering and architectural design. The distribution of fresh air in buildings and removal of exhaust air, both mechanically and passively, has been the focus of recent studies and applications of CFD in the architectural community during the last 30 years (Li and Nielsen, 443). Since one of the first applications of CFD to architectural ventilation analysis in 1973, conducted by Peter Nielsen, the surge in computing power accompanying the 21st century has allowed this type of research to expand from analysis of single rooms in apartments to apartments in buildings, and has recently expanded to the study of buildings within entire cities. From lengthy computations on early Cray supercomputers to those done quietly in the background on the Cloud, the accessibility and capability of CFD are growing each year. A report published in 2011 successfully carried demonstrated a CFD analysis of the urban heat island effect in Tokyo, requiring a model of over 5 billion computational cells (Li and Nielsen, 443).

At the heart of these tools are the Navier-Stokes equations, a collection of partial differential equations that mathematically describe the motion of viscous fluids. While basic geometries and simple conditions can be solved analytically, more complex boundary conditions require advanced numerical methods to utilize these equations—this latter method refers to CFD. In simulating airflow the primary variables are air speed, direction, temperature and turbulence quantities. Given an initial state and boundary conditions, CFD software numerically solves for the behavior of volumetric subdivisions of the original boundary—or voxels, the resolution of which is defined by the user and limited by computational capacity, but what ultimately defines the accuracy of the model. The output is a vector field that simultaneously describes air speed, direction, temperature, and turbulence at each voxel.

However, these are experimental computational tools, and as such are as limited by computational hardware capacity as they are by the inherent challenges in the application of the numerical methods for simulation. Li and Nielsen posit two primary challenges in the application of CFD. The first, is variability in accurately simulating the physics of turbulent flow; the second, owes to numerical anomalies inherent in the calculations. Without delving into the complexities of modeling turbulent flow, the fundamental challenge of choosing from a wide variety of turbulence models the one that is most accurately suited for the application is a difficult one. The boundary conditions specified might contain varying geometrical complexity, each of which would benefit from a different turbulence model, and that would negatively affect the analysis of the other. Furthermore, the models used within these simulations are themselves not perfect.

Validation in CFD Simulation

Given even simple geometry various numerical phenomena can arise, such as numerical diffusion and dispersion errors; these phenomena can significantly influence the repeatability and accuracy of the resultant simulation (Li 1997, 235). The feasibility of this study is a significant concern, and so in choosing a case study building typology it is imperative to select one that presents as few inherent impediments as possible, specifically with regard to boundary geometries. A wide range of geometrical detail in a single model, for instance, results in a corresponding increase in simulation resolution that requires additional resources to execute. Li and Nielsen suggest a simplification method that increases the resolution of analysis at critical points, such as inflows, outflows, and surrounding complex geometry while normalizing and reducing the analysis resolution elsewhere in the model (Li and Nielsen, 436). Often referred to as the *box method,* the premise relies on using the full capacity of the model to simulate behavior around crucial geometry, where the flow is hypothesized to be more turbulent; in this way, less resources can be allocated to areas where flow is hypothesized to be uniform and steady (Li and Nielsen, 446). The results from the former scenario can then be used in the latter, to save time and increase accuracy.

Accounting for numerical error—or at the very least, acknowledging it—is a topic elaborated at length by P.J. Roache in his article “Quantification of Uncertainty in Computational Fluid Dynamics.” The approaches suggested by Roache are numerical in nature and focus on the differentiation of the terms “validation” and “verification.” Both of these terms refer to obtaining a better simulation output however at different points in the process. Roache argues that “verification” refers to the examination of the application of the partial differential equations used in the simulation code, and cannot be validated; whereas, “validation” is carried out on the results of the aforementioned application of equations. Or to put it differently verification is described as “solving the equations right” and validation as “solving the right equations” (Roache 1997, 124-125).

As it pertains to this study, validation is a crucial component in the analysis methodology, and generally two forms are available. The first is incorporated into the simulation and refers to a numerical validation method that relies on convergence rates as a measure of the accuracy of the results; as a simulation executes each iteration, the convergence of error to zero is accepted as a measure of its accuracy and should be included with the results. A second method of validation is paired with an additional step in the methodology that involves actual onsite measurements (when possible) that can be then used to calibrate and subsequently validate a model. Or as Roache suggests, "Whether or not those equations and that solution bear any relation to a physical problem of interest to the code user is the subject of validation"(Roache 1997, 125).

The matter of calibration is a pertinent one to this study, as this is typically standard practice for the analysis of existing structures. However, in the particular instance of the chosen case study, the original fabric—and thus behavior—has been modified to the extent that validation of this type is impossible for this building. This being said, as the case study building is representative of a distinct building typology and behavior, the ability to verify the results of this study is still possible by measuring a different, yet similar building, as a means of calibration in the future. A validation methodology in this manner has been adopted as a recommendation beyond this extents of this study.

CFD Simulation of Historic Buildings

Perhaps the most significant takeaway from the arguments made by Roache, Li, Nielsen and others is that CFD is currently the most sophisticated method for modelling and predicting airflow, and that due to recent advances in both software and hardware its applicability is ever-increasing. Zhai suggests further that CFD can and should be applied early-on in the design of new buildings—not only the design of architectural features but of thermal comfort as well (Zhai 2006, 305). Zhai's argument is one that is particularly relevant to this study, because recently it has been shown that the application of CFD simulation methodology can be used not only to simulate new designs, but also to simulate historic ones that no longer exist in their original thermodynamic configuration. This is a key premise of this study.

Unlike the much broader topic of CFD simulation as applied to new construction or ventilation engineering, in the fields of preservation and conservation the application of CFD simulation is a nascent methodology (D'Agostino and Congedo 2014, 181). Although still developing, a dominant focus of this area of study is relegated to the protection of historic collections within historic buildings, of which the interior building fabric itself is often the primary focus. In their 2014 article, "CFD modeling and moisture dynamics implications of ventilation scenarios in historical buildings", D'Agostino and Congedo argue for the recreation and maintenance of historic, interior microclimates in order to protect collections that have adapted to a particular set of conditions over centuries. The ultimate goal of the study was to identify and test the thermo-hygrometric parameters that resulted from various operational scenarios of the space to establish an optimum, naturally ventilated indoor microclimate (D'Agostino and Congedo 2014, 182). Furthermore, it is argued that to avoid sudden changes to the microclimate a thorough understanding of the climatic behavior of the site is necessary. This approach is similar to the one adopted for this study, in that it seeks to identify an operational benchmark to achieve or visualize a certain goal, which in the case of this thesis is the optimization of human, thermal comfort. D'Agostino and Congedo's approach also succinctly emphasizes some of the unique challenges and advantages of CFD simulation in historic buildings.

A key article written by Balocco and Grazzini in 2008 brings to the forefront of this research the topic of resolving and accounting for discrepancies between initial and modified operational configurations of historic structures. Mentioned in the article is the often misinterpreted function of architectural features that results in their removal or drastic modification. Balocco and Grazzini suggest that inadequate information regarding the environmental behavior of the building as a system is often due to the resource-intensive impracticability of gathering such data manually (Balocco and Grazzini 2009, 313). The manpower, time, and hardware required to empirically catalog and subsequently process the requisite variables, at a sufficient resolution, in order to visualize the environmental behavior of a space or series of spaces within a building is untenable. In studying the well-known, inbuilt environmental features of a case-study historic building typology in Palermo, Balocco and Grazzini explore the notion that CFD simulation is the most resource efficient methodology for not only documenting the state of the building as it stands presently, but also in virtually reinstating its various configurations, both historic and experimental. This methodological format allows for experimentation without jeopardizing fabric and without expending resources unnecessarily.

The Semantics of Thermal Comfort

Also at the core of this thesis is the ambiguous yet commonsensical concept of thermal comfort and the process of defining it, a task that has proven difficult in modern times and has yet a great deal to learn from historical precedents. The manner in which we both perceive and define thermal comfort today has evolved significantly from an acknowledged sensation into a bounded and formalized concept. It will be critical for this study to differentiate the standards of thermal comfort between historical and modern contexts.

While a consensus yet exists for a definitive thermal comfort range, it is accepted that humans are consistently perceptive of minute temperature differential and have been remarkably creative in crafting personal micro-environments to take advantage of this (Heschong 1979, 1-17). From its founding in 1894, today the *American Society of Heating, Refrigerating, and Air-Conditioning Engineers* has taken on the task of quantifying thermal comfort. It specifically characterizes thermal comfort in its published Standard 55, which is devoted to the topic, as a *static* heat balance model that specifies "the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space" (American Society of Heating 2013, 4). Brager elaborates on occupants roll in this definition as "passive recipients of thermal stimuli driven by the physics of the body's thermal balance with its immediate environment, and mediated by autonomic physiological responses" (de Dear and Brager 1998, 1). The same variables at the center of thermal comfort—temperature, thermal radiation, humidity, and air speed— have been historically perceived and recently calculated, yet their product is still a function of satisfaction and acceptability, which is in perpetual flux due to the increasing availability to control our thermal environment to ever tighter tolerances for longer periods (de Dear and Brager 2002, 549).

In recent response to the tremendous resources involved in maintaining an annual thermal optimum across all building types and climate zones, and the often deleterious effect this has on building fabric, ASHRAE has acknowledged the concept of a "variable temperature standard," or what is referred to as an adaptive comfort standard or model (de Dear and Brager 2001). This approach accounts for the occupant's ability to modify their clothing level and activity level in response to *outdoor* effective temperature, as opposed to indoor dry bulb temperature. Although this standard is typically viewed through the lens of new construction, it has been briefly proposed by de Dear and Brager as an operational guide for existing buildings (de Dear and Brager 2002, 10).

Additionally, the acceptability threshold for indoor air velocity deserves some particular emphasis for this investigation, given that in the absence of mechanical systems—even electrically driven fans— ample ventilation through indoor spaces was a critical factor in the shaping of a comfortable indoor space during the late 18th and early 19th centuries. However, 'ample ventilation' historically would certainly exceed what is considered acceptable today. A debate has evolved around this topic today that questions these thresholds of air speed: 0.2m/s in an air conditioned building, and between 0.2-1.5m/s in a passively ventilated building. Candido and de Dear argue that in particularly hot humid climates these thresholds are indeed relative, and can be significantly higher (Candido 2008). An experiment carried out in northeastern Brazil established that on the hottest day of the year where indoor operative temperature can exceed 28°C, nearly 20% of occupants felt that air speeds in excess 1.5m/s were acceptable. This is particularly applicable to the New Orleans climate and significantly insightful into understanding the elevated indoor airspeeds at the Pitot House, and why these would have been considered not only acceptable but critical to making the ground floor spaces comfortable throughout the day during the hottest months.

Retroactively defining acceptable levels of comfort is not easy given the difficulty with which we can presently define it, and the fact that the concept of thermal comfort as we perceive it today was only beginning to be interpreted in the late 18th and early 19th century. John Crowley attempts to tackle the concept of comfort as an emerging notion in early modern Britain and America, arguing that the formal definition of thermal comfort emerged as a function of the available technology in regulating it (Crowley 2010). Crowley argues that initially, comfort in the pre-mechanized era was expressed in somewhat medieval terms of convenience, pragmatism, and cleanliness; and that "A man's physical requirements for comfort were clean clothes, a well-appointed bed, a fire, and someone to serve him these amenities" (Crowley 2010, 5). In other words, comfort was directly related to physical satiation. Eventually, this transformed into an obsession with architectural style; physical comfort was foregone for another form that was a byproduct of stylistic trends. Crowley is not alone in this theory, as Jeffrey Cook also posits:

> According to our standards today, up until then [1785], Americans chose to be uncomfortable, and spent their money on other things such as fine furnishings and crockery. (Cook 2002, 356)

This being said, the recent focus on adaptive comfort has been directed primarily at energy-conscious new design. Even in this context, the integration of adaptive comfort models has been challenged by mechanical engineers who discredit such natural approaches and adhere strictly to ASHRAE Standard 55 or ISO 7730 (Brager and de Dear 2000, 1). In the field of preservation design it is often only footnoted or relegated to a sentence or introductory paragraph, such as in the General Services Administration's *Technical Preservation Guidelines* (Alderson 2009, 1). In a seminal work, devoted to the topic of sustainable preservation, written by Jean Carroon in 2010, the topic of "passive survivability"[4] is only briefly discussed, and not at all visualized (Carroon 2010, 10-11). Furthermore, the larger context of interior thermal comfort as regulated by the inherent passive survivability is not addressed. It is the intent of this study to apply the simulation methodology and techniques reserved for new design to historic buildings to begin to address this otherwise underrepresented area of the field.

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[4]Jean Carroon refers to "passive survivability" as the ability of historic buildings to function in the absence of modern systems.

The State-of-the-Art as it Relates to Bioclimatic Design

The simplest methods for the regulation of one's thermal environment were historically to avoid harsh conditions by migration or by 'nesting'—that is, by finding or constructing a protective shelter; the initial forms that resulted from this latter decision are a result of an evolution of vernacular tradition by thermal adaptation (Heschong 1979, 8-17). Instinct was the driving element in constructing shelter initially. And prior to the invention of meteorological instruments capable of quantifying climate data and a system capable of standardizing it, the 'sensation' of comfort was the principal method for the regulation of personal environments. This is often referred to as the psychological dimension of adaptation, and is particularly relevant to vernacular building typologies in which occupants' interactions with the environment and personal thermal control may alter their expectations with regard to their thermal sensation and satisfaction (de Dear and Brager 2002, 1).

During the 16th and 17th centuries, when meteorological study had begun to evolve as a field in England, the ability to describe, categorize, and quantify climate began to slowly influence members of the Royal Society and the scientific, as well as social elite including gentleman architects (Hawkes 2012, 11-14). In the United States this influence was manifested most popularly through Thomas Jefferson and James Madison, who began to investigate and record meteorological factors as an alternative to British methods, but more importantly they begun to frame these factors in the context of architectural design (Solomon, Daniel, and Druckenbrod 2007). Jefferson's designs for Monticello encapsulate his efforts to work with, instead of against, its climatic context, employing the best methods available at the time—rules of thumb. Jefferson employed rules of thumb for the sizing of windows to provide optimum daylight in a space as well as for methods for ventilating spaces, for example (Jefferson and Kimball 1968).

Rules of thumb dominated architecture and the regulation of thermal comfort until the 19th century and the founding of ASHAE (American Society of Heating and Air-Conditioning Engineers) that sought to empirically study and quantify standards for comfort, building systems sizing and installation, and building behavior. The development of new technologies during the mid to late 19th century for controlling indoor environment and comfort such as forced air ventilation, steam heating, and the use of electricity in replacing coal for powering these elements, demanded greater scientific command of the thermodynamic and physiological mechanisms involved. Put simply, the long-standing and liberally applied rules of thumb would no longer suffice after 1890 (Flink 1969, 1). It is during this time that the formalized concept of comfort, as a function of the built environment, was introduced and subsequently specifically defined.

Chapter 3: The Raised Creole Cottage Typology

The case study building typology that is at the focus of this thesis is the raised Creole cottage; it is also commonly referred to by architectural historians as the French Colonial plantation house, planter raised cottage, raised Creole house, and West Indies planter (Edwards 2004, 79-80). This chapter is dedicated to justifying this choice in building types as it relates to a better understanding of adaptive comfort in naturally ventilated historic structures, and will be critical to the understanding of the various inbuilt environmental features of the Pitot House. As a provincial vernacular architecture, the raised Creole cottage stands apart from other architectural approaches in similar climates that have evolved globally in reaction to regional climatic influences. Vernacular architecture in hot and humid climates in particular is typically characterized by a lightweight construction that aims to reduce thermal mass and increase ventilation. The intense solar radiation and relative humidity levels combined with little diurnal and seasonal fluctuation in temperature (See Figure 41) shape a built environment that maximizes shading, with the roof becoming the predominant architectural and environmental element, and minimizes wall cross section thickness, or walls entirely (Daniel P. Branch 1960, 140). One such example is that of the lightweight parasol assemblies constructed near Borneo on Alor Island, a location that sees heavy rainfall, moist conditions, and intense solar radiation year round. Against this logic stands the relatively heavy mass of the raised Creole cottage, however this building type did not begin this way.

Genesis of the Creole Cottage: Climatic Preadaptation

At the time that the French arrived in Louisiana, in the late 17th century, the architectural style that manifests is characterized as a single-level, half-timber frame structure that employed some form of massive infill such as masonry; this format is referred to as *colombage.* The vertical wooded posts bore directly on and penetrated the ground, which is referred to as *poteaux-en-terre* (post-in-ground). Typically, comprising the horizontal structure and envelope was some form of a Norman, or king-post, truss that provided the formwork for a steeply pitched hip roof upon which a thatch, tile, or stone roof was loosely laid (Cazayoux 2007, 1). The eaves of the roof were typically pronounced in order to shield the exterior walls from harsh environmental conditions. But why was such a unique construction type used in this particular climate?

One possible explanation owes a great deal to the fact that the raised Creole cottage is a product of generations of climatic and architectural adaption that spanned multiple continent and climates, the evolution of which is as much of a result of the import and coalescing of architectural traditions as it is of the regional adaptation of a transplanted style. The survivability of a building typology over time is directly related to this process of evolutionary fine-tuning. As a result, a high-quality building type emerges from the “vernacular zone,” as Ronald Brunskill refers to it, at the expense of the numerous, low-quality, expendable iterations that preceded it (Edwards 2006, 243).

Given the unique set of inbuilt environmental features of the Pitot House, an investigation of the contributing forces to the raised Creole cottage is warranted.

The genesis of vernacular architectural styles can typically be traced to some form of primitive architecture: iteration zero, the sole purpose of which is to provide shelter for its builder who is singularly limited by his environment as a source for constructional material and a driving force for design (Daniel P. Branch 1960, 134). In other words, the initial premise of vernacular architecture can be summarized as "build only what was needed with what was available." In much the same way, the French settlers who arrived in Louisiana during the late 17th century brought with them the architectural traditions that they were familiar with and had initially available to them. This preliminary phase of settlement is often to referred to as "initial occupance," during which the primary focus in the foreign setting is survivability and occupant welfare (Kniffen 1990, 50). As Jay Edwards elaborates, "There was little glamour in the origins of Louisiana's Creole architecture. Pioneer's cottages were generally based on an asymmetrical two-room unit referred to as a *sale-et-chambre* (parlor-and-bedroom)"(Edwards 1994, 158-159).

The initial materials and methods employed early-on by the French may have been hastily-implemented but were not haphazard by any means. Similar to the wide-ranging environmental contexts spanning North America, the regional climatic variations between northern and southern France meant that the various traditions transplanted to America were already preadapted, in one form or another, to similar climatic conditions. The patterns of French provincial architecture in the North America, from the hot-humid south to the sub-arctic and artic regions of the northern portions of the continent including Quebec, closely match the architectural patterns in France within similar latitudes (Edwards 2006, 244).

Rural architecture in medieval France provides a baseline for understanding the cross-section of the environmentally-motivated, architectural traditions imported to Louisiana, traces of which are later found in the Creole cottage. The use of timber for both the vertical and horizontal framing, as well as foundation, for instance, is ubiquitous in provincial French architecture. Given its abundance, ease of procurement, and superb thermal performance compared to stone, timber was the constructional material of choice for provincial French layman in both northern and southern regions. Before evolving to stone foundations, the origins of both the *poteaux-en-terr* (post-in-ground) and the later *poteaux-sur-solle* (post-on-sill) timber foundation methods are both found in medieval France and England (Chapelot 1985, 247). Optimum thermal performance, however, came from the hybrid assembly comprised of a timber frame and a substantially thick, non-load bearing infill material, particularly in the colder and more humid regions of northern France. The implementation of materials such as wattle and daub, cob, and turf infill are thus frequent in early rural French architecture. The application of cob infill, for instance, resulted in thermally massive wall sections often in excess of 20in (50cm) (Chapelot 1985, 254-259). A distinct resemblance emerges between the medieval use of unfired clay or mud, reinforced with hay or straw, and the *bousillage* infill initially implemented by French settlers in 17th century Louisiana. Even the earliest versions of the Creole cottage in Louisiana, a form of the *poteaux-en-terr* method, consisting of a palisade of vertical posts, is an adaptation of a similar method used in the southern regions of France. The use of Spanish red moss in place of hay or straw as a binding material in the infill mixture was an influence of the indigenous Native American traditions (Cazayoux 2007, 2). This cross-pollination of methods and details early-on with the native cultures of North America by the French is perhaps one of the earliest demonstrations of the development of a unique Creole architectural typology.

Another element inherited by the Creole cottage of New France was the central masonry hearth and fireplace, a characteristic feature shared by both impermanent structures in the Colonial south and French provincial architecture. The necessity of a cooking-fire, sheathed in masonry to protect it from the surrounding wooden structure, was paramount even during periods of initial occupance and was ubiquitous from the New England region to Virginia (Carson et al. 1981, 158). Not coincidentally, in response to climate, the masonry of the chimney acted not only as a thermal mass for reradiating heat centrally in the winter but also would have provided a modicum of stack-effect ventilation, a result of the height of the chimney, during warmer months. The French, then, were well-equipped with an environmentally-adapted architectonic 'kit of parts,' so-to-speak, as they moved southward from Canada.

As early as 1732 the structures built by the French in the upper Mississippi valley, particularly in Illinois, can be viewed as intermediary snapshot into the evolution of the Creole typology that would later emerge much farther south. Employing the distinctive massive wall construction, comprising of *colombage* frames, *bousillage* infill, and *poteaux en terre* structure, these buildings were clearly more adapted for a colder climate. New elements are introduced at this time, however, such as exterior gallery spaces, that begin to allude to the dynamic atmosphere of French settlement architecture in varying climates across North America. These elements are demonstrated in structures such as the Cohokia Courthouse, built in 1737 by Captain Jean-Baptiste Saucier in Cohokia, Illinois.

Re-Adapting For Climate

The series of developments made to this initial prototypical form, once the French had settled in Louisiana, were primarily reactive and occurred rather rapidly out of necessity. These developments were influenced particularly by Caribbean and Spanish architecture, but motivated primarily by climatic factors such as the effects of seasonal hurricanes, flooding and the persistent heat and humidity. These were all critical to the shaping of the raised Creole cottage (Cazayoux 2007, 3). As will be discussed, some features imported from overseas added to the performance of a building in this climate, such as the use of a slate roof for instance.

The key to an optimally tuned building in a hot-humid climate, as mentioned earlier, and as is demonstrated by vernacular structures in similar climates globally, is ample ventilation—both within the building and around it.[5] To the benefit of extending the longevity of a structure by protecting the timber frame from moist soil conditions and flooding, it was quickly was raised off of the ground. An account by architect Benjamin Henry Latrobe of early 19th century Louisiana attests to the conditions in New Orleans that were the catalyst for such a response by describing the difficulty of burial given the incredibly high water table in New Orleans, "There are two or three graves open and expecting their tenants; eight or nine inches below the surface, they are filled with water, and were not three feet deep" (Crété 1981, 46).

In plan, the Creole cottage also began to evolve from the basic *sallet-et-chambre,* or parlor and bedroom layout, and expand into more permanent settlements capable of accommodating larger families. From a single room, the cottage expanded to a two room configuration, which is commonly referred to as the Norman plan. The core rooms typically opened to an elongated covered gallery that extended the length of the house while a covered loggia in the rear, referred to as a *ti galerie,* provided additional ventilation. Houses in this style were popular along the waterways of Colonial Louisiana during the 18th and early 19th centuries (Edwards 1994, 158). A second primary grouping of building plans were significantly larger, and symmetrically planned around a center parlor or *salon.* The distinction to be made between these two plan types is the

[5] For more information on similar global vernacular responses to hot-humid climates see the work of James Marston Fitch *Primitive Architecture and Climate* and *History of Climatic Influences in Building Design.*

emphasis on symmetry and the incorporation of open-air spaces. The Pitot House can be described as a combination of these two layout types.

As mentioned, two key architectural influences shaped the further development of the raised Creole cottage in Louisiana: the effect of the previous experience that the French had already gained in the Caribbean, another hot-humid climate, just before arriving in Louisiana, and the influence of Spanish authority over Louisiana at the time the initial prototypical style was implemented.

Caribbean Influences

Unlike the typical French Creole house, which evolved little from the imported traditional primitive cabin traditions, the raised Creole cottage in Louisiana bears a strong resemblance to the symmetrical geometry of Caribbean structures in the West Indies. Given that many of the settlers of the Tidewater and Gulf Coast regions, and in Louisiana specifically, spent a significant amount of time in the West Indies engaging in various commercial enterprises, historians believe that this implies a considerable level of cultural diffusion took place. A focus on the colony of Saint Domingue is of primary importance to tracing the outside cultural influence on the domestic architecture of New Orleans and the raised Creole cottage building typology (Edwards 1994, 155-156).

The domestic architecture of Saint Domingue, which is also located in a hot-humid region, was also heavily driven by climate; concerns for providing ample ventilation influence the lightweight, predominantly vegetal constructions, while shading from the overbearing sun was provided by a similarly lightweight thatched or shingled and often oversized roof. Examples of this type of building are found equally distributed throughout the Caribbean, such as the *bohios* of Cuba or the *La kay á lo* of Haiti (See Figure 19 and 20). Apparent in both of these typologies is the presence of a gallery covered by a protruding shading element of some form. It is also argued that the there was a significant influence by the British presence in the West Indies that accelerated the assimilation of this building feature into the contemporary domestic architecture in the Caribbean at the time. Jeffrey Cook theorizes that British naval and army officers stationed in the West Indies in the 18th century played an important role in the incorporation of piazzas, verandas, and gallery spaces to accommodate the hot and humid climate of the Caribbean (Cook 2002, 356). These architectural features became a characteristic feature of naval hospitals in the West Indies, in what was then the British Empire; it is not unreasonable to believe that this could have influenced the import of this environmental innovation to colonies along the Gulf during this period as well. The construction date of the Pitot House, 1799, chronologically coincides with this new influx of Caribbean ideas which reached a peak between 1791-1810 as a result of the Haitian Revolution (Edwards 1994, 248). Furthermore, James Pitot had been living in Saint Domingue for nearly ten years at this time, and was forced to leave Cap Français during the same slave revolts that swept across the entire island in 1791 (Pitot 1979, xx). It is certain that the domestic architecture of the West Indies, and its environmental efficiency at alleviating the climatic discomforts wrought by a hot and humid climate would have made a lasting impression on him arriving to New Orleans from the West Indies in 1796.

Spanish Influences

The year when James Pitot arrived in America happened to be a pivotal and transitional period for Louisiana. Spain accepted Louisiana from France in 1762, somewhat hesitantly; political antipathy of the Spanish was pervasive throughout Louisiana, "among Louisianans, there was the feeling that Spain regarding the colony as a necessary liability in which her expenditures exceeder her revenues"(Pitot 1979, xix). Nearly four decades after this exchange, formalized by the Treaty of San Ildefonso on October 1, 1800, Louisiana was retroceded to France. In the relatively short period between these two events, however, the influence of Spanish control over Louisiana was apparent. The influence on domestic architecture in New Orleans was no exception.

A surge in new architectural commissions in New Orleans as a result of the inflow of prominent Spanish political figures and merchants gave rise to new building types such as the densely, urban-scaled townhouse typical of the Spanish Colonial period. Interestingly, Bartholemé Bosque, the Spanish merchant who commissioned the Pitot House first commissioned such a building on Chartres Street, in the city center, four years earlier (Wilson 2011, 7). The Chartres Street house, similar to the Pitot House, was a double story, brick between posts structure a slate roof and covered, exterior galleries. What is perhaps most significant however is that the Spanish had a distinct influence on the choice of constructional materials employed in domestic architecture in

New Orleans during the mid to late 18th century, primarily in response to the growing anxiety over the risk of fire.

The first great fire to strike New Orleans occurred on Good Friday in 1788, surprisingly on the site where Bosque constructed his first residence in New Orleans, and destroyed nearly nine hundred buildings (Wilson 2011, 7). It was not until the second great fire to strike New Orleans, however, in 1794 that the Spanish enacted strict building regulations specifying the use of robust masonry construction (Poesch and Bacot 1997, 35-36).

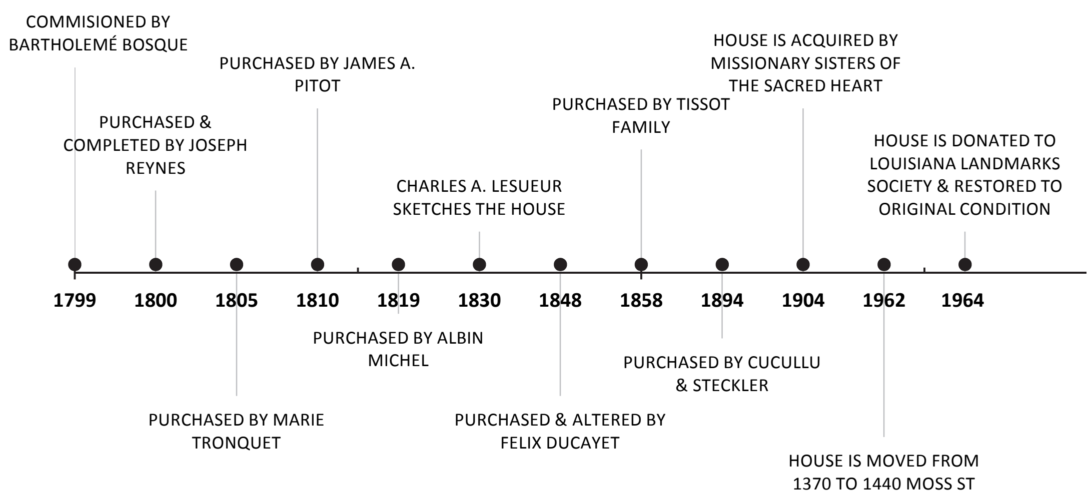
> Fires were a constant source of anxiety. There had been two particularly devastating fires in living memory, one in 1788 and one in 1794, and the inhabitants of New Orleans were extremely fire conscious. It was forbidden to construct new dwellings in the Vieux Carré in any material other than brick, and in recent years shingle roofs had been replaced by tile. (Crété 1981, 59)

It is not inconceivable then to believe that in commissioning his new home, Bosque would have advised or recommended to his architect, the supposed Hilaire Boutteé—who had himself, firsthand experience with design a number of other replacement buildings destroyed during both fires—to specify the use of slate roofing tiles and masonry walls.

Chapter 4: The Pitot House

> "Similar in a way to Egypt, in its floods, climate, products, and fertility, in antiquity it was neither the cradle of the arts and sciences that have enlightened the world, nor the storehouse of a commerce as valuable as it was rich, which exposed Egypt to so many revolutions, and which has recently made it of great importance in European affairs. Always uncivilized and listless in the past, the present begins to smile on Louisiana, and the future should make it a flourishing colony" –James Pitot, 1802.[6]

Brief History & Ownership Timeline



The building that is referred to today as the Pitot House was constructed circa 1799 by a Spaniard, Bartholeme Bosque on the Bayou St. John in New Orleans. The direct Spanish influence on the design of the house, both with regard to its spatial

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[6] For more detail regarding James Pitot's initial impressions of Louisiana, particularly regarding climate and environmental conditions, refer to Pitot, James. 1979. *Observations on the Colony of Louisiana, from 1796 to 1802*. Baton Rouge: Published for the Historic New Orleans Collection by Louisiana State University Press.

organization but also material choice, is significant and will be discussed in depth later in this chapter. Although commissioned by a Spaniard, historians today believe that the design of the house is accredited to Hilaire Boutté, a prominent Louisiana architect-builder whose work spanned the late 18th and early 19th century (Wilson 1982, 9). Prior to being acquired by James Pitot on April 3, 1810, the house and property at 1370 Moss Street experienced three different periods of ownership. Following the commission to construct the house, but prior to its completion, Bosque sold the property to Joseph Reynes in 1800, who completed the construction of the house. On June 22, 1805 Reynes sold the house to Marie Tronquet, widow of Vincent Rillieux, who occupied the house until selling it to James Pitot five years later (Pitot House 1991). Felix Ducayet purchased the property from the Albin Michel family, who had owned the house for twenty-nine years; it was Ducayet who altered the roof by constructing a hip-roof with a steeper, single pitch as well as adding two dormers to the west elevation (Daspit 2004, 76). The home was owned by the Tissot family from 1858 to 1894.

The last period of ownership was under Mother Xavier Cabrini who transformed the house into a convent for the Missionary Sisters of the Sacred Heart before donating it to the Louisiana Landmarks Society in 1964, when it was moved from 1370 Moss Street to 1440 Moss Street, its current location. It was at this time that the house was returned to its original configuration: most notably, the added dormers were removed, the original multi-pitch roof was restored, and an enclosed exterior staircase, that had been added in the 19th century, was also eliminated (Daspit 2004, 76-78). The restoration was guided by a hand sketch of the house and surrounding grounds dating to 1830[7] (See Figure 21). The sketch was made by Charles-Alexandre LeSueur, a French naturalist, illustrator, and amateur architect residing in New Harmony, Indiana at the time, and who would make frequent trips to New Orleans to document the native flora, fauna, landscape, architecture, and people (Stroud 2000). The sketch was critical to the restoration of the house, and it is also a key piece of information that will be used to validate the surrounding terrain and boundary conditions when designing both the indoor comfort and CFD simulations.

Configuration & Design

In 1813, after being sold by Pitot to Beverly Chew and Richard Relf, and while it was still in its original configuration, the house was described as such:

> FOR SALE. That handsome and agreeably situated property, occupied by the Hon. James Pitot, on the Bayou St. John, consisting of about 30 superficial acres; and on which there is a large convenient and extremely pleasant dwelling house, and out houses, such as kitchen, servants houses and fowl houses, stable, carriage house and barn; all in the best order. The garden is extensive and in good order…planted with choice fruit trees, 16 or 18 acres of the land is enclosed in meadow, and the remainder wood land. (Wilson 2011, 19)

The house today sits within a suburban setting, however historically, as can be seen from LeSueur's sketch, the house was considerably less bounded. The absence of a dense urban landscape surrounding the site would have allowed for distinctly higher wind speeds due to the lack of an urban boundary layer condition. The structure is

[7] At this time, the house was occupied and owned by Albin Michel.

situated on a partially skewed north-south axis[8]. This axis is a product of the building's relation to the adjacent Bayou St. John; it is an architecturally defining feature of the raised Creole cottage to position the roof ridge beam in parallel to the primary road or nearby river (Edwards 2004, 80). In plan the Pitot House is fundamentally composed of covered exterior gallery spaces, and primary as well as secondary interior occupied spaces.[9] Functionally, the massing of the house raised is raised, and sits upon a masonry *rez-de-chaussée,* or ground floor. Within the context of the vernacular typology, this ground floor was considered a form of an above-ground basement, within which were allocated the utilitarian spaces of the house such as kitchen, office, and storage spaces. The ability for this ground floor space to remain cool during the hottest and longest days of summer was a critical feature for spaces occupied during the day. The ability to exhaust the high internal gains of the kitchen and to cool spaces dedicated to the storage of goods and to work was a characteristic environmental behavior of the house.

The ground floor is flanked on the south and west elevations by twelve Doric, masonry columns that enclose the exterior gallery and support an identical gallery space on the second floor above. On the interior, each floor consists of a three larger rooms on the west, and two smaller rooms on the east that each sit on either side of an exterior, recessed loggia (no.106). This spatial organization is typical of similar houses

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[8] The primary axis of the house is approximately 60° from true north. See Figure 42 for a site plan of the house.

[9] For this purpose of identification, the room numbers from the 1991 HABS documentation will be used. See Figures 9 & 10.

built in Louisiana during the Colonial period (Wilson 2011, 8-9). Vertical circulation is accommodated by an exterior stair located within this loggia space.

On the ground floor, the larger center space acts as a dining room (no.103), and is adjacent to a foyer and office space to the north (no.102). The dining room is adjacent to an office storeroom (no.104). The dining room is centered upon the ground floor and is another typical feature of similar houses during this period. A kitchen occupies the smaller room in the southwest corner, referred to traditionally as a *cabinet* (no.105); a second, symmetrical *cabinet* is located in the northwest corner (no.107-109). Traditionally, the kitchen spaces were always compartmentalized away from the rest of the spaces in the house due to the risk of fire, often occupying outbuildings entirely detached from the main house (Wilson 2011, 9).

Each room on the ground floor is provided with abundant access to the exterior, either by placement of windows, French doors, or a combination of both. The emphasis on openness, whether by incorporation of dedicated covered exterior spaces, such as the gallery, or by increasing the wall to opening ratio, is an architecturally defining feature of the raised Creole cottage. This feature will be critical to the understanding of the environmental behavior of the building and is particularly emphasized due to the fact that the majority of these openings are shielded from solar radiation by the exterior galleries.

The second floor is organized similarly in plan; the primary difference being that the central space is occupied by the parlor (no.203) and is flanked by two bedrooms (no.202, 204). The *cabinets* house additional, smaller bedroom spaces. The centerlines of the heavy masonry columns continue up from the first floor and are replaced with lighter, wooden colonnettes that support the roof above the gallery. The Pitot House also has two centralized, masonry chimneys; they are located in between the three larger, west facing spaces on each floor.

Construction & Materials

An understanding of the methods and materials used in the construction of the Pitot House are critical to demonstrating its environmental behavior, especially during the summer season during which exterior environmental loads are the most severe. The primary structure of the house is comprised of load-bearing masonry walls on the ground floor and load-bearing masonry columns in the galleries spaces that support the second floor. These masonry walls and columns on the ground floor were historically covered with plaster and the overall wall-section is approximately 18" thick.[10]

Walls on the second story are constructed in a different manner using a *columbage* or half-timber framing method in which masonry is used to infill a primary, heavy timber structure (See Figure 12). Where the exterior walls are offered protection from the elements by the gallery they were coated with plaster; the exterior faces of walls that were left exposed, on the north and east elevations, were clad with wooden shiplap siding boards (See Figure 13). The cross-sectional width of the walls on the

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[10] The overall wall-section thickness is approximated based on scaled architectural drawings provided by HABS.

second story is significantly reduced compared to the ground floor, given that the masonry is acting as infill and not as the loadbearing structure; these walls are approximately six inches thick. Similarly, the construction of the floors on the second floor differ considerably than that of the first floor. The floors of the second story are constructed from gap spaced floor boards; it is assumed that the spacing is not strictly uniform, but is approximated at one half inch for purposes of this investigation. The exposed, beaded wooden beams and ceiling are typical of French Colonial architecture in New Orleans during this period (Edwards 2004, 80). The floor of the first story, which sits on grade, is constructed of masonry (See Figure 14). The secondary structure within the house, supporting the floors and spanning between the loadbearing walls, is a heavy timber construction (See Figure 17). These timber members are left exposed on the interior, and are highlighted as an architectural feature as they are beaded in each room of the house (See Figure 15).

The roof is supported by a variation of a heavy timber Norman truss structure as was typical of French Colonial architecture in Louisiana at this time (See Figure 16). Typically, a Norman truss is a through-purlin truss that is comprised of a collar tie beam, doubled "truss blades" to support the purlins, and a center post to support the ridge beam[11] (Edwards 2004, 142-143). The structure at the Pitot House differs slightly in that the roof trusses lack the center king post. A layer of gap spaced wooden planks act as a

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[11] For more detailed information on Creole vernacular timber structural elements refer to *A Creole Lexicon: Architecture, Landscape, and People* by Jay Dearborn Edwards.

nailing substrate for the slate tile roof. According to the available architectural documentation of the house, the slate tiles on the roof, too, were loosely set (Pitot House 1991). The gap spacing of these elements is not uniform, however what is significant is that while the roofing assembly acted to shed rainwater falling on its exterior face, given the spacing of both the planking and tiles, it did little to impede the flow of air across the envelope—a significant detail that will be discussed at length in the following chapter.

Chapter 5: Inbuilt Environmental Features of the Pitot House

The Pitot House is host to numerous inbuilt environmental features, many of which have been touched upon already in this investigation, and that have helped to differentiate it from a run-of-the-mill Louisiana cottage. These features transformed the Pitot House into a well-tuned machine for providing comfort for its occupants, centuries before the advent of modern mechanical systems. In general, the environmental systems at the Pitot House each focus on modulating ventilation, solar radiation and re-radiation. An adequate place to begin is with the larger, fundamental architectural elements of the house.

Galleries

Perhaps the most significant environmental elements present on the Pitot house, and certainly some of the most architecturally distinguishing, are the galleries that enclose the building on the south and west faces. The timber framed gallery extends approximately nine and half feet from the face of the building; the floor surface is paved on the ground floor, and constructed from wooden floor boards on the second floor. Environmentally, this gallery acts as a buffer as it shields the building face from some of the harshest solar loads from the south and west (See Figure 44). The floors of the gallery spaces were not just solar fans; the entire gallery itself acted as an additional space for interior activity to spill out into when the conditions were right. By operating the window and French doors, the boundary between interior and exterior could be flexibly adjusted to fine-tune comfort both inside the house and outside, in the gallery.

Often this meant that the gallery spaces had both a daytime and nighttime function. Of life daily life in Louisiana during the early 19th century Lilian Crété writes, "In the daytime, the inhabitants stepped out on the balconies to take the air; in the evening, they dined in them and enjoyed the evening breeze from the river"(Crété 1981, 255). This being said the depth of the galleries is such that the thermal mass of the masonry walls are left exposed to the lower angles of the sun during the winter, as low as 39° above the horizon compared to 83° during the peak of summer, helping to add thermal gain to the spaces within. Furthermore, in addition to moving between rooms directly on the interior, the galleries also provided the primary means of circulation through the rooms of the house on each floor, as halls and corridors were not a common architectural elements of the Creole cottage or plantation house type (Cazayoux 2007, 5).

The evidence of chair rails and baseboard trim in the gallery spaces indicate that these were functioning elements of the program and not simply shaded exterior spaces (Henry 2007). A hypothesis for the position of the galleries exclusively on the south and west sides of the building is directly related to the availability of wind to the building. The abundance of air flow, the restraint of solar load, and the view of the Bayou are driving factors in the location of the primary galleries on the south and west sides of the house. However, architectural features alone did not make for a comfortable gallery space; what makes the galleries at the Pitot House particularly environmentally unique is their seasonal operation.

Again returning to the hand sketch of the exterior of the house by Charles LeSueur (See Figure 21), canvas curtains can be discerned hanging from the timber framing in the second floor gallery (Wilson 2011, 24). These curtains are part and parcel of the environmental system of the Pitot House; seasonally operated, they provided additional shading from the particularly harsh western sun in the summer, and a heavier variety would have provided an insulative buffer layer during the relatively benign, yet occasionally uncomfortable winters. By modulating this transient barrier system, it was possible to precondition the air in gallery spaces on both floors. The evidence of the hooks used to hang these curtains can still be seen at the house today (See Figure 15).

Operable Features

As previously mentioned, the emphasis on openness and connection to the exterior is a defining feature of the raised Creole cottage. Collectively, at least sixteen percent of the wall space of the rooms at the Pitot House is allocated to an operable feature such as a window or door (See Figure 32). Larger spaces, such as the central dining room and parlor have a higher percentage of openings, upwards of twenty percent. The second floor parlor has the highest percentage of openings, approximately twenty-six percent. The only other two rooms with a measure of openness exceeding twenty percent are the office and foyer on the ground floor. When the interconnectivity of the contiguous spaces are considered, and connected rooms are regarded effectively as single zones, the percentage of free-air wall space increases considerably. On the ground floor, when accounting for the ability that occupants would have had to operate interior doors, the opening-to-wall percentage is redistributed to a collective eighteen percent. The same is true for the second floor where the collective window-to-wall percentage normalizes to twenty percent. In this way, along with the increased opportunity for natural ventilation also comes the increased ability to fine tune its speed and distribution.

These features are no series of coincidences. Given the particular air flow pattern through the house, the programmatic organization of the house, although asymmetrical, was not haphazard, and clearly took full advantage of the predominant winds available on the site.[12] The integration of transoms also was particularly innovative for their ability to exhaust higher temperature air that gathers along the ceiling during the day. This being said, the Pitot House was tuned remarkably well for allowing its occupants a wide range in control over the behavior of the house with regard to self-regulation of interior conditions by way of opening and closing primary fenestration elements such as doors and windows. A second layer of adjustment was also provided in the house in the form of shutters and ceiling-mounted paddle-fans on the interior for fine-tuning airflow on the interior.

Materials

The use of masonry in the Pitot House is idiosyncratic for its building type, a hybrid byproduct of the constituent architectural influences that are responsible for its

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[12] These calculations are approximate and include all windows and doors, both interior and exterior, as the interconnectivity of the rooms was exploited for maximum cross ventilation.

resultant typological form, a topic which will be discussed in detail in the following chapter. However, what is significant is that the use of masonry in a hot and humid environment seems counterintuitive, however its strategic implementation in the house allows for its thermal mass to act in favor of reducing interior temperature during the hottest of summer. The thermal mass of the masonry walls at the Pitot House act as a heat sink, thermally grounded to the relatively constant temperature of the ground, which in New Orleans is approximately 20.3°C (68.55°) year round at a depth of 0.5 meters (20inches) below the surface.[13] Even during the hottest month, where the exterior dry bulb air temperatures can exceed 36°C (97°F) the ground temperature is a constant ten degrees cooler. Additionally, the masonry exterior was coated in white plaster, which helped to keep the first floor cool by moderating the mean radiant temperature of the spaces on the interior. The mean radiant temperature of the interior walls governs the rate at which the body radiates heat to the surrounding space and vice versa; thus, added thermal comfort could be achieved by keeping the interior surfaces of the walls cool during the day.

The Horizontal Envelope: Roof & Attic Design

The configuration of the roof at the Pitot House is a remarkably significant feature of its environmental design. The roof shape is characterized by Edwards as a class II broken pitch hip roof, also referred to as a witch's cap or bonnet roof (See Figure

[13] The temperature at the surface of the ground is actually quite similar to the average annual ground temperature up to a depth of 4 meters below the surface.

18) (Edwards 2004, 59). In many ways the various inbuilt environmental features of the Pitot House are united in function at its roof. Essentially, the particular pressure distribution pattern across the roof envelope of the raised Creole Cottage and of the Pitot House is a function of its fundamental roof geometry. That is, the double-pitch hip roof has distinct airflow qualities and advantages over a standard gable-end roof. First and foremost, the hip roof, particularly the double-pitch hip roof that is so characteristic of the Creole Cottage in New Orleans, is simply more aerodynamic. As mentioned earlier, in typical New Orleans raised Creole Cottage fashion, the roof ridge is aligned in parallel with the adjacent river or bayou. This feature would place the flat end of a gable roof abruptly in the path of incoming predominant airflow across the site. Whereas, the same building massing with a hip roof reduces the cross-sectional area exposed and allows for a more streamlined airflow distribution over the building and roof (See Figure 27). CFD analysis helps demonstrate that, in a purely geometrical regard, had the Pitot House been constructed with a standard gable roof, the movement of air and distribution of pressure around the building would have been significantly altered (See Figure 28 & 29).

In terms of pressure distribution, which is key to uniformly ventilating the spaces of the Pitot House, a hip roof allows for a much more even distribution across the building from windward to leeward. An otherwise abrupt roof edge causes the buildup significant positive pressure on the windward face of the building, the south elevation in the case of the Pitot House, and negative pressure on the leeward face of the building

(See Figure 28). Apparent in the analysis of the gable roof is the distinct neutral pressure plane that appears in plane with the south elevation. This plane demarcates an abrupt switch from positive to negative pressure. As airflow within the house is driven by the equalization of pressure from areas of higher, or more positive pressure to areas of lower pressure, the location of this plane is critical. What is noticeable in the hip roof variation is that much lower pressures are present on the leeward side of the house (approximately between -10 and -11 pascals) compared to the gable roof variation (approximately between -3 and -8 pascals). Furthermore, it can be seen that the pressures along the length of the hip-roofed house are much more evenly distributed. This is in contrast to the gable roof variation in which a less stratified dispersal of values occurs. This distribution pattern can cause drastically increased and uneven airflow circulation on the interior, concentrating flows only between openings without allowing the flow to deaccelerate and disperse through the central spaces in the house such as the dining room and parlor.

Furthermore, the space enclosed by the broad roof lines is rather expansive: in the particular case of the Pitot House, the floor area of the attic space alone is approximately 231m^2 (2486ft^2), and contains approximately 291m^3 (10,276 ft^3) in volume. This is a considerable volume of air. This enclosed attic space was typically never considered a part of the living space of the raised Creole cottage and as such was not used during day-to-day living (Fricker 1984, 2). However, the roof and attic system still performed a significant environmental function for the Pitot house, which is commonly referred to as “Night Flushing.”[14]

The basic principle behind night flushing is to replace hot, stale air that accumulates within the building during the day with cool, fresh air at night. This can be achieved a number of different ways, however the primary means takes advantage of stack effect and the thermal buoyancy of hot air. Naturally, hot air rises, and due to the gap spaced floor boards is permitted to collect in the attic space in the Pitot House. To facilitate this process, the thermal mass of the slate roof, having stored a significant amount of solar gain during the day, amplifies the convective flow within the attic, heating the air further and forcing it to exhaust through the gap spaced roofing assembly. Lastly, given the prevailing wind speed and direction, enough of a pressure differential exists between the windows and doors of the first and second floors and the roof surface to forcibly draw air vertically through the house, effectively ventilating each floor passively. This will be demonstrated later in this investigation. Most importantly, however, is that in combination with thermal mass walls, such as in the Pitot house, the night flushing strategy works especially well. Daytime surface temperatures in a building with significant thermal mass wall construction can be reduced by up to 3°C (5.4°F) as a result of sub-cooling interior surfaces and fabrics at night (Griffin 2010).

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[14] For more information regarding night flushing refer to Griffin, Kenneth A. 2010. "Night flushing and thermal mass: Maximizing natural ventilation for energy conservation through architectural features." 1476151 M.B.S., University of Southern California.

Chapter 6: Analytical Methodology

The analysis methodology involved in this investigation is separated into four segments, each corresponding to a different scale of the analysis, and is at each step informed and validated by the aforementioned historical and documentary research. In support of the thesis, to illustrate that the case study building typology, in fact, provided adaptive comfort in the absence of mechanical systems, four scales are studied ranging from the macro-scale environment of the building situated on its site; the response of the interior environmental conditions on each floor to the fabric of the building, namely the thermally massive wall construction and inbuilt environmental features; the resultant airflow through the interior spaces as a result of both interior and exterior factors; and lastly, the micro-scale behavior of the building, namely the subtle, vertical, convective movement of air through the gap-spaced floorboards and slate roof tiles at night—otherwise referred to as 'night flushing.' To achieve these results and to visualize the resultant behaviors a series of computational simulation tools and methods will be employed separately yet in synchrony to achieve a comprehensive result, that being twofold: the visualization of natural ventilation within the space; and the resultant levels of indoor comfort, taking into account indoor operative temperature, relative humidity, and air speed.

Summary Climate Analysis

In order to accurately define the necessary scope of the investigation an analysis of the hot-humid climate is required. Furthermore, as replicability is of utmost significance to this thesis, it is important to note that second to historical and documentary research, a thorough understanding of the particular climate that the building typology is located is critical. In order to ensure consistency, each of the simulation methods used rely on verified meteorological data compiled by the National Renewable Energy Laboratory (Wilcox 2008). Specifically, a typical meteorological year (TMY) is referenced in order to capture the most accurate representation of the climate patterns of the given site. In this way, the influence of climate on the building is not limited by the availability of historical meteorological data, specific to a given year. The vicissitudes in climate was among the first things observed by James Pitot upon arriving to Louisiana in 1796:

> When I arrived in Louisiana in August, 1796, all existing circumstances indicated to me that the colony was in a distressed state…Its debt-ridden planters and completely ruined agriculture—the result of either the weather's uncertainty, destructive hurricanes, or the fury of a river which during five or six months every year threatens to swallow up all the inhabitants along its banks. (Pitot 1979, 3)

Access to this data, although illuminating in its own right, is not particularly helpful to this thesis. Furthermore, the occurrence of meteorological phenomena, such as hurricanes, can considerably influence annual data from year to year. One such event caused significant damage to the Pitot House in 1962. For the reasons described, it was imperative to use compiled typical year is necessary for use in simulation.

The most recent data, compiled in the TMY3 format, was sourced that samples records spanning a period 1991-2005 to create a compiled hourly dataset representative of an average year.[15] This being said, four weather data source locations are available for the given site, however the New Orleans International Airport was chosen due to its geographic proximity as well as for the reliability and availability of the most up to date TMY3 data (See Figure 23).[16]

As mentioned earlier, New Orleans is located in a heavily environmentally loaded region. Using the international climate zone definitions published by ASHRAE, the city of New Orleans is located in climate zone 2A and is categorized as "hot-humid"[17] (See Figure 22). A study of the annual psychrometric conditions in New Orleans reveals the exact nature of the elevated levels of year round temperature and relative humidity (See Figure 39). The highest concentration of conditions are characterized by approximately 26°F and 80% relative humidity. The full temperature range, annually, on the site is between -3°C to 36°C (26°F – 97°F). Diurnally, temperatures in the summer can swing between 23° and 34°C (73°-93°F). Given the elevated humidity and

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[15] For more information on the source, format, or collection methods involved with the TMY weather file visit https://energyplus.net/weather/sources or refer to the *User's Manual for TMY3 Datasets* published by the National Renewable Energy Laboratory.

[16] Louis Armstrong New Orleans International Airport is located approximately 15 miles directly west of the site. The TMY3 weather data for this location can be acquired at https://www.energyplus.net/weather-download/north_and_central_america_wmo_region_4/USA/LA/USA_LA_New.Orleans.Intl.AP.722310_TMY3/all.

[17] For more information on the international climate zone definitions refer to ANSI/ASHRAE/IESNA Standard 90.1-2007 *Normative Appendix B-Building Envelope Climate Criteria, Tables B-2, B-3, and B-4.*

temperature levels, the risk of heat stress is this particular climate is great, which emphasizes the importance of evaporative cooling and the availability of natural ventilation.

Winters in New Orleans are relatively benign, although temperatures do occasionally reach freezing (See Figure 40 & 41). From September through February, temperatures range between 10°C and 25°C for a considerable portion of the season; the real issue during the winter months are the elevated levels of relative humidity.

Wind speed and direction onsite are of utmost importance to this investigation as these factors have a significant influence on the perception of comfort in this hot-humid climate. The predominant wind frequency at the data source location originates from the south at an annual average speed of approximately 3.48m/s at approximately ten meters above grade (See Figure 43). However, it should be noted that it was necessary to calibrate the wind speed data for the appropriate height at the Pitot House before using it in the simulations. As the wind speed and direction is gathered at an international airport, the height at which it is monitored is typically ten meters above grade. Once adjusted, the average annual wind velocity from the south at the Pitot House is approximately 2.52m/s at one meter above grade to 3.11m/s at five meters above grade (See Figure 42).[18] Lastly, it was necessary to specify the nature of the

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[18] The wind profile power law is used here to adjust the height from which wind speed and direction was sourced, approximately +10m, to a height that is calibrated to the scale of the Pitot House.

surrounding terrain to accurately approximate the wind speed on site. To do this, historical documentation was consulted to provide an accurate result.

Establishing Historic Boundary Conditions

In describing the terrain of Louisiana, it should first be noted that Louisiana as a state, according to a recent study based on data compiled by the NASA Shuttle Radar Topography Mission, is the fourth flattest state in the continental US—second in terms of percentage of state area in the flattest category (Dobson and Campbell 2014). Through a more detailed lens, a combination of maps and historical excerpts written about the Pitot House at various points since its construction help portray the specific boundary conditions of the surrounding site, and help to understand the behavior of wind around the building.

A map of New Orleans and its surrounding environs dating from 1798 was an invaluable resource for interpreting the boundary conditions surrounding the Pitot House at the time it was constructed (See Figure 24). It is clear from the map that in 1798 little existed beyond the city center of New Orleans other than cypress swampland, particularly along the Bayou St. John, where the Pitot House is located. And although the formal boundary of the city expanded significantly in the twenty years that followed, the Pitot House remained on the fringe between the suburban developments expanding northward from the Mississippi river and the cypress swamp forests to the north (See Figures 25 & 27). An 1834 map made by Charles F. Zimpel provides a closer look at the Pitot House parcel and those adjacent to it. Clear is the bend in the Bayou St.

John, providing an open vista to the south and the expanse of wooded lots to the east (See Figure 26). By 1819, when the house was again sold, an advertisement of the property still referred to it as a country residence:

> A handsome country seat, situated on the bank of the Bayou St. John, near the bridge, the late residence of the Hon. James Pitot, consisting of a tract of land 200 feet front on the Bayou, running back 8 arpents, where it opens to the width of 470 feet, extending back 12 arpents, distributed over a flower and vegetable garden and an extensive meadow, the back land well supplied with wood. There are on the premises a large convenient two story dwelling house, kitchen, barn, and other out houses, rendering it a desirable country residence. (Wilson 2011, 20)

In finer detail, the hand sketches made by Charles-Alexandre LeSueur in 1830 show the immediate surroundings of the house, depicting a country-side setting where neighboring cypress tree canopies outnumber and outweigh the neighboring buildings (See Figure 21). Even during the period of urbanization, the house is left quite exposed to the south due to the bend in the Bayou St. John. The open expanse of waterway would have provided a clear avenue for predominant winds to approach the building. This being said, given the siting of the house and the hip roof shape, the availability of wind to the interior of the house would have been considerably amplified. There is some reason to believe, however, that the incorporation of onsite landscaping elements such as trees, shrubs, and low fences would have had some impact on the airflow behavior around the building. “The façade of the house was often partially obscured by trees and flowering bushes that both sheltered the building from the summer sun ad surrounded it with pleasant smells” (Crété 1981, 255). Evidence of these elements are visible in LeSueur’s sketch, however as they were not in the direct path of the prevailing winds from the south, their presence is not considered dramatically influential air flow availability to the Pitot house.

In establishing a boundary condition, the general categories available for the simulation are urban, suburban, country, and expanse of water; each refers to the presence of terrain roughness as well as the height and density of obstructing objects, such as buildings. Given the aforementioned historical evidence, namely the expanse exposed to the adjacent waterway, the boundary condition used for this investigation is most closely approximated by a country-type setting[19]. This option most closely represents the setting of the Pitot House before being subject to a series of modifications in the late 19th and early 20th centuries. This setting, within the context of the simulation, refers to flat ground with scattered objects that are less than ten meters in height.

Analysis Scope

As mentioned previously, the prototypical house design imported to New Orleans from France was already climatically pre-adapted to a colder climate and long winter seasons, given its thick, high thermal mass walls, and robust construction; the real challenge was to readapt for the hot, humid summers. The number of strategies for retaining heat and generating warmth significantly outnumbered those for staying cool

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[19] For more information on other possible terrain types refer to the Ladybug© primer found at https://github.com/mostaphaRoudsari/ladybug-primer/blob/master/text/components/Wind_Speed_Calculator.md.

during the early 19th century. The use of rugs on the interior to prevent drafts through gap spaced floor boards, heavy curtains in the galleries, and most significantly the adaptive concept of simply dressing warming during colder months were all popular adaptive strategies (Cazayoux 2007). This being said, due to the heavy dependence on sufficient air flow velocities in providing interior thermal comfort, it is the intent of this investigation to simulate air distribution within the house based on conditions during the hottest point on the longest day of summer, June 21. Being the longest day of the year in the northern hemisphere, the effects of the thermal mass roof, which relies considerably on maximum solar gain exposure, will be most apparent.

Delimitations

The collective strategy for this series of investigations is to simulate a climatic worst-case scenario. A selective analysis period during June 21st is capable of addressing the widest sampling of the inbuilt environmental features of the Pitot House, including the effects of night flushing, thermal mass, and cross ventilation. A winter worst case scenario is not included in the scope of this thesis as it presents a number of variables in both the three-dimensional modeling and simulation phases that cannot be accounted for accurately. For instance, the simulation and representation of elements such as the hanging gallery curtains and placement of interior floor rugs—both elements critical to the wintertime “dressing-up” of the house—could only be vaguely approximated at best and might compromise the accuracy of the entire simulation. With regard to interior CFD studies, interior furniture is not accounted for, however it is not considered by the author to significantly affect interior airflow distribution. Similarly, not considered is stack effect from vertical flue elements such as chimney stacks; however, the high airflow rate through openings in the exterior envelope during the day and the considerable movement of air volume vertically at night likely would likely supersede this affect. Lastly, although accounted for within the exterior boundary condition, the presence of landscaping elements such as trees, shrubs, and fences or outbuildings were not modeled. These are considered variable and fugitive features that change throughout the history of the Pitot House. Given the openness to the south and west created by the bend in the Bayou and low adjacent urban density associated with the period modeled, the boundary condition established is considered to be the most appropriate in representing the conditions to which the Pitot House was most exposed to during its history.[20]

Modeling: Phase 1

In pursuit of simulating the environmental behavior of the Pitot House, multiple three-dimensional models were required, each representing a different scale of the analysis. As reference, the documentation provided by the Historic American Buildings

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[20] In fact, given the documented position of landscaping elements in the 1991 HABS drawings, these elements would have certainly only added to the shading benefit on the northeast and southwest elevations; not to mention, also redirect and concentrate airflow on the south elevation. Further analysis would be required to validate this.

Survey of the house from 1991 was used.[21] The first phase of the analysis involves identifying the manner in which prevailing winds interact with the building onsite. To do this, an exterior massing model was created using Rhinocerous3D® modeling software. Detail is limited in scale during this phase, however key architectural elements such as the rear loggia, gallery columns, the gallery floor, and protruding roof eaves are incorporated (See Figure 48). The boundary domain, given the scale of the building, is sized at 40m (131ft) in the transverse (east/west) direction and 60m (197ft) in the longitudinal (north/south) direction. This domain size proved adequate without causing any interference between the domain edges and the building.

A second stage is required to construct a mesh model of the geometry in preparation for use in computational fluid dynamics software. This is accomplished using the inbuilt meshing features in Ansys® Workbench. The details of this process can be found in Appendix II.

Simulation: Phase 1

Using the prevailing wind speed and data sourced from the EPW file, airflow around this model is simulated using Ansys® Workbench and Fluent® CFD simulation software. For the period of analysis, June 21st at 13:00, the average adjusted wind speed is recorded at 3.11m/s. The objective at this scale is to identify the pressure field that

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[21] Two sets of HABS drawings exist of the Pitot House. One dates from 1991, and is considered the most accurate to the original configuration of the house to which it was restored and moved. The other dates to 1965 and represents the condition the house was found in while it was occupied by the Missionary Sisters of the Sacred Heart and predates the move from 1370 to 1440 Moss Street.

results on the exterior surface of the building, particularly at each of the window and door openings. The resultant pressure gradients can then orthographically mapped onto the existing drawings (See Figure 31).

Modeling: Phase 2a

Having established the site behavior of the building, the second phase involves an investigation at the building scale. For this phase, a second three-dimensional centerline model is created that incorporates fenestration elements such as windows and doors, both on the interior and exterior. Interior partitions between rooms are also incorporated at this stage (See Figure 46). Two separate models are required at this scale. The first is used to establish a relationship between the interior environment as it responds to the behavior of the building fabric and the exterior conditions present during the analysis period. The object of this phase is to establish baseline values of interior dry bulb temperature, operative temperature, relative humidity, and mean radiant temperature. This centerline model does not indicate wall thicknesses as they are specified during the simulation phase.

Simulation: Phase 2a

To simulate the interior baseline conditions Honeybee is used, which is an open source environmental plugin for Rhinoceros3D and Grasshopper. The plugin allows for the creation and modification of energy models in Rhinoceros3D, but is built upon the standalone EnergyPlus™ energy simulation software[22]. The surfaces of each space are reconstructed within the software and assigned the requisite parameters: thickness, constructional assembly, material properties for each layer in the assembly, and boundary condition. The same is applied for the fenestration elements, however for the purpose of simulating maximum possible interior airflow, these particular elements are modeled as “air walls.” This setting allows for full transfer of heat across these boundaries, simulating an ‘open’ condition. Given that the scope of analysis is the worst case scenario, it is assumed that the doors and windows would have been opened fully to take full advantage of cross ventilation on both floors. The settings for the remaining opaque surfaces reflect the constructional specifications and material properties already discussed for the Pitot House in previous chapters.

The interior spaces are represented as zones within the software; as this is an energy simulation tool, it is necessary to specify each zone as unconditioned, ensuring that a passive environment is represented. Regarding airflow, it is also necessary to account for air movement between the spaces[23]. This is done mathematically and is a function of specified exterior wind speed, area of opening, and a specified inter-zone air

[22] For more information on the environmental plugins used refer to Sadeghipour, Mostapha Roudsari and Michelle Pak. "Ladybug: A Parametric Environmental Plugin for Grasshopper to Help Designers Create an Environmentally-Conscious Design." In 13th Conference of International Building Performance Simulation Association. Chambery, France, 2013.

[23] It is important to differentiate air flow within and air flow between zones. It is not possible during this phase using this particular software to simulate and account for air flow within the zones; this will be simulated next using computational fluid dynamics. Airflow between zones here simply accounts for the movement of air and heat between zones.

change rate that has been set to 0.3m^3/s per square meter of air wall contact to account for a historic building that relies on above-average interior air speeds.[24] As a result of this simulation, it is possible to derive the indoor surface temperature, outdoor surface temperature, operative temperature, indoor air temperature, mean radiant temperature, and relative humidity, among others.

Modeling: Phase 2b

A second model at the building scale is constructed in order to study the effect that exterior wind patterns and pressures have on interior air flow velocity. This model is effectively a representation of the indoor air volume of the building (See Figure 47). Given the programmatic organization of the spaces, this particular model is in actuality four models as the cabinet spaces on the second floor are not connected to the primary spaces to the west. Of primary concern in this investigation are the contiguous zones: the entirety of the first floor, with exception to room 107, and the primary rooms on the second floor 202-204. Similar to phase 2A, the model is meshed for CFD simulation, yet at a considerably higher resolution than at the site scale in order to achieve an accurate result. The mesh sizing is specific to each case, yet attention is paid to the inlet and outlet geometry as well as to the interconnections between spaces; a higher quality mesh is attained by reallocating mesh cells where greater detail is needed at these points (See Appendix II).

[24] This is compared to 0.0963m3/s for a standard, modern building with relatively low inter-zone airflow.

Simulation: Phase 2b

The CFD model used in this investigation is pressure based, and is designed to account for each exterior opening as an individual pressure inflow or outflow. These values are calibrated using the exterior surface pressures generated in phase one. This method is chosen over a velocity based inlet and outlet configuration primarily to maintain consistency through the simulation process, but also to account for the possible use of shutters, which would reduce forced airspeed through the space considerably. The airflow on the interior of the Pitot House is driven by pressure differential on the exterior of the house, and whereas actual air velocity rates may fluctuate, the general behavior of the building in terms of pressure is considerably more stable, which is ideal for simulation. Each floor is simulated separately. The objective during this phase is to identify the average interior air velocity per floor during the analysis period. The simulation is initialized from the inlet faces using standard initialization and is executed until residual error converges or decreases by at least three orders of magnitude; this is typically between 500 and 1000 iterations.

Synthesis

Having calculated the average interior air velocity on each floor, this value is then recorded and used to re-calculate the interior baseline comfort values achieved during phase 2A. The results from phase 1, 2A and 2B can now be synthesized to redefine indoor comfort values. Indoor operative temperature, relative humidity, and air speed can be plotted on an adaptive psychrometric comfort chart to illustrate this for various time steps throughout the day. To achieve this latter step, the Honeybee indoor adaptive comfort psychrometric chart component was used to plot these elements for each space.

Modeling: Phase 3

Lastly, as discussed previously, it is imperative to determine the viability of the night flush feature at the Pitot House, and to prove the effectiveness of its construction in further facilitating its efficient environmental performance during the summer months. To achieve this, a final three dimensional model is required. As the objective is to visualize vertical airflow through the gap space floorboards and out through the loosely set slate roofing tiles, a transverse section (See Figures 49-51) is most suitable as it is perpendicular to both the roof ridge and floor boards to allow for a clearer demonstration. Furthermore, a transverse section allows for a greater surface area of the gaps between floorboards, which is critical to achieving a successful CFD mesh; a longitudinal section, parallel to the floorboards, would result in bottlenecking airflow at too few points would and ultimately an inaccurate result. Additionally, great care was taken to model the spaces between the slate roofing tiles as well (See Figure 50); each of these surfaces was accounted for as an outflow within the simulation model, to represent the ventilated quality of the roofing assembly.

Simulation: Phase 3

Again, the exterior pressures recorded during the earlier CFD simulation were used to calibrate the inlet pressures at the doors and windows on each floor. The temperature of the roof was calibrated based on the material properties of slate and supporting research that demonstrated slate roofs in regions of intense solar exposure can reach upward of 70°C (158°F) during the peak summer months (Cárdenes et al. 2012). Temperature of the inflowing air as well as interior surfaces on the ground and second floor mimic the exterior dry bulb air temperatures at night.

Chapter 7: Discussion of Results

With regard to interior comfort, the basic strategy for this investigation is twofold: first, to identify the maximum sustained indoor air velocity per floor as a function of both the external behavior of the building as well as the response of the interior microclimate to the building itself; and second, to use this data to demonstrate that during the longest day of the year, June 21st, that the house can maintain comfortable living conditions.[25] In determining the effectiveness of the building assembly, namely the configuration of the roofing assembly and its role as a convective thermosiphon, the strategy was to calibrate a representative section model based on conditions identified on the interior and exterior of the building during earlier phases to visualize vertical airflow.

Indoor Thermal Comfort

Results from the EnergyPlus energy simulation revealed that on June 21st conditions on the ground floor and second floor differed considerably. Spaces on the second floor are significantly warmer, with an average operative temperature range between 29° and 30°C (84° - 86°F). Portions of rooms, particularly where adjacent to openings exhibit temperatures in excess of 32°C (90°F) as a result of solar gain and

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[25] Although there are in fact hotter days in the year, particularly in August, the longest day is chosen for a number of reasons. Aside from the fact that it is often considered a standard in energy simulation to investigate the longest and shortest days, June 21st and December 21st, it is imperative to visualize the effect of the night flushing strategy at the Pitot house, which fundamentally relies on the solar loading of the slate roofing tiles, to initialize the study on the day when the slate has the longest exposure time to solar radiation.

amplified heat transfer. Ground floor spaces exhibit operative temperatures in the range of 27 to 28.5°C (80.6° - 83.3°F). Rooms along the southern portion of the house are generally cooler than those on the north, as a result of the added benefit of the gallery buffer which acts primarily as a solar shade in the summer months.

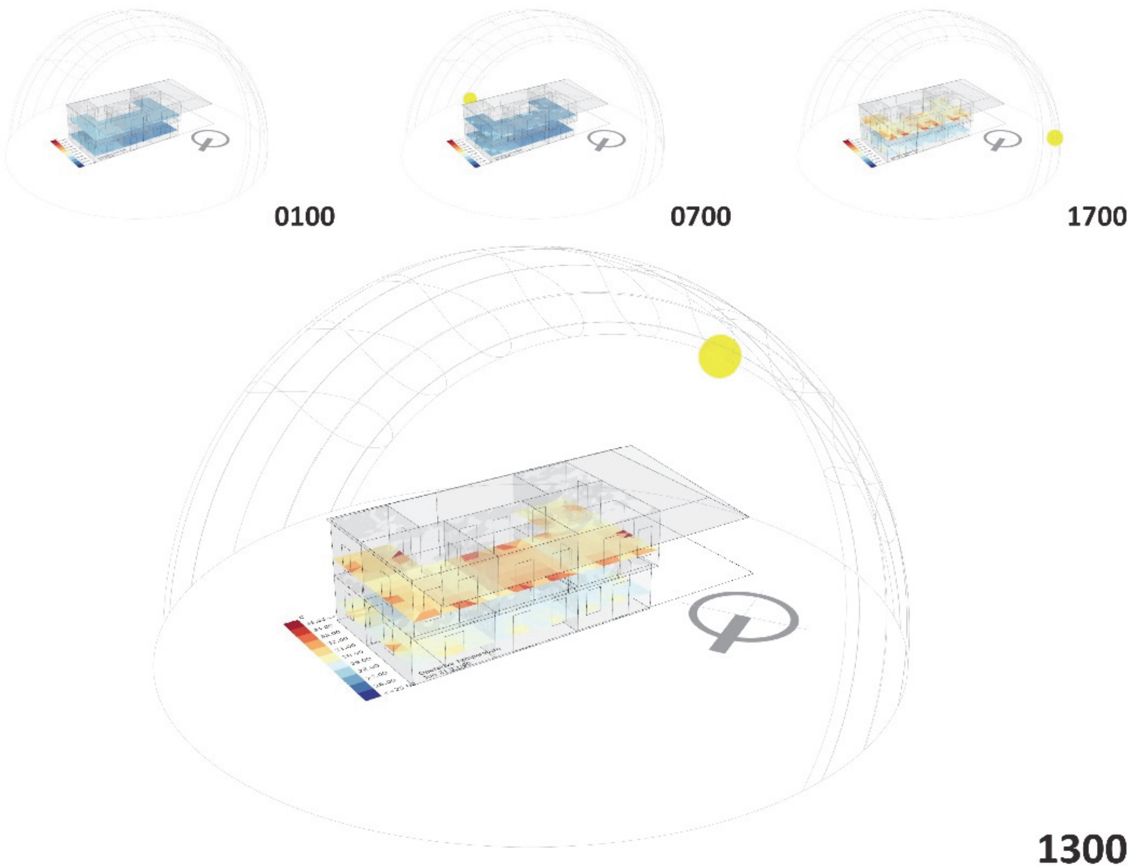

Figure 1. Indoor operative temperature on June 21st at sunrise, sunset, and the middle of the night at 1am. Enlarged image illustrates indoor operative temperature and relative sun position at noon on June 21st.

The methodology used in this investigation returns data at an hourly resolution for the sole purpose of allowing for a finer level of analysis from hour to hour, in addition to the aggregate and average values. The analysis of the hourly operative temperature for each space during the analysis period of the month of June is particularly helpful in identifying at which hours certain spaces have the potential to be more comfortable than others (See Figure 33). Particularly on the ground floor the spaces achieve temperatures consistently below that of the outdoor air temperature during the day. While spaces on the second floor are considerably hotter during the day, the presence of sustained elevated temperatures in the attic through the evening hours reinforces the confirmation of the attic thermosiphon feature. The attic space acts fundamentally as a reservoir of hotter air accumulated through the day, and aids in the vertical flow of air via convection during the evening when the spaces on the first and second floors cool down.

Indoor conditions, accounting for thermal mass, and night flushing, however without taking into to account simulated natural ventilation, are thermally comfortable approximately 69 percent of the time on June 21st (See Figure 5). This represents both floors of the house. Compared to an identical structure without the use of night flushing strategies or heavy thermal mass construction, which for the same analysis period, is only thermally comfortable less than half of a percent of the day (See Figure 4).

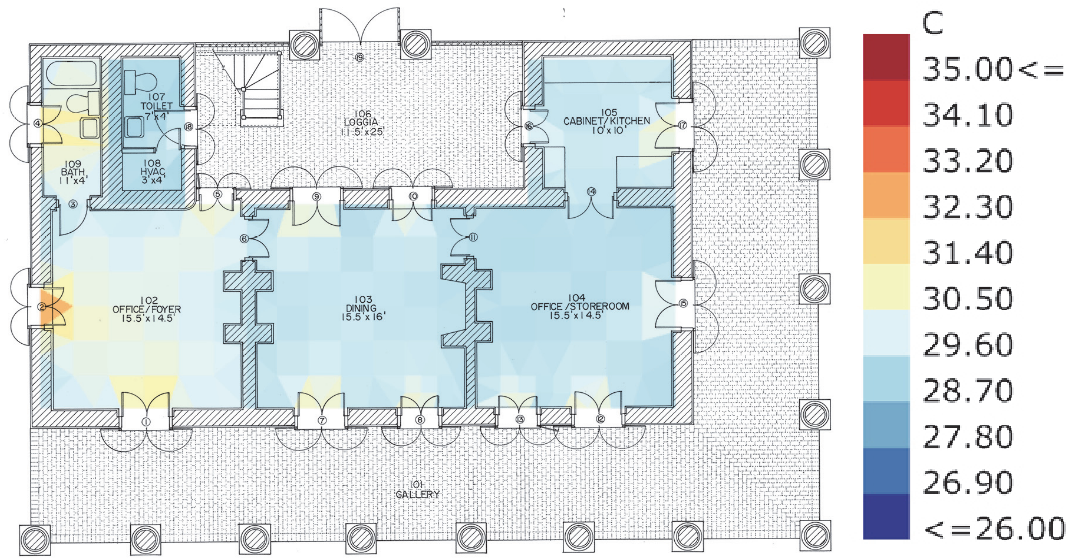

Figure 2. Indoor operative temperatures on the ground floor of the Pitot House on June 21st at noon. Drawing underlay sourced from HABS. For a larger reproduction of this image refer to Figure 34 in Appendix I.

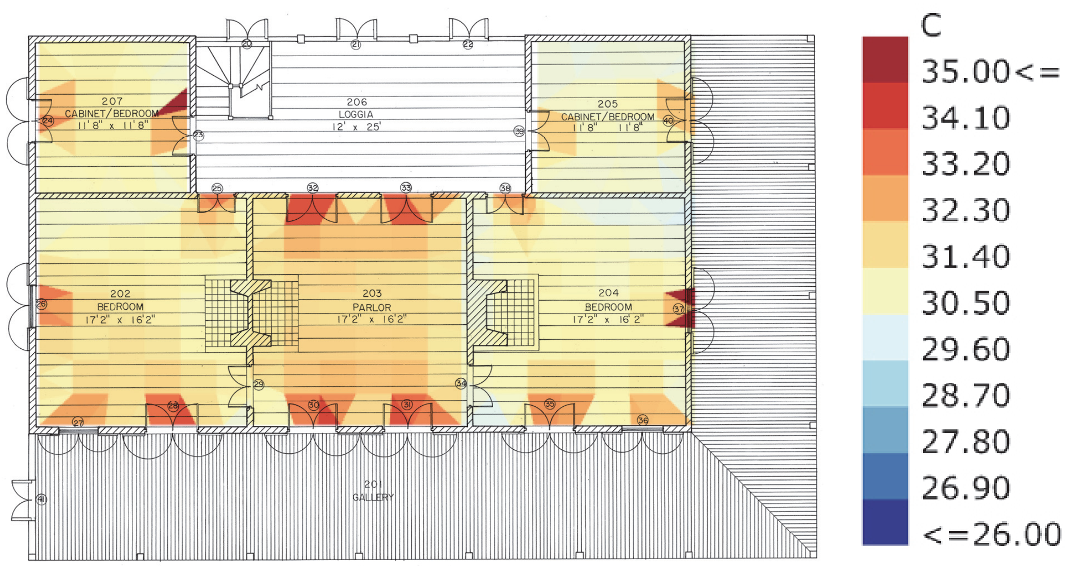

Figure 3. Indoor operative temperatures of the Pitot House on June 21st at noon. Drawing underlay sourced from HABS. For a larger reproduction of this image refer to Figure 35 in Appendix I.

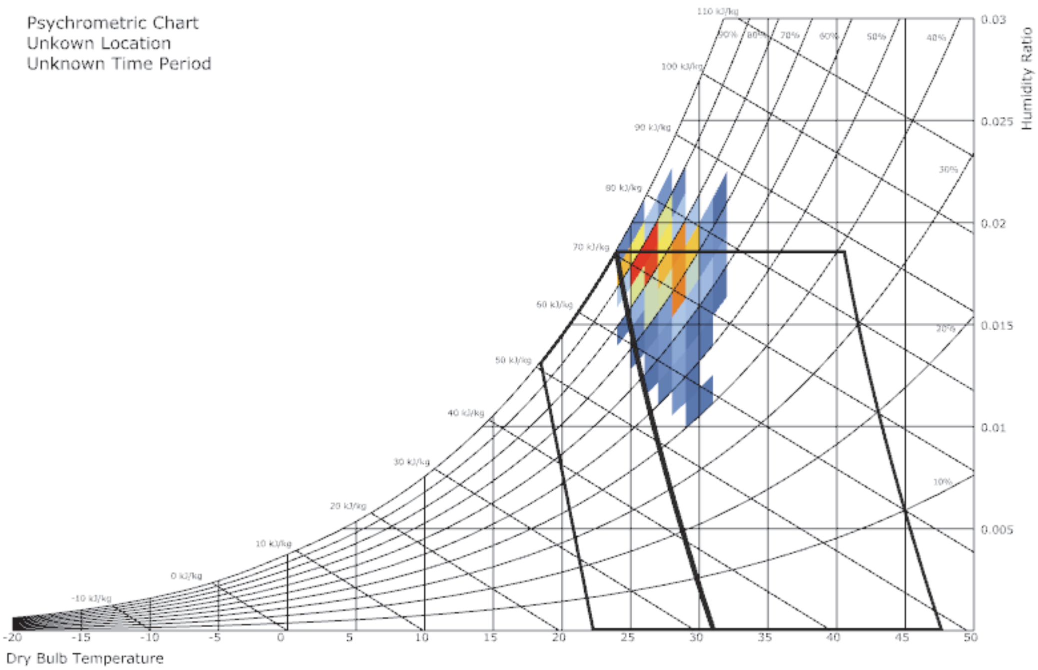

Figure 4. Psychrometric chart illustrating interior conditions of the Pitot House on June 21st without accounting for actual natural ventilation rates. The bounding shape on the left represents a building without thermal mass construction or night flushing capabilities, while the shape on the right illustrates the configuration of the Pitot House.

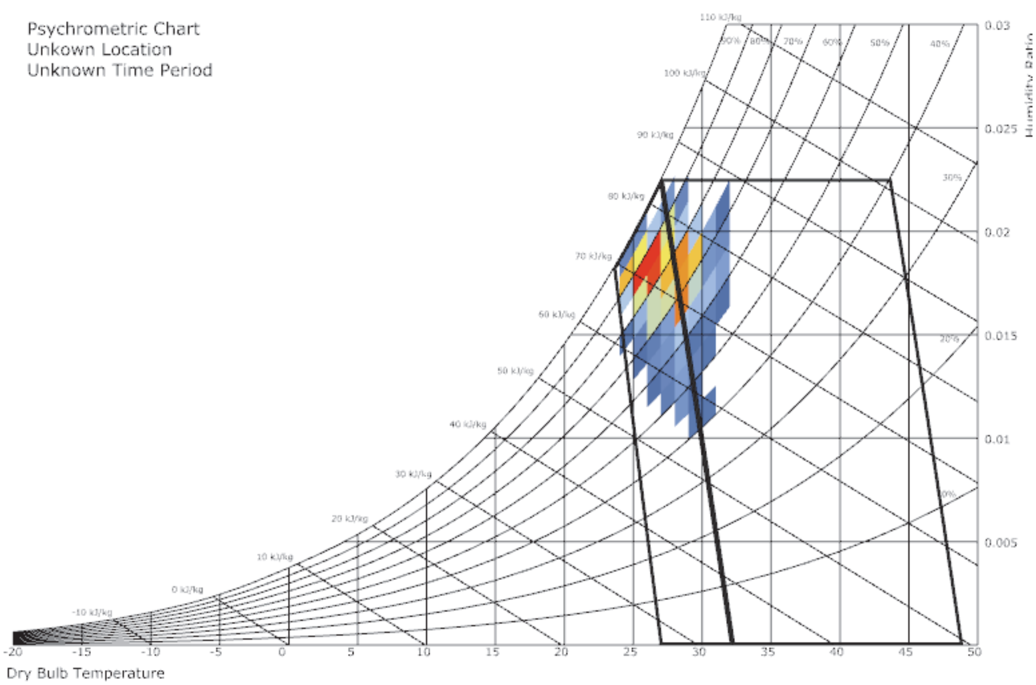

Figure 5. Psychrometric chart illustrating interior psychrometric conditions of the Pitot House on June 21st accounting for interior air flow of 1.5m/s, thermal mass construction, and night flushing capability.

The results change considerably when the simulated air flow is accounted for within the spaces during this same analysis period. On the ground floor, interior air velocity, the result of the distribution of pressures on the exterior of the building, reach an average sustained value of 2m/s and approximately 1.5m/s on the second floor (See Figures 6 & 7, 36 & 37). When this air velocity is accounted for in defining the indoor psychrometric conditions the results are clear; on June 21st, the Pitot House can achieve comfortable interior conditions of nearly 90% throughout the day by employing passive ventilation, thermal mass construction, and night flushing strategies (See Figure5).

The added aerodynamic benefit of the double pitch hip roof at the Pitot House, can be seen in the distribution of airflow on both the ground floor and second floor. The primary central spaces, the parlor on the second floor and dining room on the ground floor, benefited the most; these spaces could take advantage of cross ventilation both in the transverse and longitudinal directions.

Moreover, one can see that during the hottest point during the day, the ground floor was evenly and sufficiently ventilated in terms of air flow rate and distribution; it is this feature that permits a higher level of comfort even given the intensity of the hot and humid climate of New Orleans during the summer.

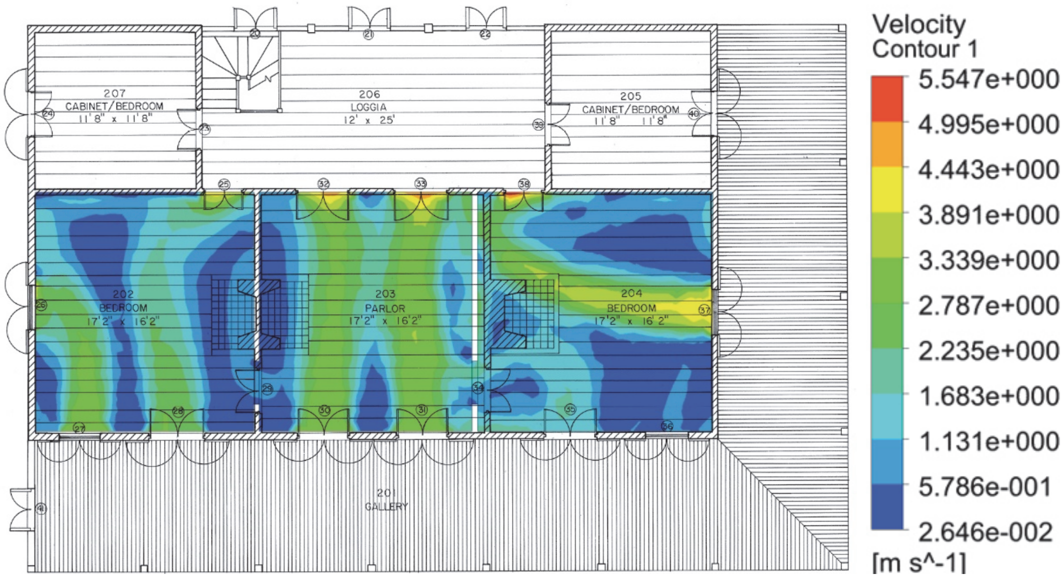

Figure 6. CFD results illustrating interior air flow on the second floor. Average velocity simulated +1.5m above finished floor is approximately 1.53m/s for the entire floor. Drawing underlay sourced from HABS. For a larger reproduction of this image refer to Figure 37 in Appendix I.

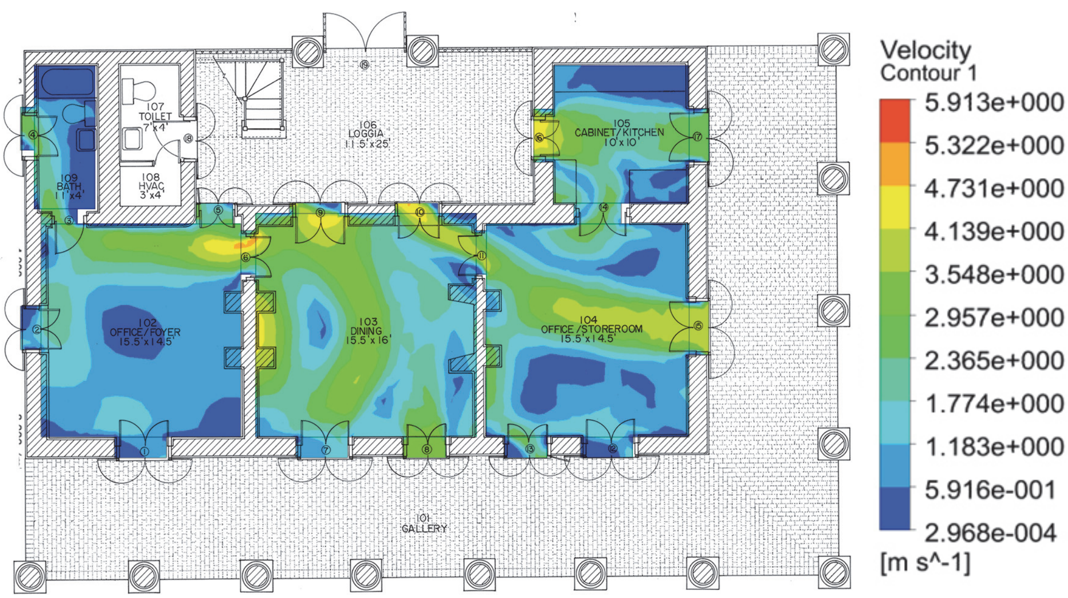

Figure 7. CFD results illustrating interior air flow on the ground floor. Drawing underlay sourced from HABS. For a larger reproduction of this image refer to Figure 36 in Appendix I.

Night Flushing

In demonstrating the effectiveness of the night flushing strategy at the Pitot House, the simulation confirmed the hypothesis that by leaving the windows and doors open on both floors, the thermal mass of the slate roof and the influence of stack effect, are significant enough to drive convective flow between the floors (See Figures 8 & 38). The rate at which this occurs is also enough to provide perceptible air movement in the spaces, enough to allow for evaporative cooling at night. Even so, given the sheer volume of the attic space, an exhaust rate of 0.5m/s through the floor boards is a significant.

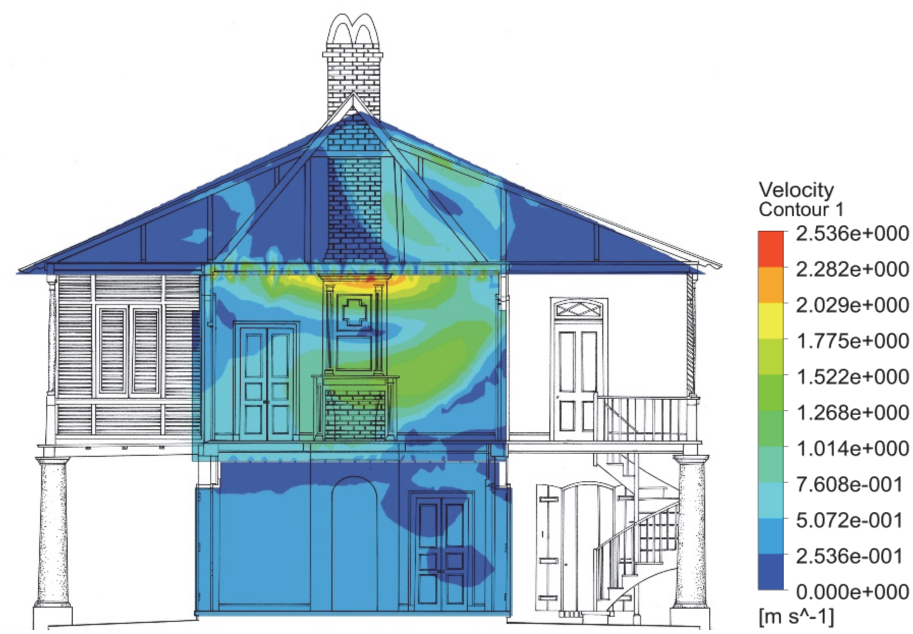

Figure 8. Transverse section illustrating the vertical air movement as a result of night flushing and the effect of the slate roof as a thermal mass. Average velocity noted. Drawing underlay sourced from HABS. For a larger reproduction of this image see Figure 38 in Appendix I.

The results of this series of investigations speak to the inherently diurnal operation of the house, which in are characteristic of architecture designed to work with climate as opposed to against it. Even an adequately designed vernacular building that accounts for all aspects of regional climate and occupant behavior will have moments throughout the day during which certain spaces are meant to be used in order to provide a sufficient level of acceptability or comfort. In the case of the Pitot House, it is clear that during the hottest moments of the day, the ground floor spaces remain cool; these are spaces that could be functionally occupied such as the kitchen, office spaces, and dining room. The same results illustrate that the interior spaces on the second floor are best suited for nighttime occupation and use, both due to the influence of cross ventilation but also to the influence of night flushing—or vertical ventilation. It is no coincidence that the bedrooms then are placed on the second floor to take advantage of this.

Chapter 8: Conclusions

Historical Environmental Simulation and the Ability to Recreate the Past

Heretofore this investigation has established an analytical methodology for the application of computational simulation to the study and visualization of the environmental behavior of a historical vernacular building typology, the raised Creole Cottage. By first understanding the evolution of this typology as one inherently shaped as much by the influence of climatic factors on its exterior form as by the influence of the requisite functionality on its interior spatial organization across a variety of a constantly changing settings it is possible to validate and calibrate these simulations. Given the strictly analytical method of the simulation methodology, this is a seemingly unorthodox approach; however, it is again worth emphasizing that the Pitot House, as so many historic buildings like it, no longer exists in its original environmental configuration. The overall outward architectural aspect of the Pitot House has been painstakingly returned to the arrangement associated with its occupation by James Pitot between 1810-1819, thanks to the effort of the Louisiana Landmarks Society between 1964 and 1972 (Wilson 2011). Unfortunately, with regard to its environmental function today, the galleries of the Pitot House are a vacant representation of their former selves.

Following a restoration campaign spanning over a decade, on November 8, 1973 the Louisiana Landmarks Society opened the Pitot House to the public as an interpreted, furnished house museum. And with this change in programmatic function, so too came a change in expected levels of interior thermal comfort for visitors; the Pitot House underwent a transformation from an occupant-operated, naturally ventilated building to a mechanically conditioned, enclosed vitrine. The introduction of air-conditioning to the house in the late twentieth century set forth a series of requisite building modifications to maintain a stable, mechanically-conditioned interior environment. Two of the principal and original systems were altered: the roof-attic assembly, and the galleries. The most influential of these modifications were the ones that targeted the thoroughly ventilated attic space. Open to above and below, it was the feature at the core of the house's ability to passively ventilate itself during the hot-humid evenings. Insulation was installed in the attic, and the gap spaced, slate roofing tiles were removed. In their place, a roofing felt substrate was installed overlaid with modern composite roofing shingles. Unlike the original construction detail, these shingles are tight-fitting and they inherently prohibit, or at the very least significantly restrict the movement of air across the assembly and reduce overall convective flow (Henry 2007). Additionally, fiberglass batt insulation was installed in the attic floor (second floor ceiling), effectively restricting airflow across this boundary from the second floor below. As a result, the attic no longer is capable of functioning as it once did as the thermosiphon regulating night flushing of the second floor, demonstrated earlier.[26] Furthermore, as in any mechanically ventilated building, modern or otherwise, the stasis of interior conditions is absolutely imperative to reducing loads on the mechanical system and the resulting increase in energy usage. What this means for the Pitot House today, is that the once integrally dynamic features of the exterior envelope—the windows, shutters, gallery curtains, and doors—are now static elements. The gallery curtains themselves have been since entirely removed. Where once the occupants were the adaptive, thermostatic regulators of the house in their place is contemporary, mechanical "equivalent". The galleries can no longer be considered as environmentally-controlled extensions of interior space in the summer or pre-conditioned thermal buffers in the winter; they are reduced simply to porticos or porches—that, had the overhanging roof not enclose them, would seem as architectural afterthoughts attached, and not integrated, to the exterior of the house.

This is not to say that these changes were unwarranted or that should be perceived as illogical. First and foremost, as mentioned, the conversion of a building from a residential program to a museum program is significant enough to warrant many of these modifications—environmental considerations aside. Considerations for the

[26] It should be noted that the ceiling above the galleries was not insulated. The gap spaced boards in this region still permit the movement of air. This is to say that the attic is not entirely sealed. This being said, the introduction of the aforementioned modifications to the majority of the roof-attic assembly, particularly the zones directly above significant, occupied spaces—such as the cabinets and bedrooms—has effectively disabled the thermosiphon function of the house as a system.

strict regulation of interior relative humidity and temperature are typically at the forefront of historic museum conditioning strategies. Gennusa et al. argue that not only does a difficult tradeoff exist between indoor thermal microclimate as it relates to the preservation of fabric (in this case, the building itself) and indoor occupant comfort, but that it often biases the former (La Gennusa et al. 2008). But the introduction of this new system into a building that has reached equilibrium, both on a macro and micro scale in terms of moisture levels within the fabric, not only subjects the fabric to a great deal of hygrothermal stress but also introduces new, unforeseen complications. Monitoring data taken at the house indicates that given the sealed nature of the Pitot House, its HVAC system is not capable of sufficient dehumidification:

> Analysis of environmental monitoring data suggests that the thermostatically controlled air-conditioning system does not address the need to dehumidify during periods of coincident high ambient RH and moderate temperatures that frequently occur throughout the year. Furthermore, by depressing the interior ambient temperature of the building from the traditional norm, the ambient interior RH is elevated as moist exterior air enters the cooler building. (Henry 2007)

Interpreting Historic Comfort in Preservation Design

This most recent evolution of the house sheds a great deal of light onto the value and significance of the methodology proposed in this investigation. The series of simulations carried out in this investigation are based on three-dimensional reconstructions of the original Pitot House; they prove that this specific house and the building typology under which it is categorized functioned as posited by historians. What is most significant, however, is that this methodology is capable of visualizing past environmental behaviors of buildings that have since been altered from their initial configurations. This emphasizes and calls for the incorporation of environmental functional and historic levels of comfort as interpretive elements in historic preservation design. By definition, many of the architectural features of this vernacular typology are in fact environmental devices, and as such are intrinsic elements in its architectural and historical narrative. The disjunction of this direct relationship jeopardizes not only the environmental function but also its interactive value. Of the intangible values of the Pitot House Samuel Wilson writes:

> It is evident that the Pitot House is emerging as a significant community asset, with its own special personality. As the city's only colonial house museum, it can be a center for interpreting New Orleans' earliest history and everyday life. (Wilson 2011)

But one might immediately question, upon entering an interpreted museum of a raised Creole Cottage from the late eighteenth, early nineteenth century why it feels like stepping into an interpreted museum of any building in any location from the mid to late twentieth century—particularly, in a hot and humid climate where the distinction between outdoor climate and a mechanically conditioned interior space is drastically emphasized. The interpretive value of the Pitot House, and raised Creole cottages like it, can be *supplemented* and not substituted by accurate period furniture and finishes; the narrative is in its ability to provide comfort in an otherwise inhospitable, hot-humid climate and it should be interpreted as such.

Strengthening a Trend & Looking Forward

As mentioned earlier, there is evidence of an emerging trend among historic buildings and museums today that forego mechanical conditioned and rely on the inbuilt environmental features to provide an appropriate level of indoor thermal comfort. Drayton Hall, an 18th century plantation house located near Charleston, South Carolina is one such example of a historic structure that does not rely on a modern climate control system and still functions sufficiently as an interpreted historic building that is open to the public. The Aiken-Rhett house, an early 19th century building also located in Charleston, South Carolina is another such example that emphasizes an emerging trend in the interpretation of historic buildings in hot-humid climates as originally intended without invasive mechanical retrofits. This includes not only architectural qualities but environmental ones as well, such as levels of thermal comfort. In this way, it is just as important to the validity and success of the methodology set forth in this thesis to understand its broader applicability to the field of preservation.

While the various phases of the methodology discussed in this thesis appear complex it is imperative to examine them in the context of the available alternatives to achieving a similar result. In this way, the efforts made at Drayton Hall and the Aiken-Rhett House to more accurately interpret their historic levels of comfort can be compared against the highly involved and elaborate system of environmental monitoring that has been adopted as the active approach at the Lower East Side

Tenement Museum in New York City, NY. The objective at the latter being to achieve a better understanding of the microclimates within the building and how the building behaves environmentally, a goal not unlike that of this thesis in investigating the Pitot House. The efforts being made at the Tenement Museum are valuable in highlighting provide a sense of scale to the efforts made in this thesis in modeling and simulating the behavior of the original configuration of the Pitot House.

Ignoring for a moment that the case study building of this thesis was altered from its initial state, the resources required to construct the requisite three-dimensional models and carry out the various simulations to ultimately provide a glimpse into the historical behavior of this building still pale in comparison to the endeavor of installing, maintaining, and post-processing the data from a high resolution spatial monitoring system that would otherwise be required to provide a similar result. The use of continuous monitoring systems is in many ways is the de facto standard in the field today. Zivkovic, et al. captures this approach in his article on the topic:

> With a team consisting of a curator, conservators, architects and on times mechanical engineer, through observation of facilities, state of collections, history of conservation conditions in which the collections were kept, consulting old documentation and projects, interviewing the staff on observed changes in climate conditions and on objects, as well as gathering data through current or continuous monitoring of relative humidity, temperature, light and particulates pollution, we are able to determine the necessary environmental control requirements for a specific collection or a museum. Monitoring shows if there are extreme conditions, when they occur, in which part of the building and to what extent the building is effective in providing the stable climate conditions and buffering the outside extremes. (Zivkovic 2015)

The manner in which a building responds to its environment is the fundamental question at the core of this thesis, and that is at the heart of any monitoring methodology; but by what means and to what resolution are the variables that ultimately define its validity. The identification of the interior conditions within a building, extreme or otherwise, is a direct function of exterior weather conditions and its construction; they can be estimated without installing a single data logger (Otterbein 2010). In this way the tremendous resources required by the method popularly adopted by Zivkovic and others can be considerably reduced (Balocco and Grazzini 2009).

The methodology outlined in this thesis offers one such alternative that relies on the fundamental understanding of the behavior of a building typology in response to a particular climate. A primary difference is the resolution or scale that is adopted which allows the use, for example, of a typical meteorological year with regard to exterior climatic factors which, as a result, circumvents the need for installing and processing data from data loggers to record weather real-time weather events for a minimum of one entire, uninterrupted year. What is not sacrificed however is the resolution of the output. Whereas a full-scale, high resolution spatial monitoring campaign using data loggers provides only readings for the particular location the device is installed, a computational simulation methodology allows the analysis of an entire space or system (Balocco and Grazzini 2009). This methodology is made possible by the expanding availability of computational simulation tools such as Ansys, Fluent, Honeybee, Ladybug, and other used in this investigation and the nearly limitless possibilities to estimate interior conditions once a baseline model is constructed. Any number of operational scenarios can be investigated. This approach is further strengthened in scenarios such as the one that has unfolded at the Pitot House, in which the ability to monitor the building, as it originally existed, is not available. Once established as a methodology, perhaps one day even a standard, the logical next step toward creating sustainable operating manuals for naturally ventilated historic buildings can be taken. Furthermore, the ongoing transition to cloud-computing strategies and open source software will only compound the availability, applicability, and capability of a methodology, such as the one proposed in this thesis, in the near future.[27]

[27] Open source solutions for each of the pieces of software used in this thesis are available and are constantly being improved. CFD solutions such as OpenFOAM are tremendously powerful and completely open source. Ladybug, Honeybee and EnergyPlus are also open source and free to the public. For more information regarding OpenFOAM refer to http://www.openfoam.com/.

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Appendix I

Drawings

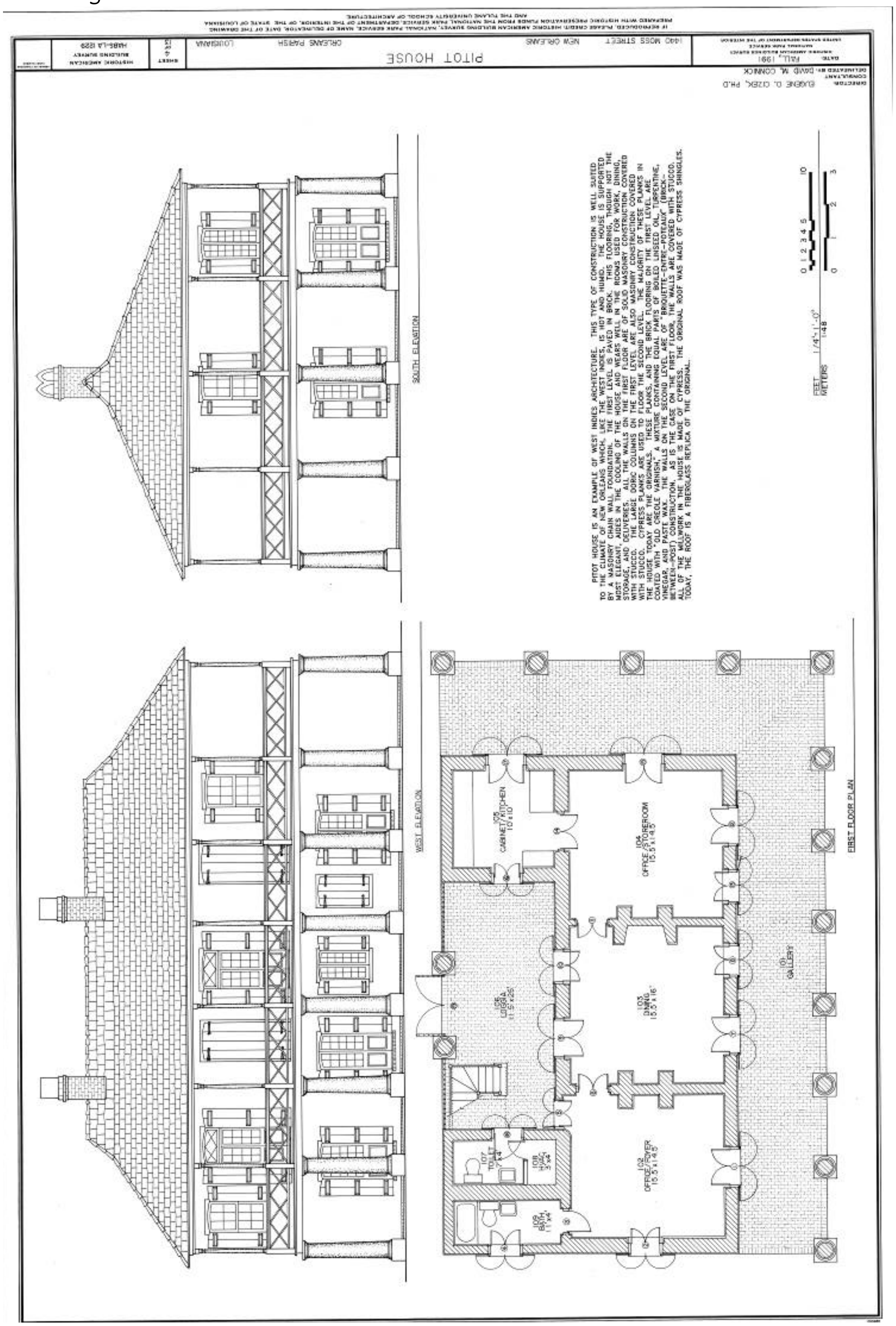


Figure 9. Ground Floor Plan; West and South Elevations. Source HABS.

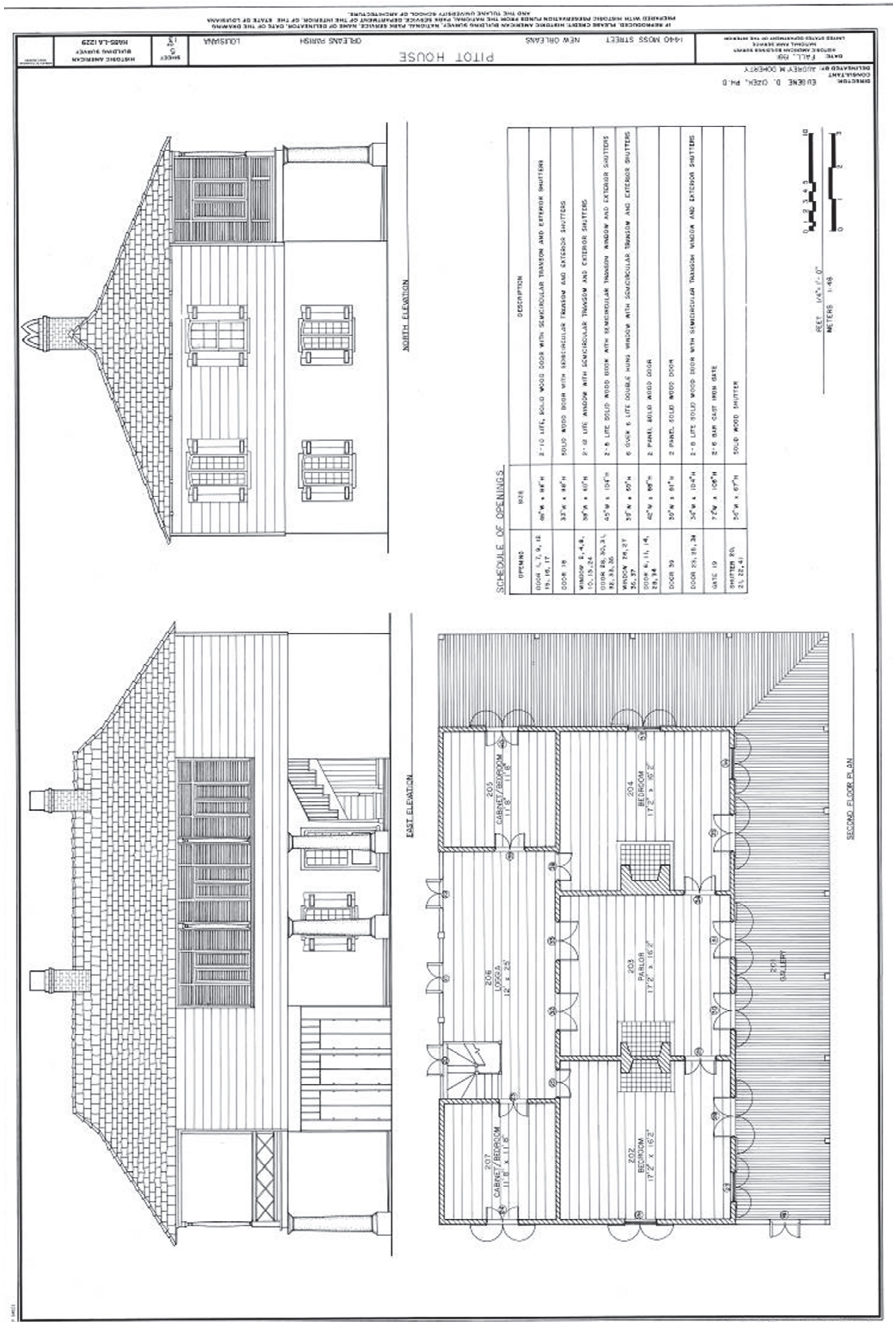


Figure 10. Second Floor Plan, East and North Elevations. Source HABS.

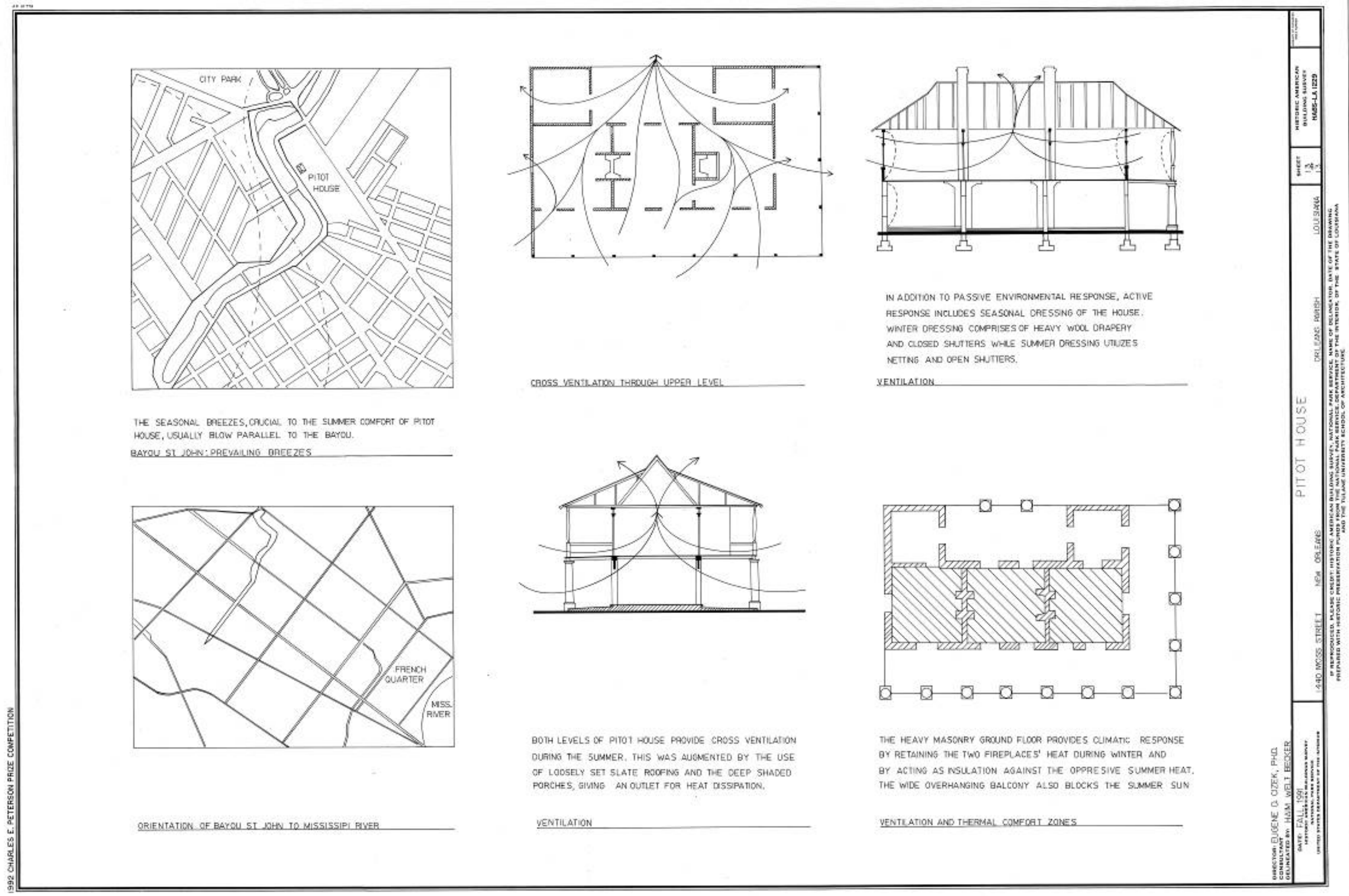


Figure 11. Diagrams illustrating the environmental features of the Pitot House. Source HABS.

Photos

Figure 12. Historic Photo taken during the restoration of the house in 1964 showing the wall construction on both floors.

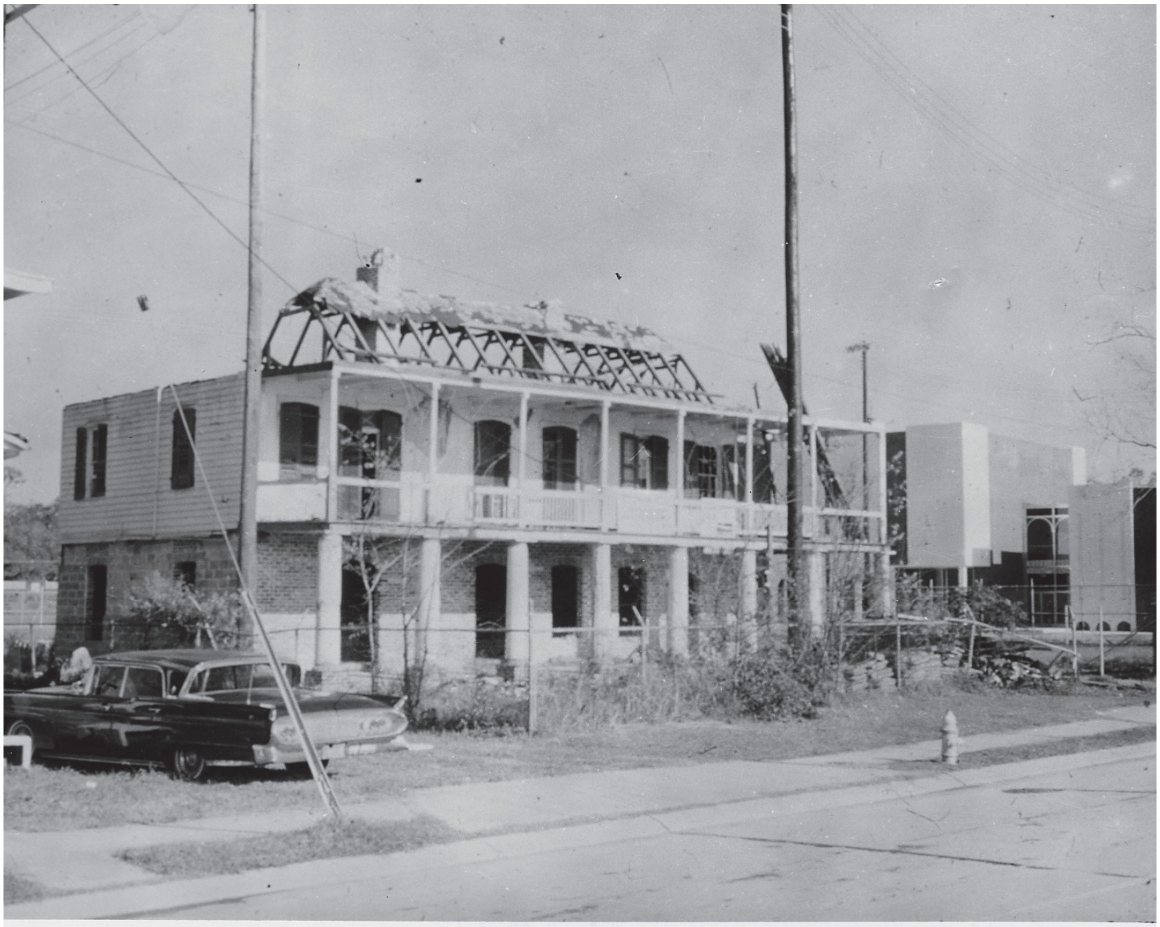


Figure 13. Historic Photo taken during the restoration of the house in 1964, note the shiplap siding on the second floor exterior wall.

Figure 14. Present day photograph of the first floor gallery, note the masonry floors. Image Credit Michael C. Henry (MCH).

Figure 15. Present day photograph detailing the beading of the beams. Image credit MCH.

Figure 16. Present day photography illustrating heavy timber roof structure and masonry chimney. Image credit MCH.

Figure 17. Present day photograph illustrating baseboard trim in the upper gallery. Image credit MCH.

Illustrations

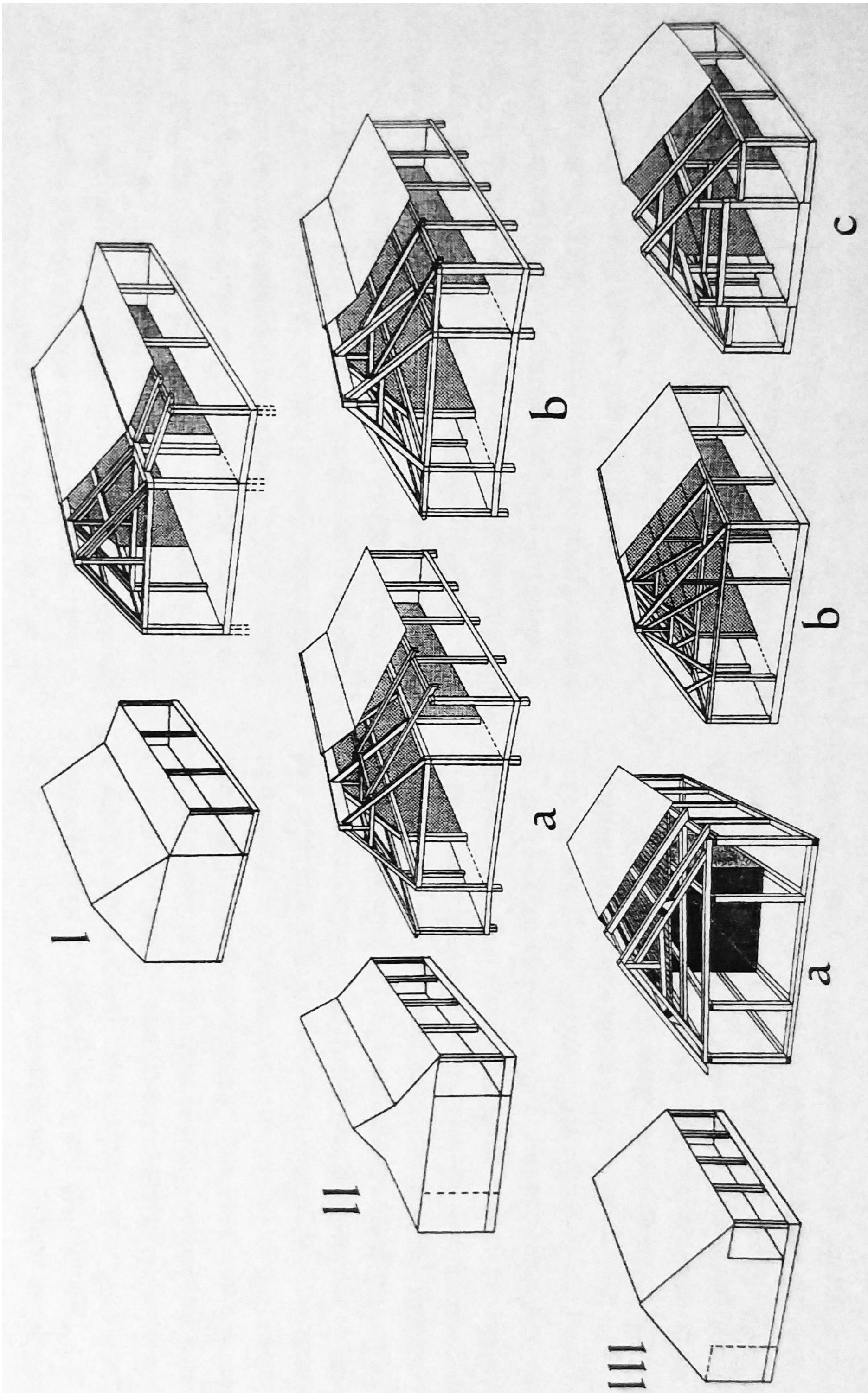


Figure 18. Diagram illustrating the general variation in Creole roof and building types (Edwards 2004) .

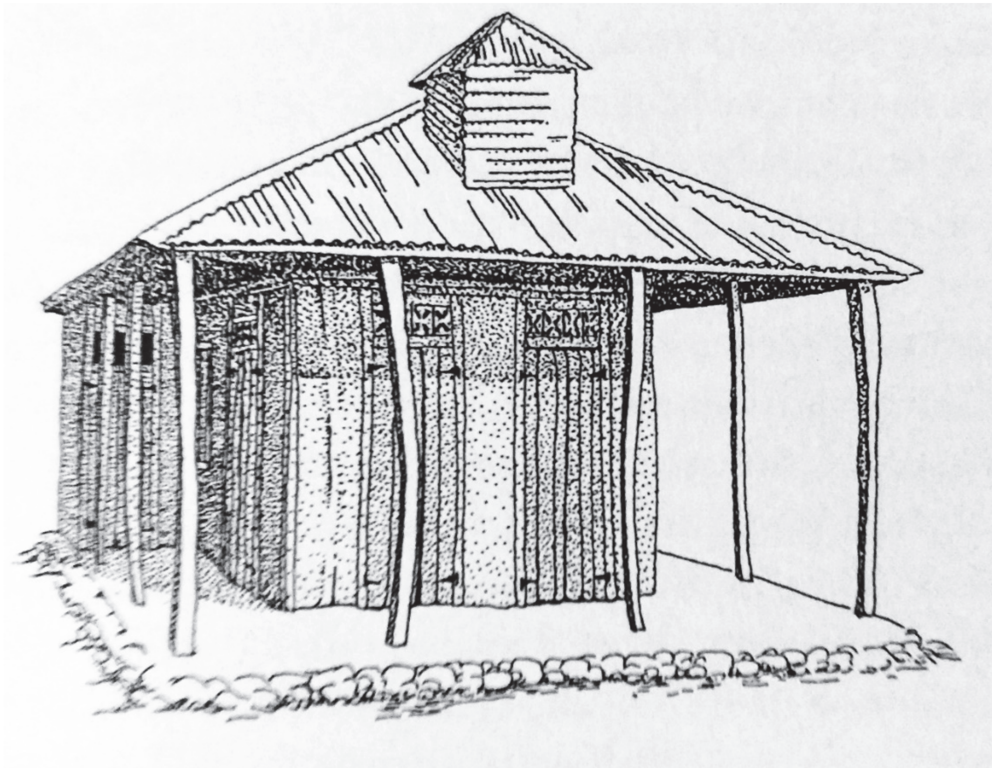


Figure 19. Diagram of a la kay a lo vernacular building type native to Haiti (Edwards 2004).

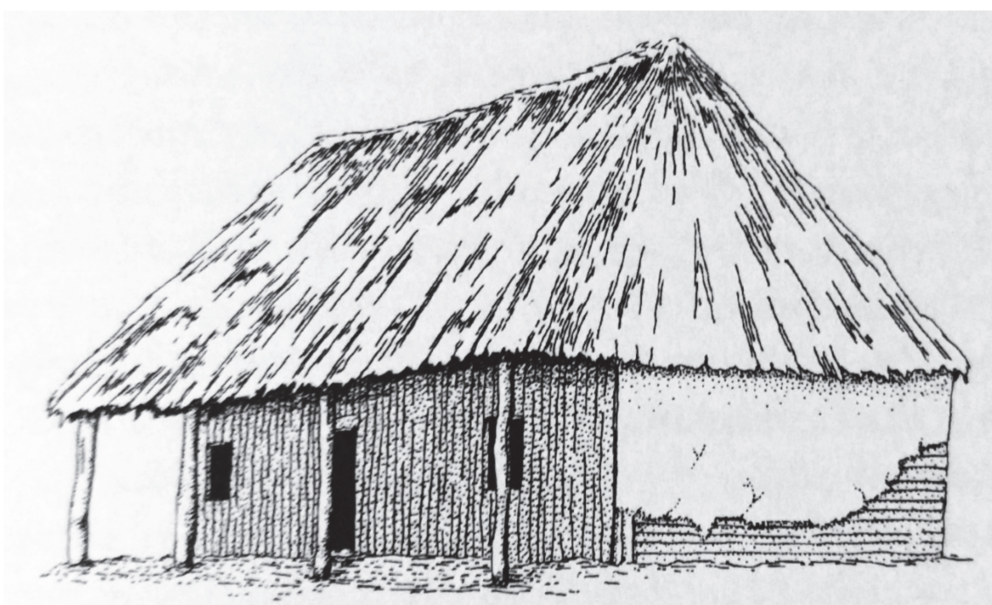


Figure 20. Diagram of a bohio vernacular building type native to Cuba (Edwards 2004).

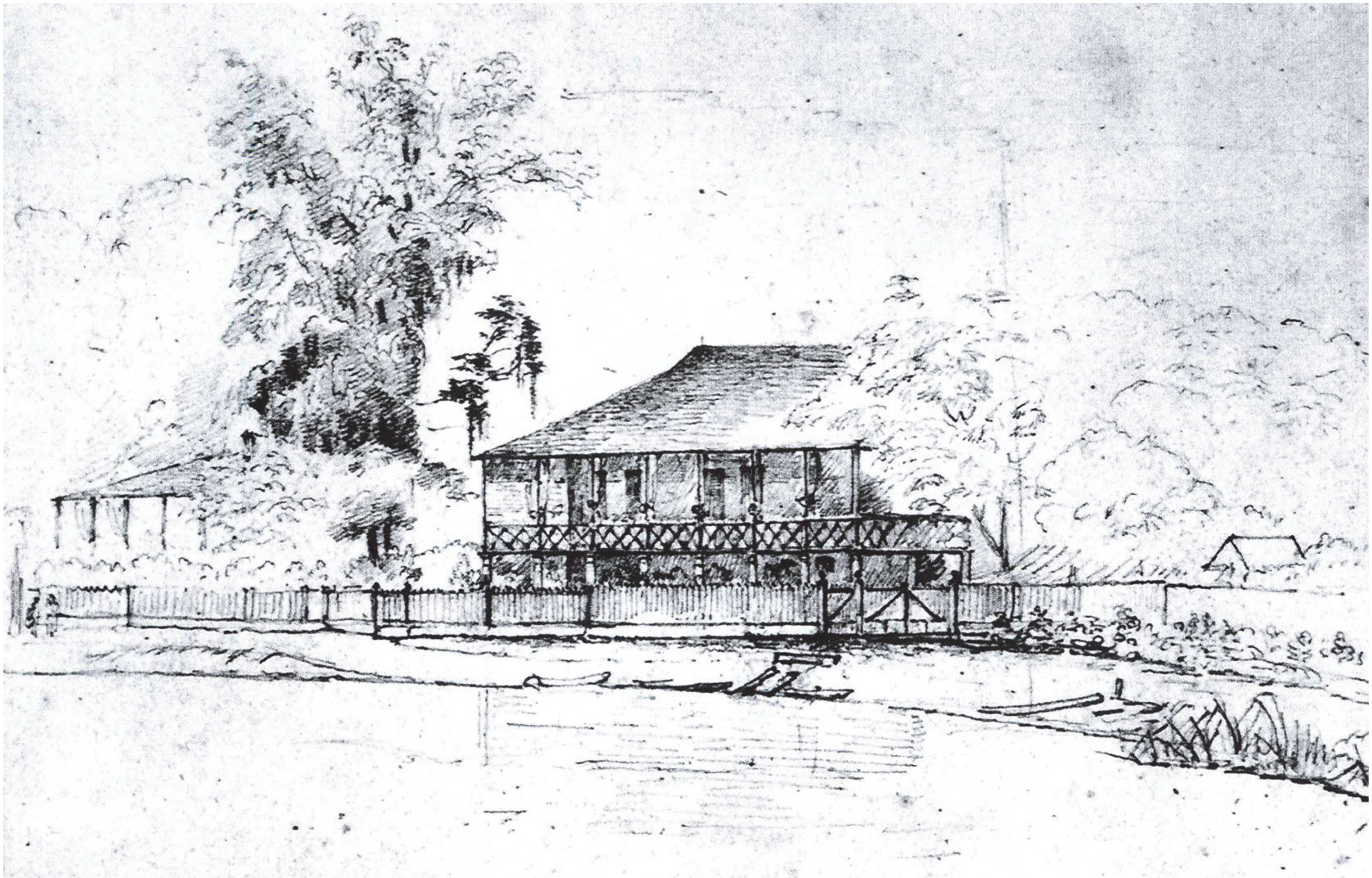


Figure 21. Hand Sketch of the Pitot House c.1830 made by Charles-Alexandre LeSueur (Wilson 2011).

Maps

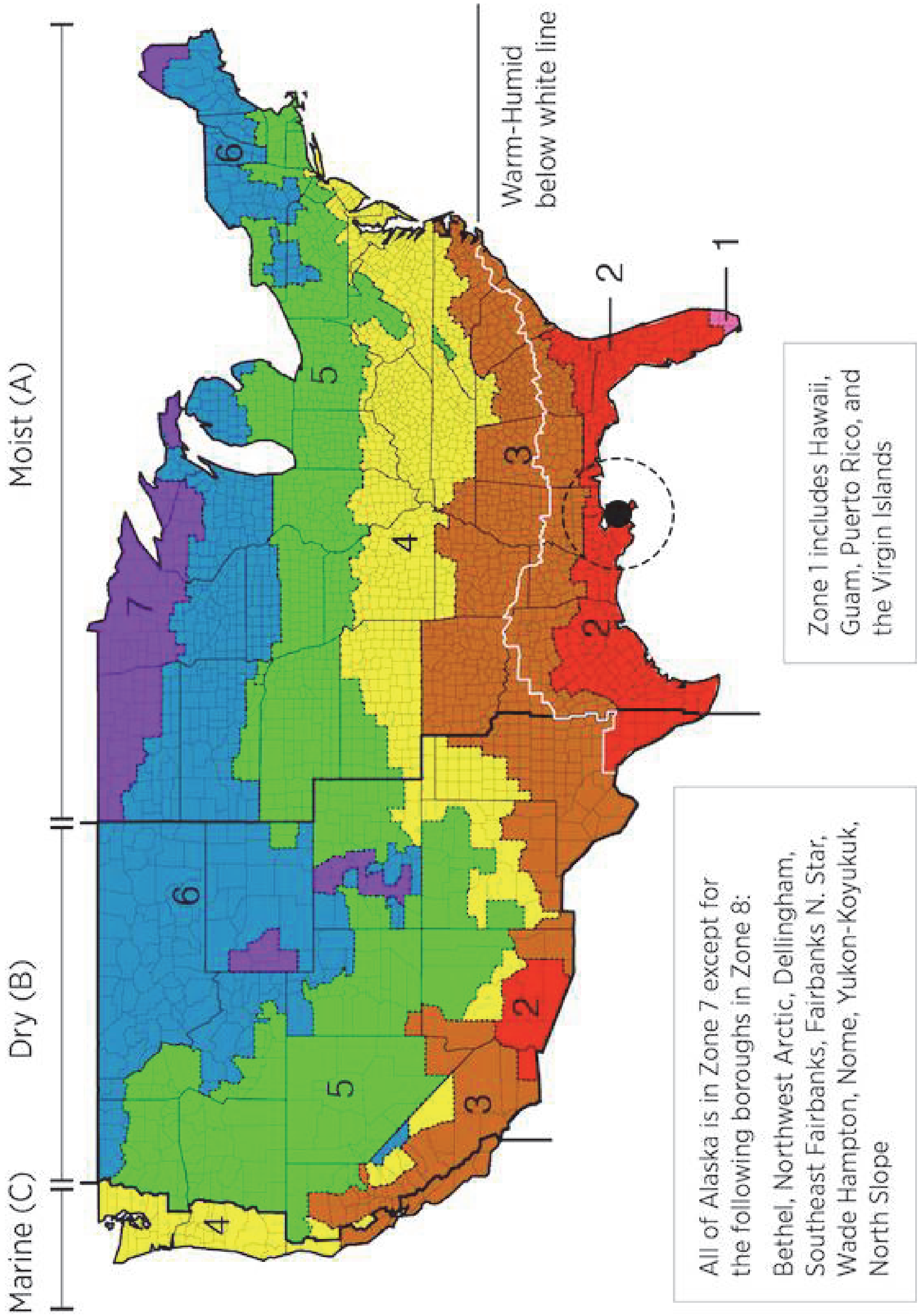


Figure 22. US Climate Zone Classifications. New Orleans, LA is indicated by a black marker (Energy 2013).

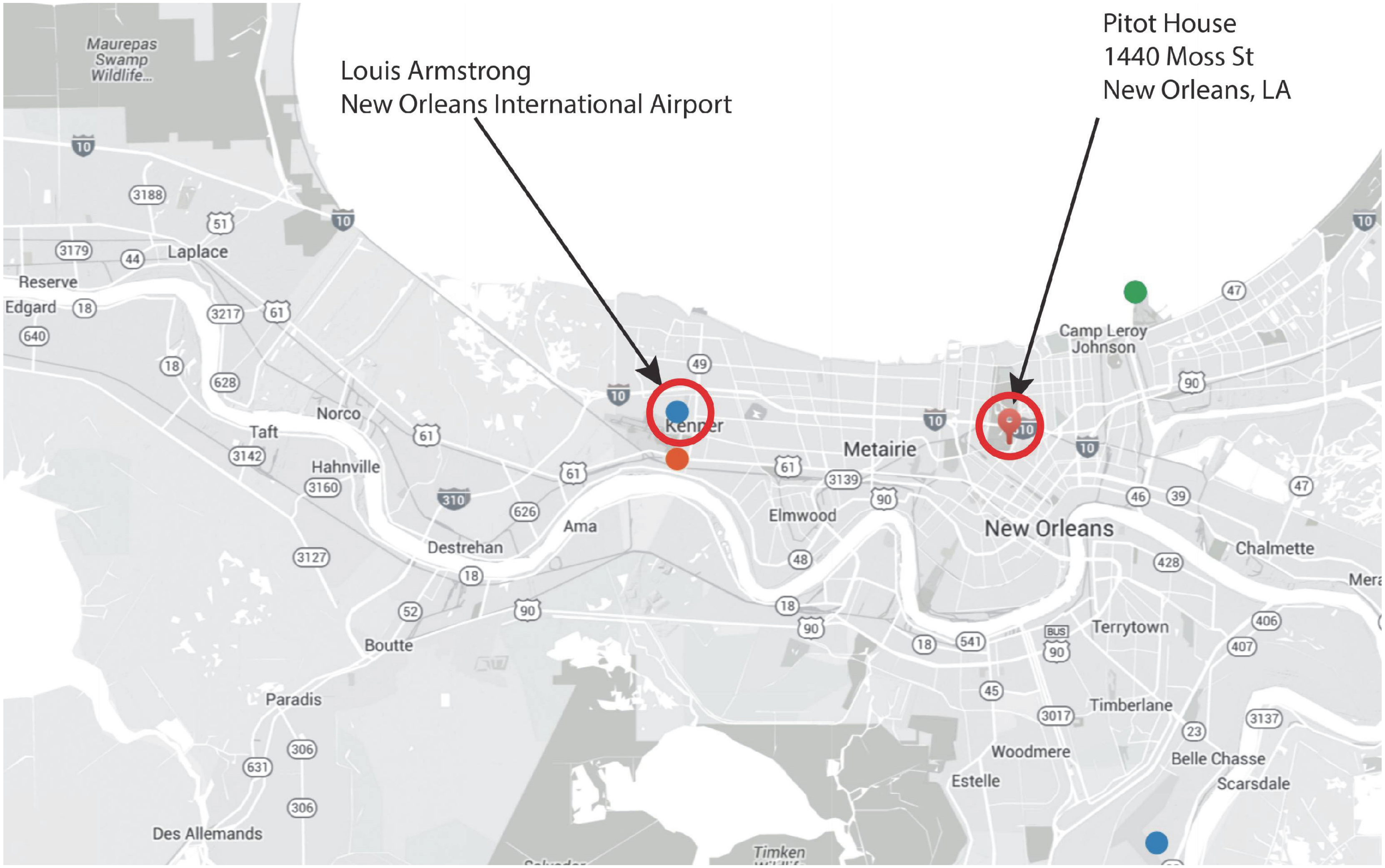


Figure 23. Locations of available weather files near the Pitot House (Sadeghipour 2016).

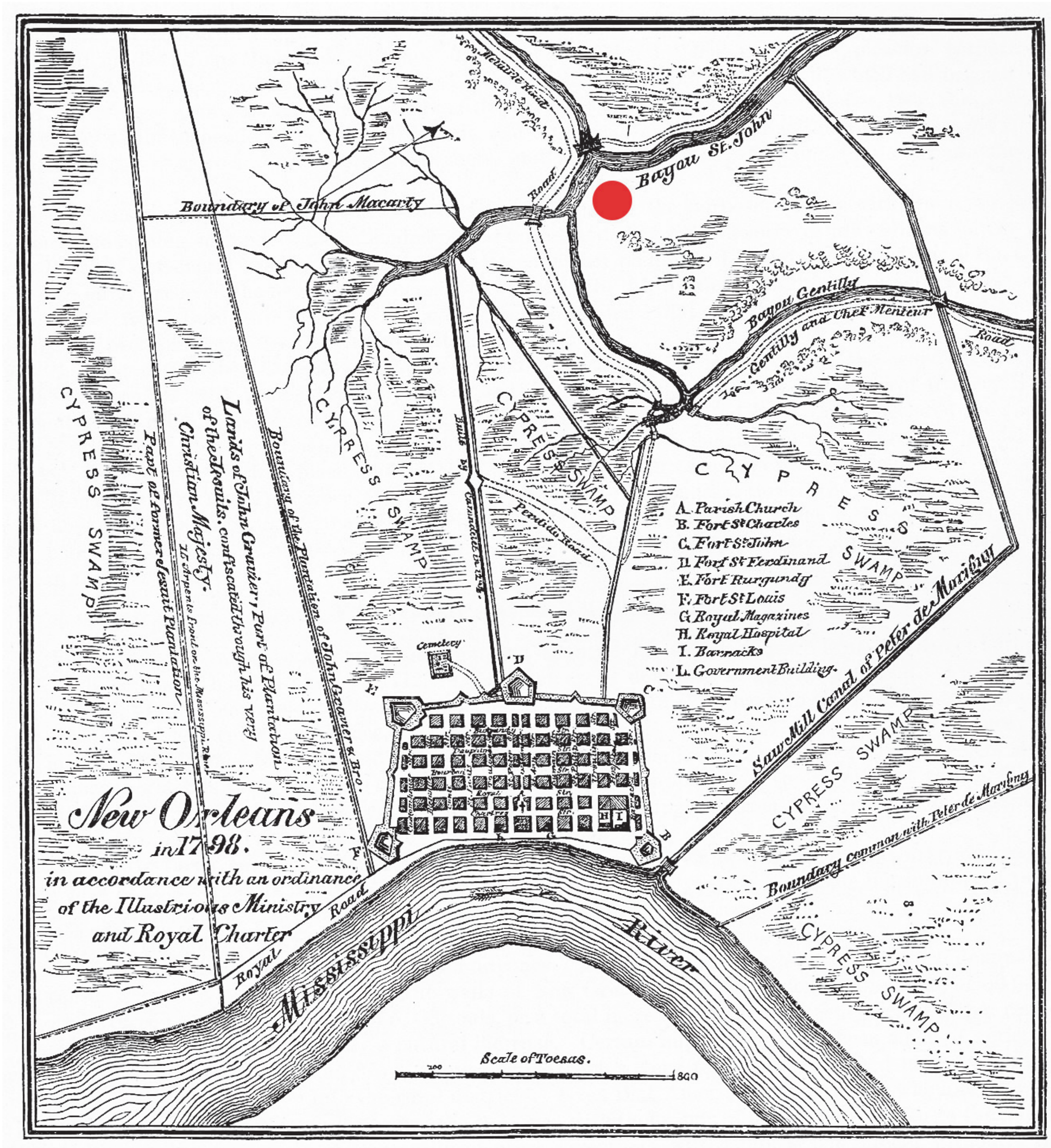


Figure 24. Map of New Orleans and Surrounding Territory c.1798 (University of Texas at Austin Perry-Castañeda Library Map Collection).

Figure 25. Map of New Orleans and Surrounding Territory c.1816 (University of Texas at Austin Perry-Castañeda Library Map Collection).

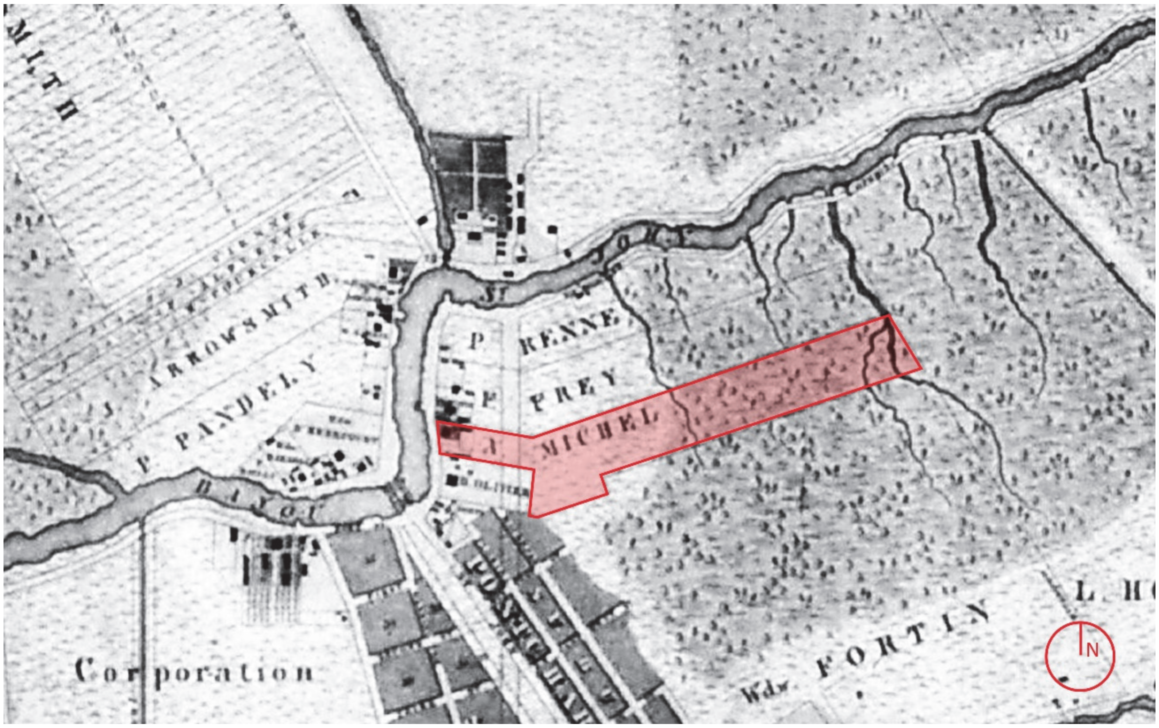


Figure 26. Map of New Orleans made by Charles Zimpel C.1834 illustrating Pitot (Michel during this period) property boundary conditions (The Historical New Orleans Collection).

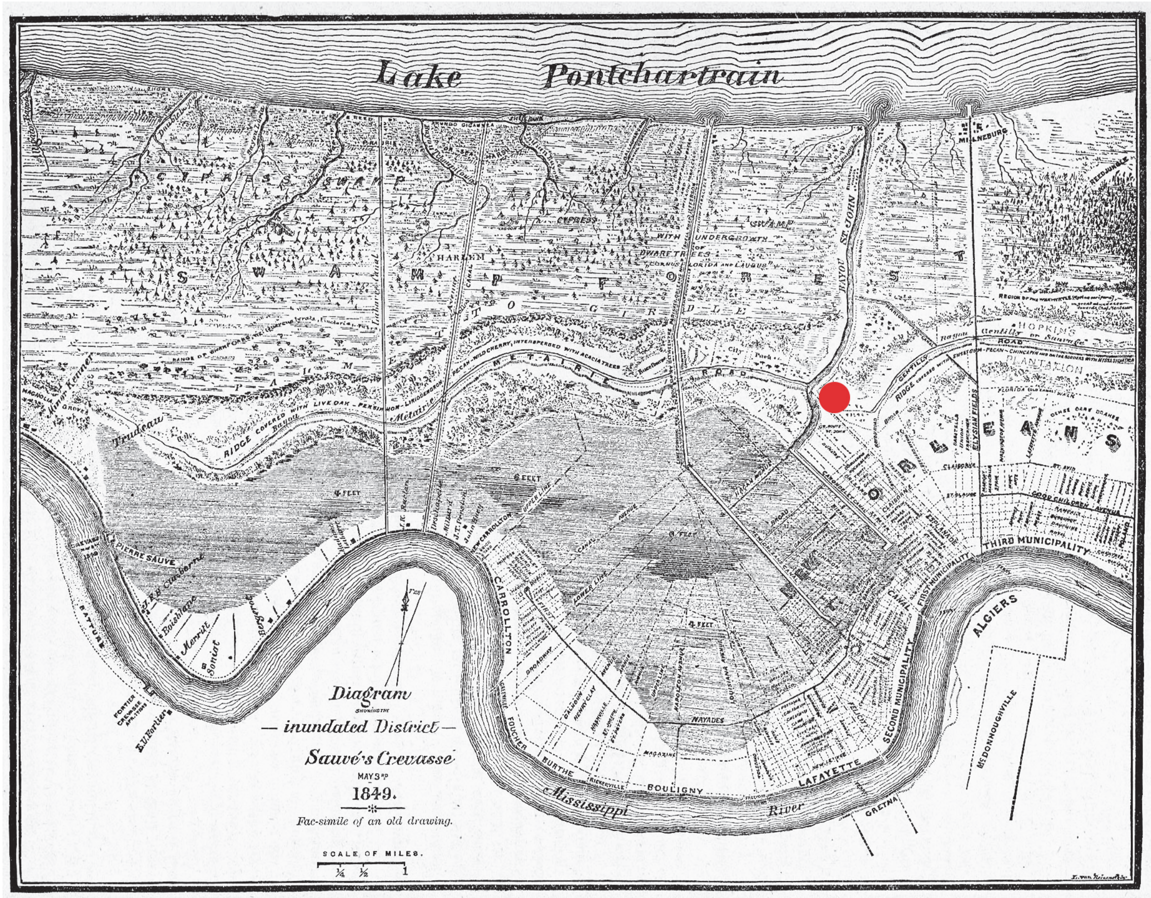


Figure 27. Map of New Orleans and Surrounding Territory c.1849 (University of Texas at Austin Perry-Castañeda Library Map Collection).

Analysis Figures[28]

Figure 28. CFD comparison illustrating the pressure distribution across a typical longitudinal section of a gable-end (top) and hip roof form (bottom). 3.65m/s SSW wind. North is to the right of the image.

[28] The environmental graphs and charts referenced here were created by the author using the Ladybug and Honeybee plugins for Grasshopper/Rhino3D. All data presented here is sourced from EPW weather file unless otherwise noted. The data file can be found at https://www.energyplus.net/weather-download/north_and_central_america_wmo_region_4/USA/LA/USA_LA_New.Orleans.Intl.AP.722310_TMY3/all.

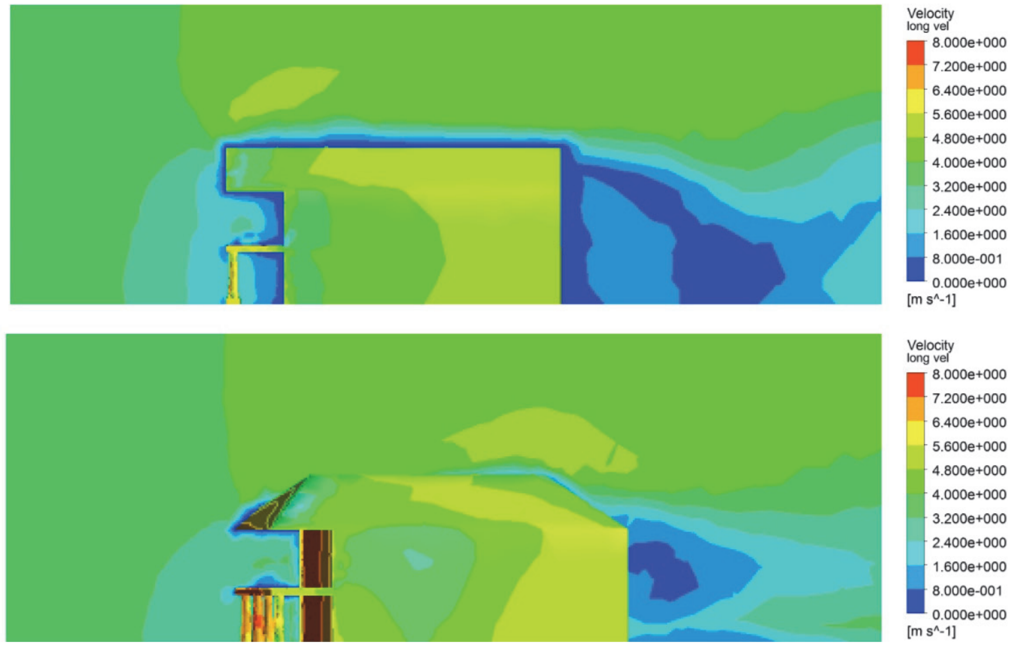


Figure 29. CFD comparison illustrating the airflow patterns across a typical longitudinal section of a gable-end (top) and hip (bottom) roof form. 3.65m/s SSW wind. North is to the right of the image.

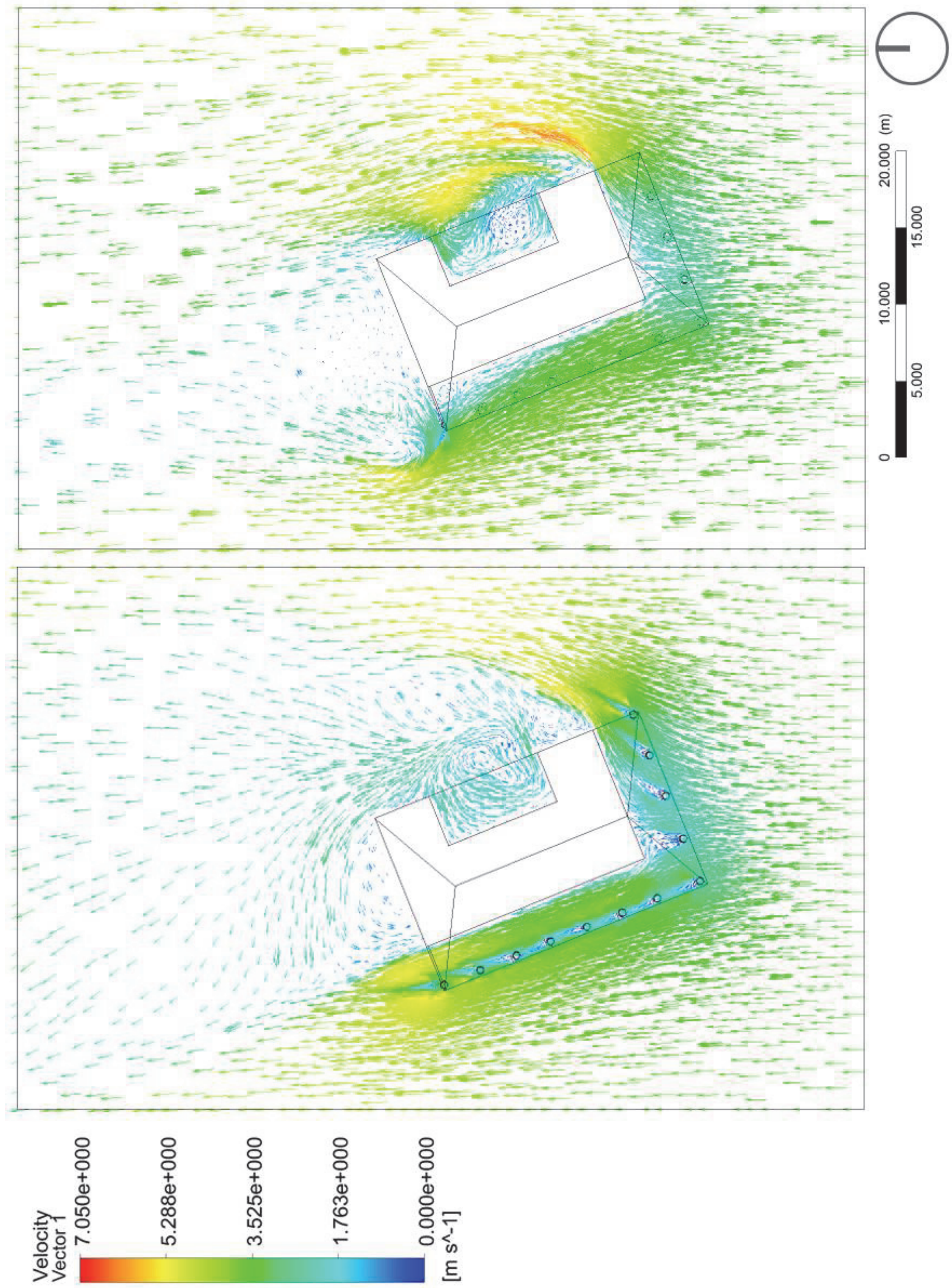


Figure 30. Site CFD model illustrating air flow around the building at +1m above grade (left) and +5m (right). Image is oriented toward prevailing wind, due south.

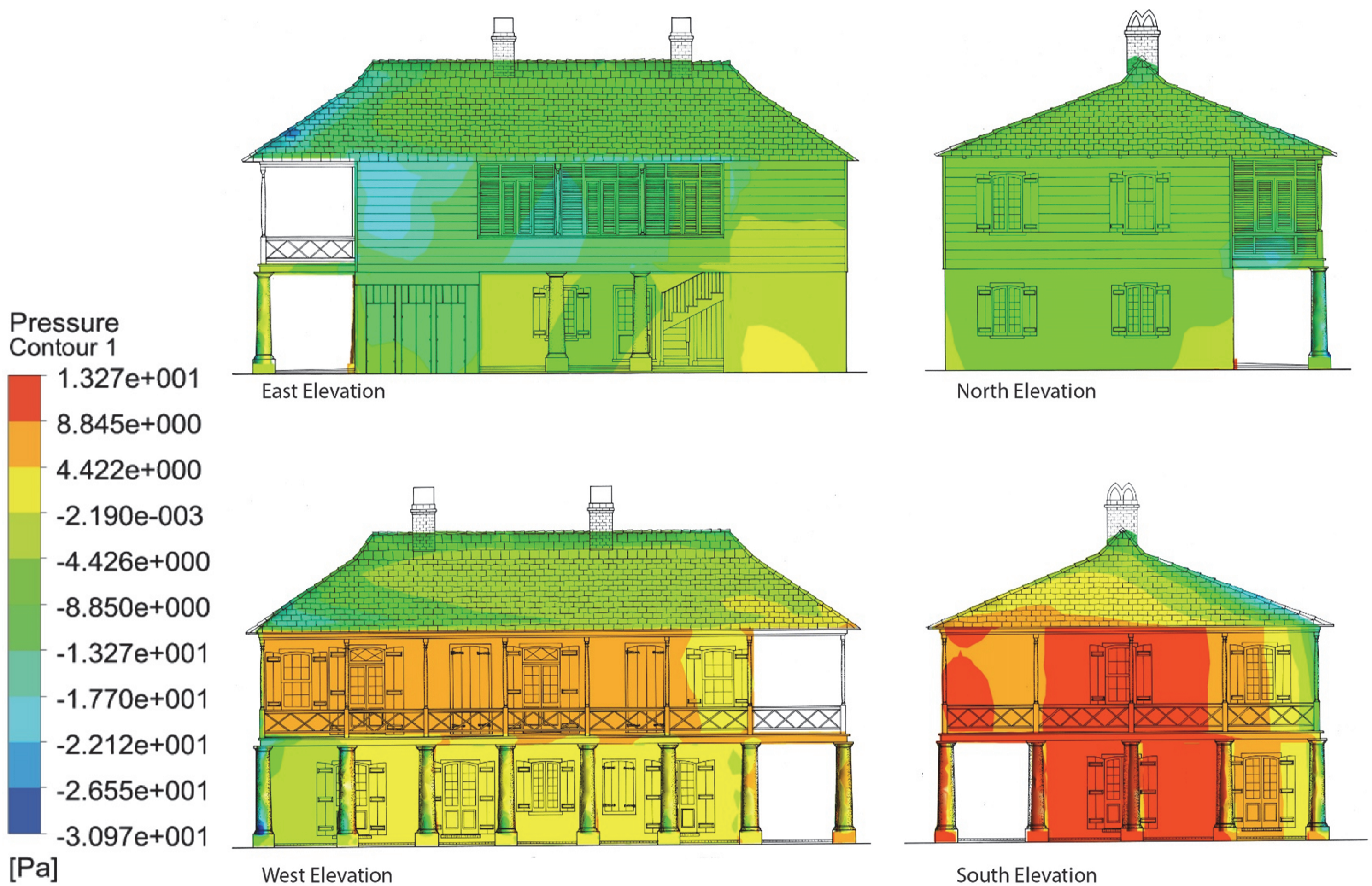


Figure 31. Measured drawing with pressure overlay from exterior CFD analysis.. Underlay image source HABS.

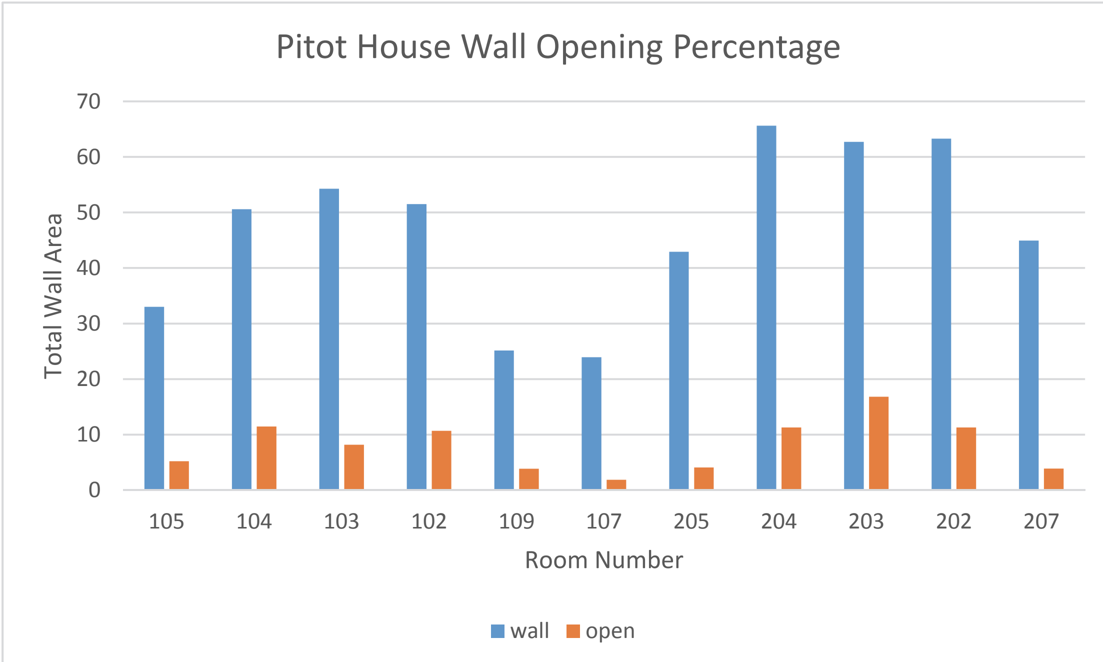


Figure 32. Diagram illustrating percentage of wall opening to wall area in each room at the Pitot House.

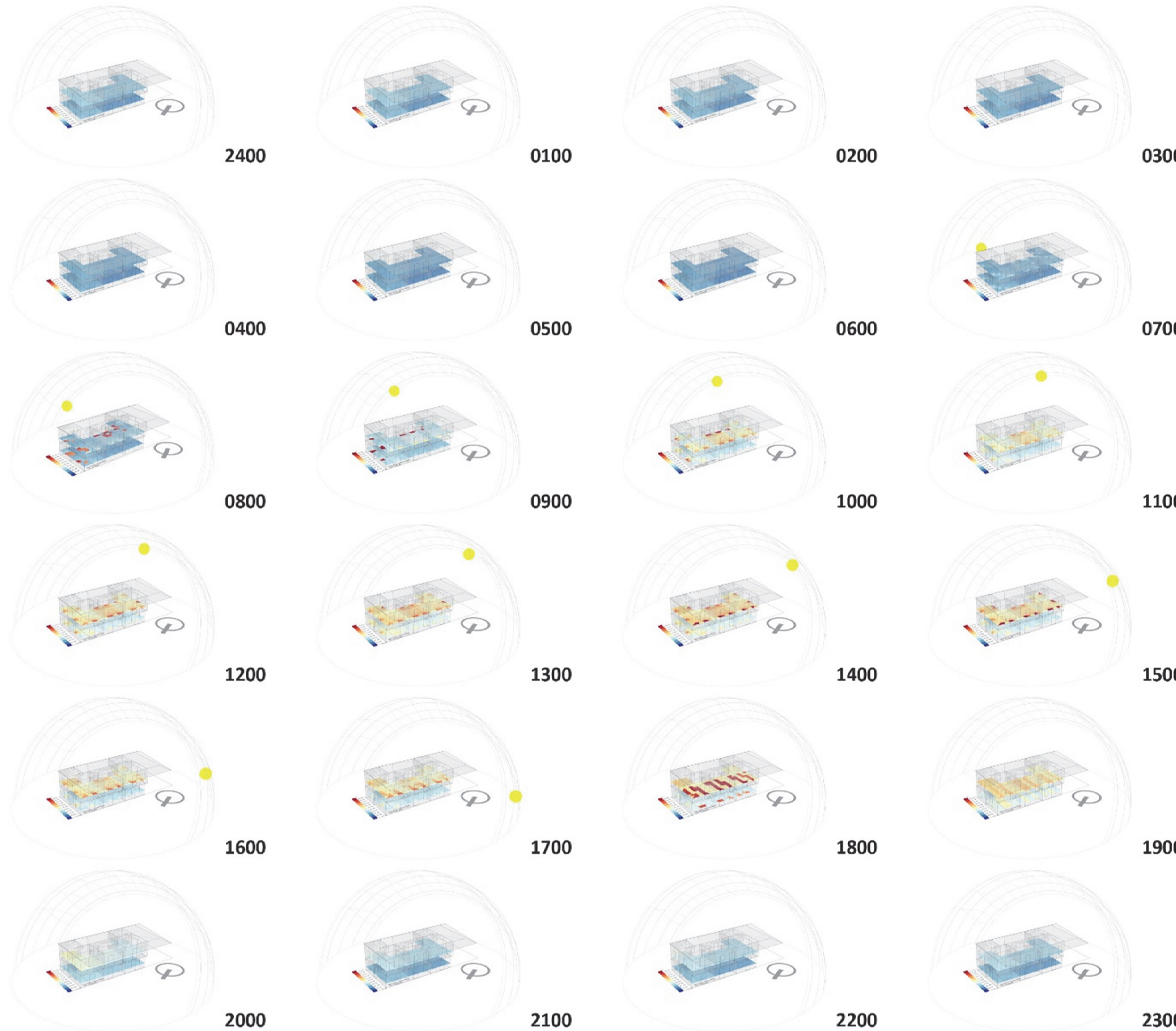
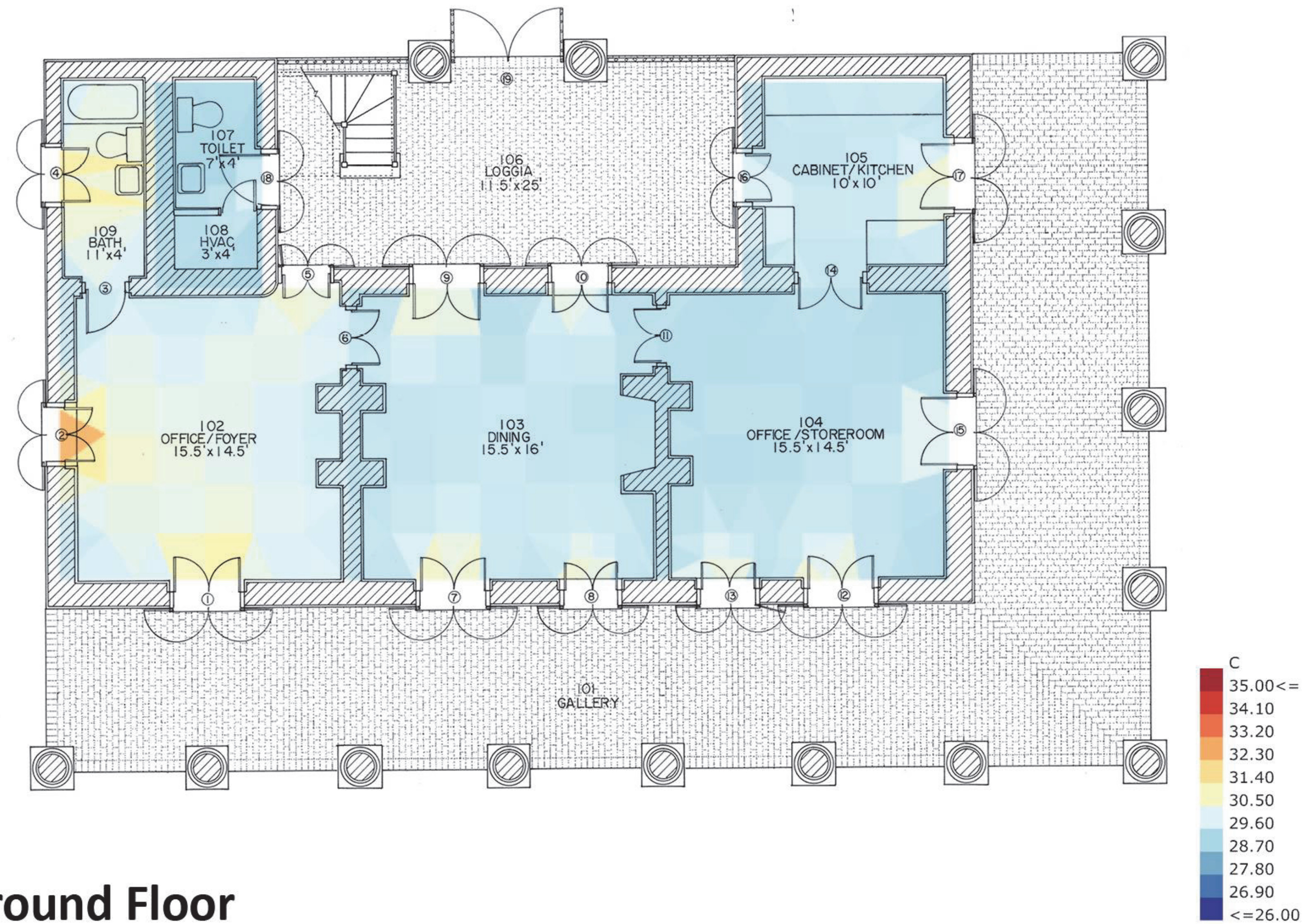


Figure 33. Indoor Operative Temperature on June21st. Images show relative position of sun at each hour.



Ground Floor

Figure 34. Honeybee/EnergyPlus simulation illustrating iindoor operative temperatures on the ground floor of the Pitot House on June 21st at noon. Drawing underlay sourced from HABS.

Second Floor

Figure 35. Indoor operative temperatures of the Pitot House on June 21st at noon. Drawing underlay sourced from HABS.

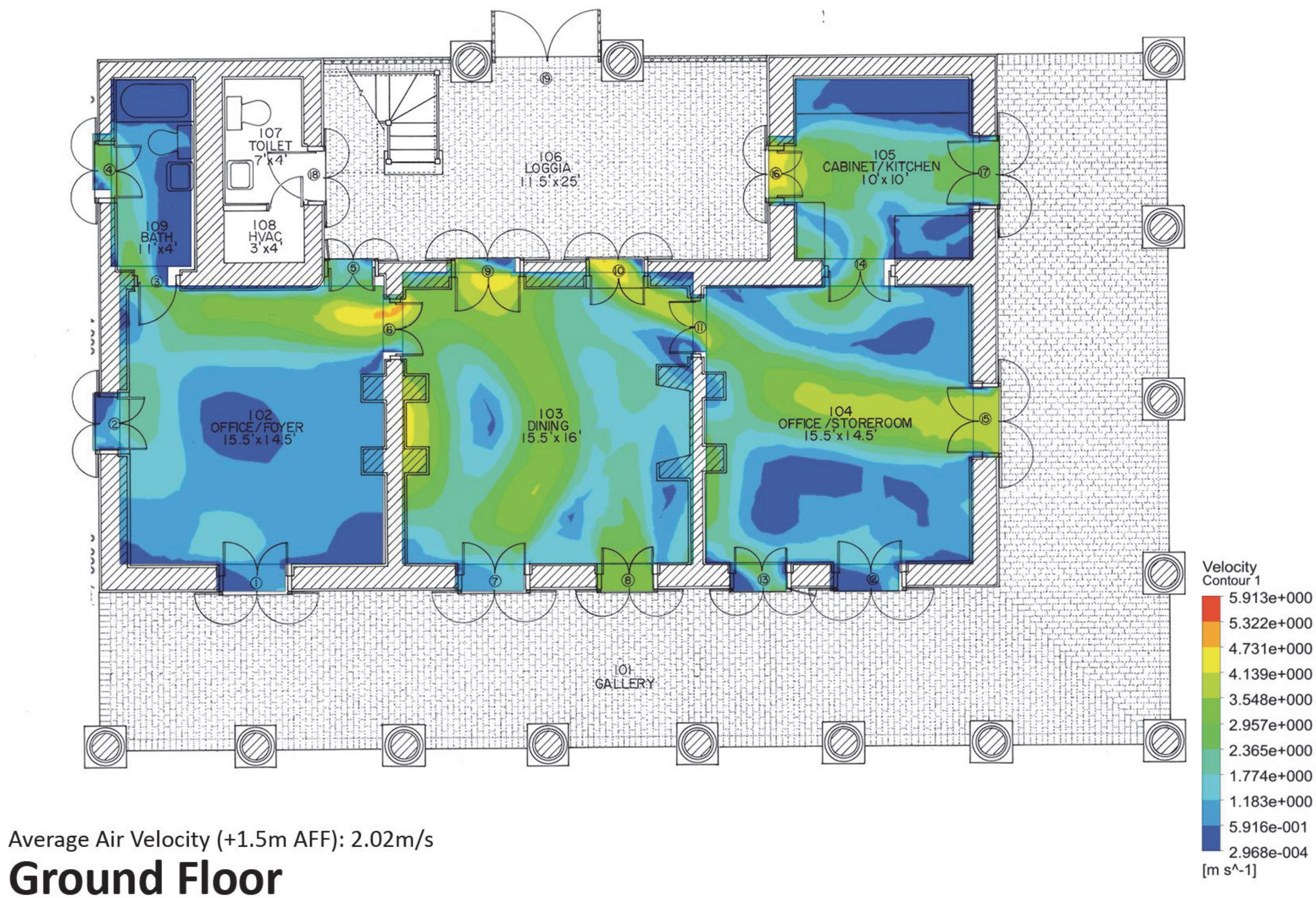
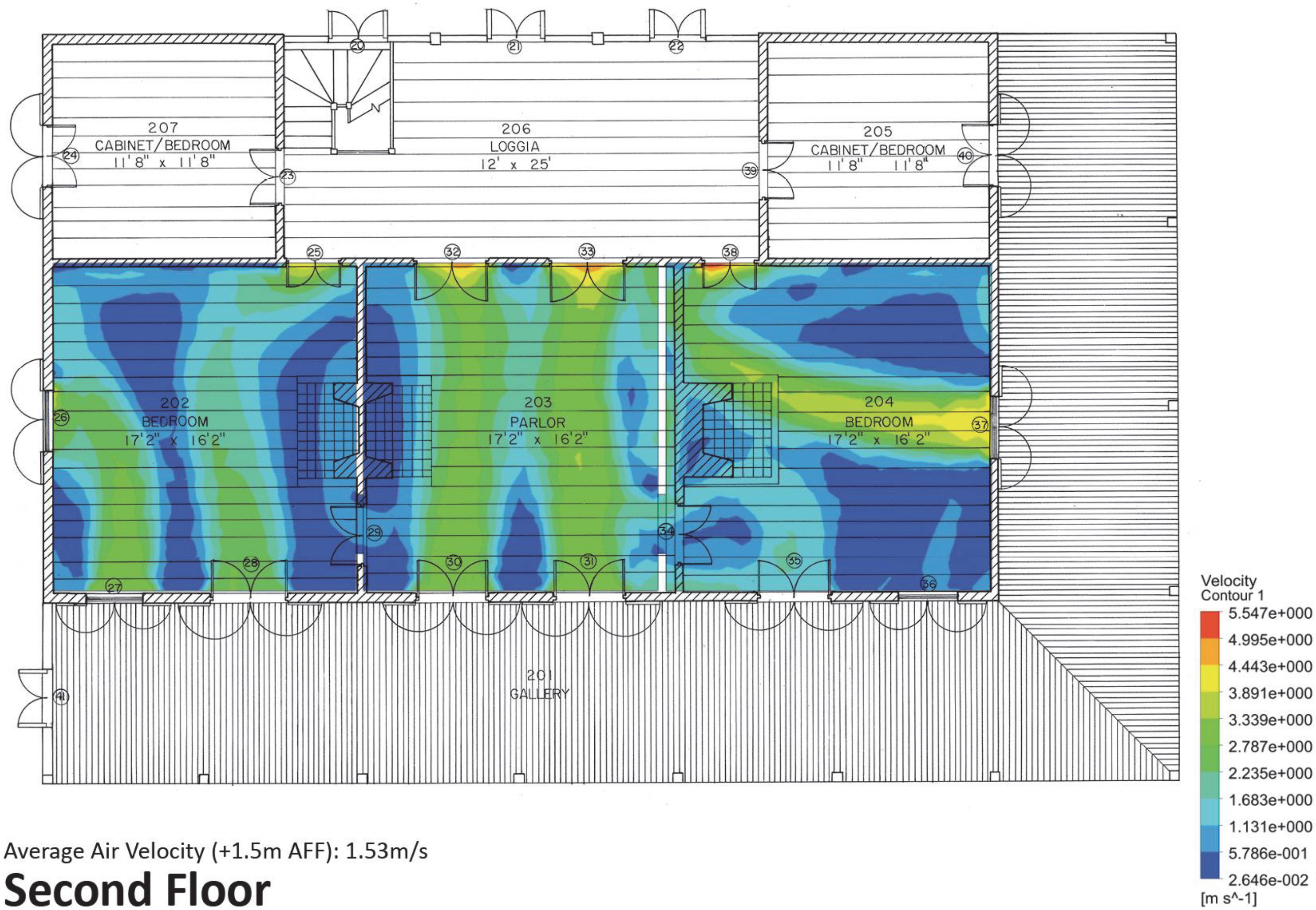


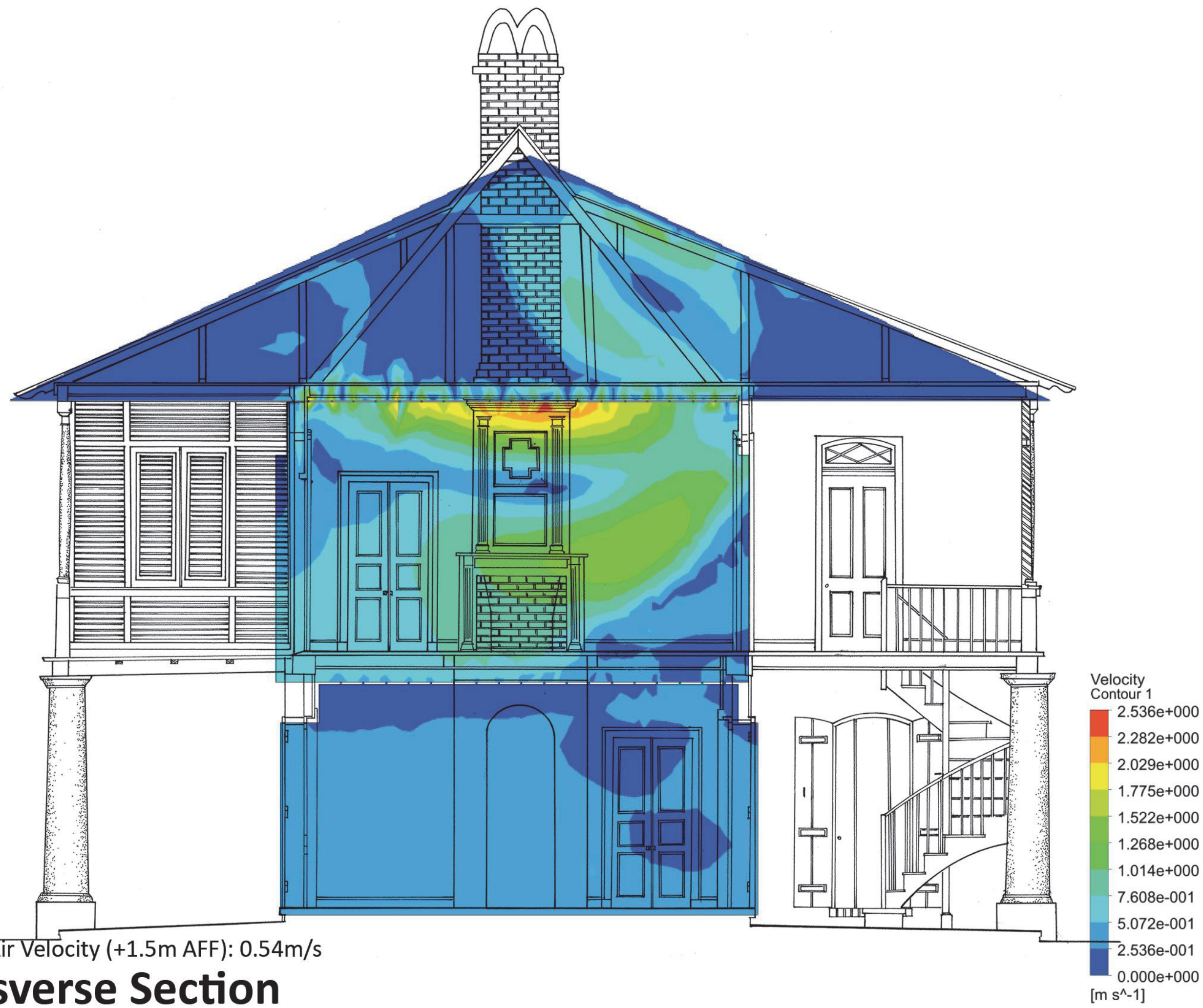
Figure 36. CFD results illustrating interior air flow on the second floor. Average Velocity noted. Drawing underlay sourced from HABS.



Average Air Velocity (+1.5m AFF): 1.53m/s

Second Floor

Figure 37. CFD results illustrating interior air flow on the ground floor. Average velocity noted. Drawing underlay sourced from HABS.



Average Air Velocity (+1.5m AFF): 0.54m/s

Transverse Section

Figure 38. Transverse section illustrating the vertical air movement as a result of night flushing and the effect of the slate roof as a thermal mass. Average velocity noted. Drawing underlay sourced from HABS.

Climate

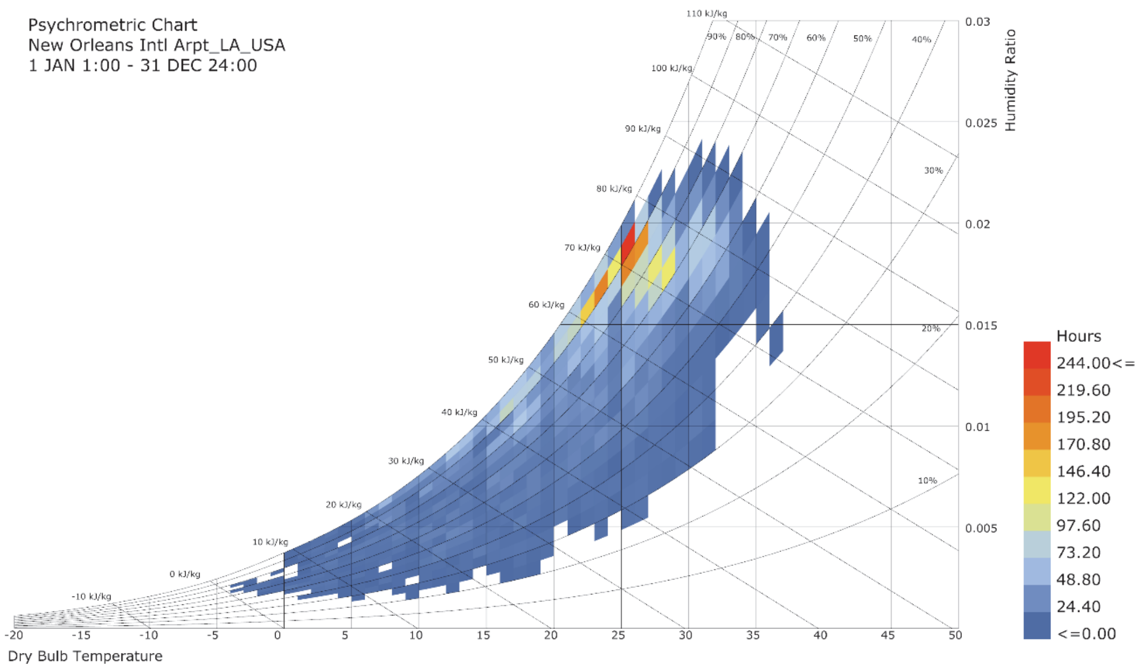


Figure 39. Annual Psychrometric Chart for New Orleans, LA.

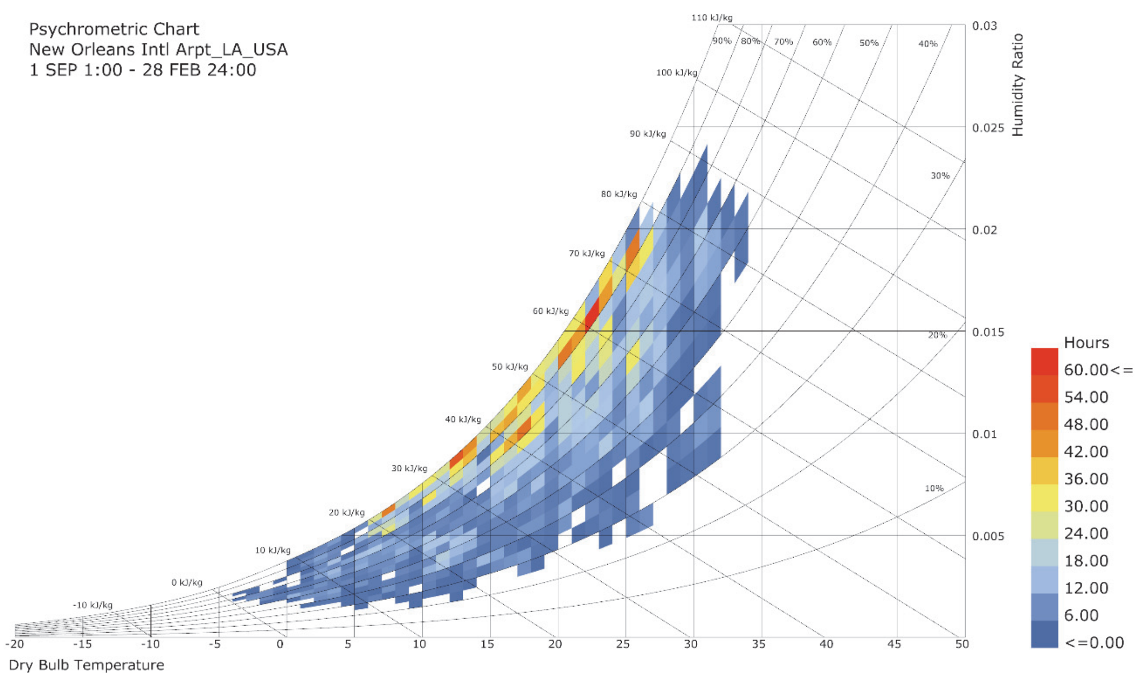
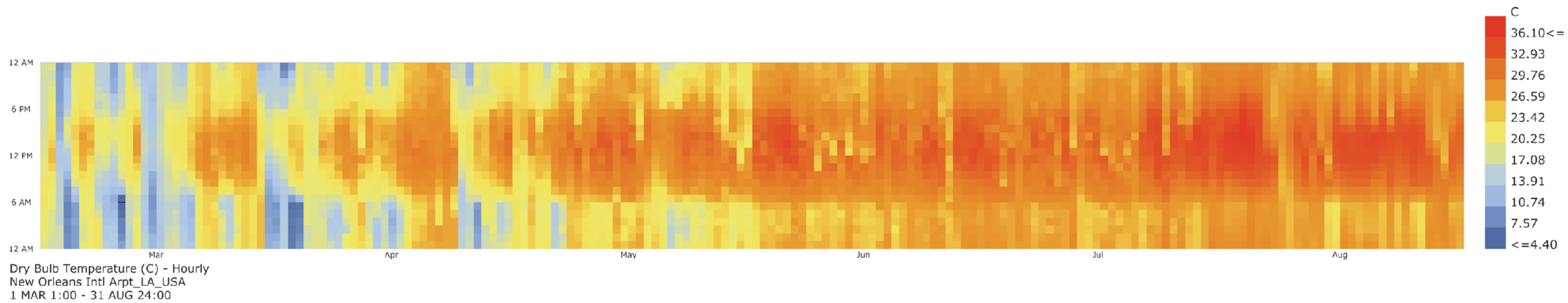


Figure 40. Winter Season Psychrometric chart for New Orleans, LA.



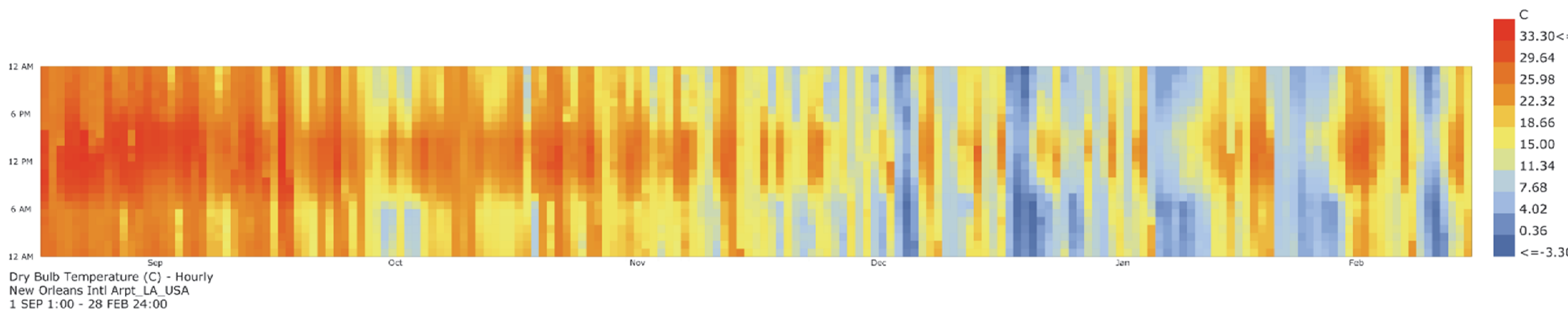


Figure 41. Dry bulb Temperature Spring-Summer (top) and winter-fall (bottom).

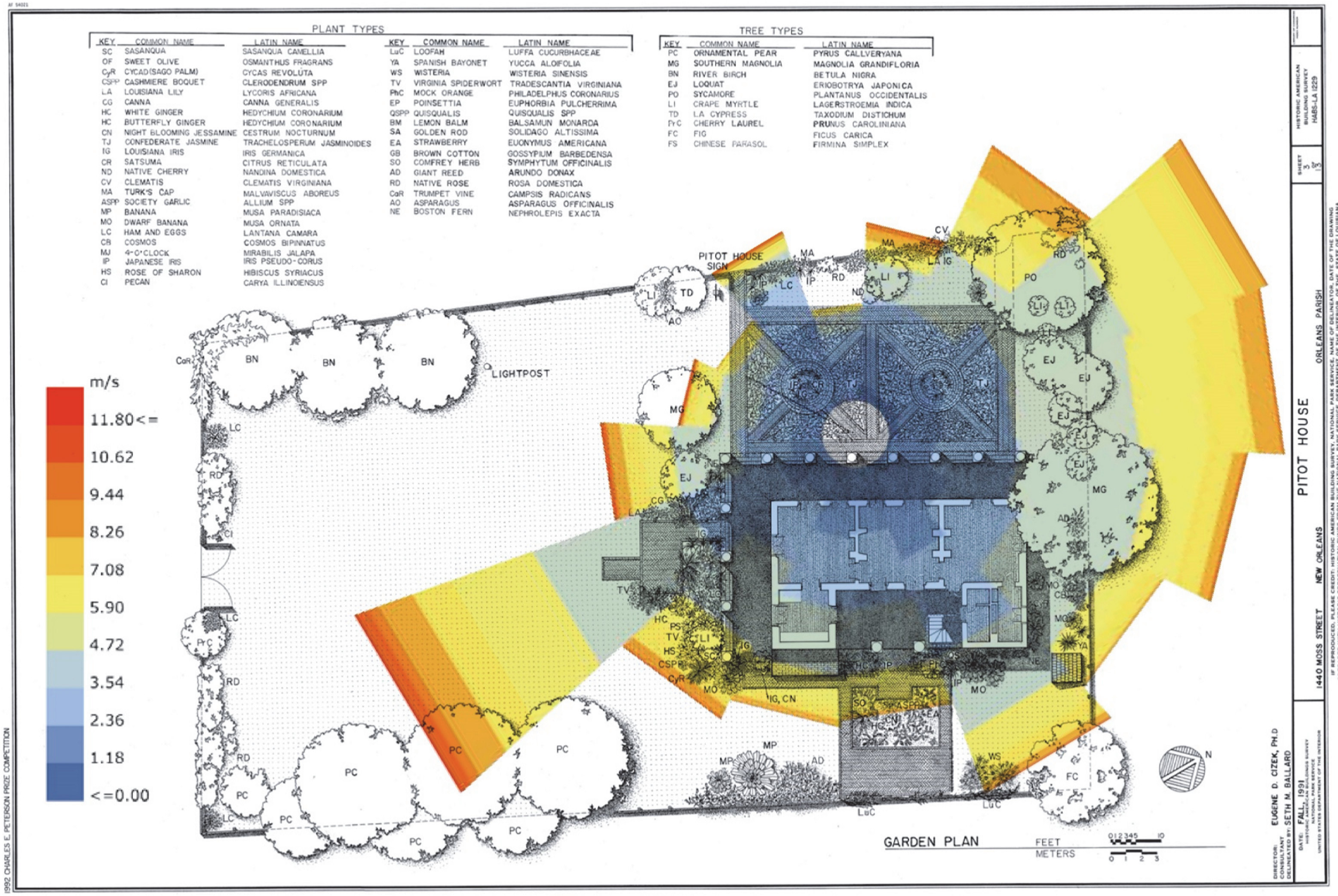


Figure 42. Annual Wind Rose for New Orleans, LA (recalibrated for height +5m and country setting). Site plan underlay sourced from HABS.

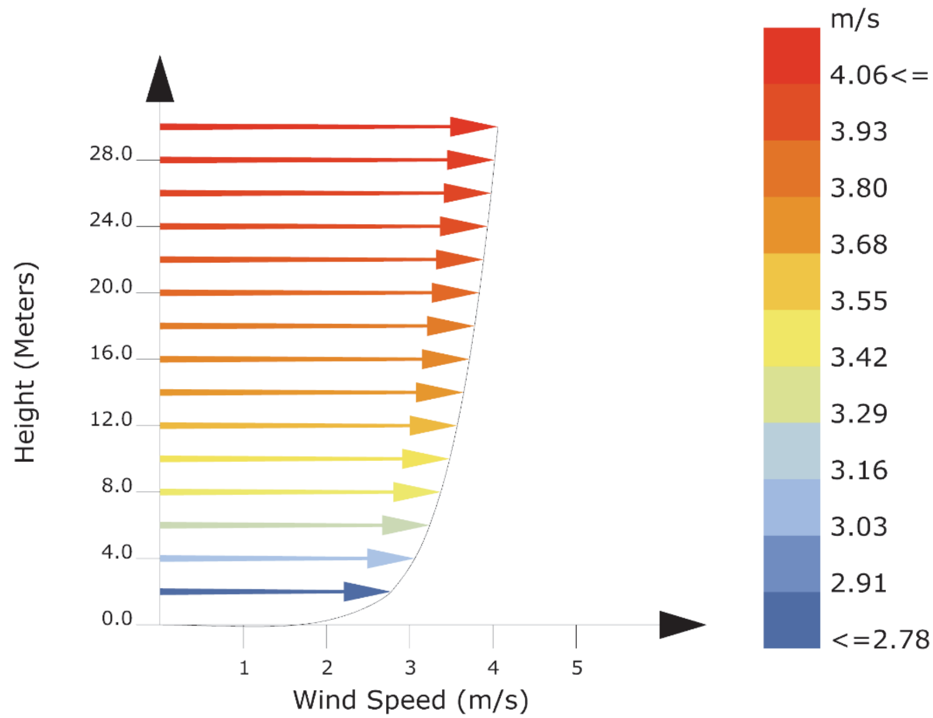


Figure 43. Wind Boundary Profile for New Orleans, LA.

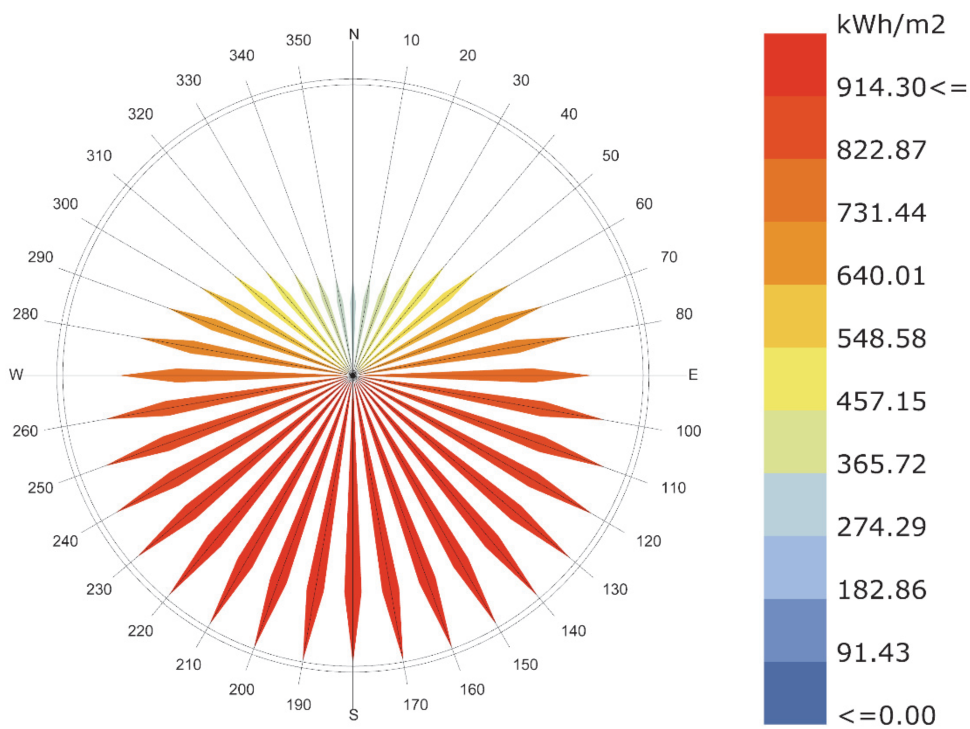


Figure 44. Solar radiation rose diagram depicting annual solar loads in New Orleans, LA.

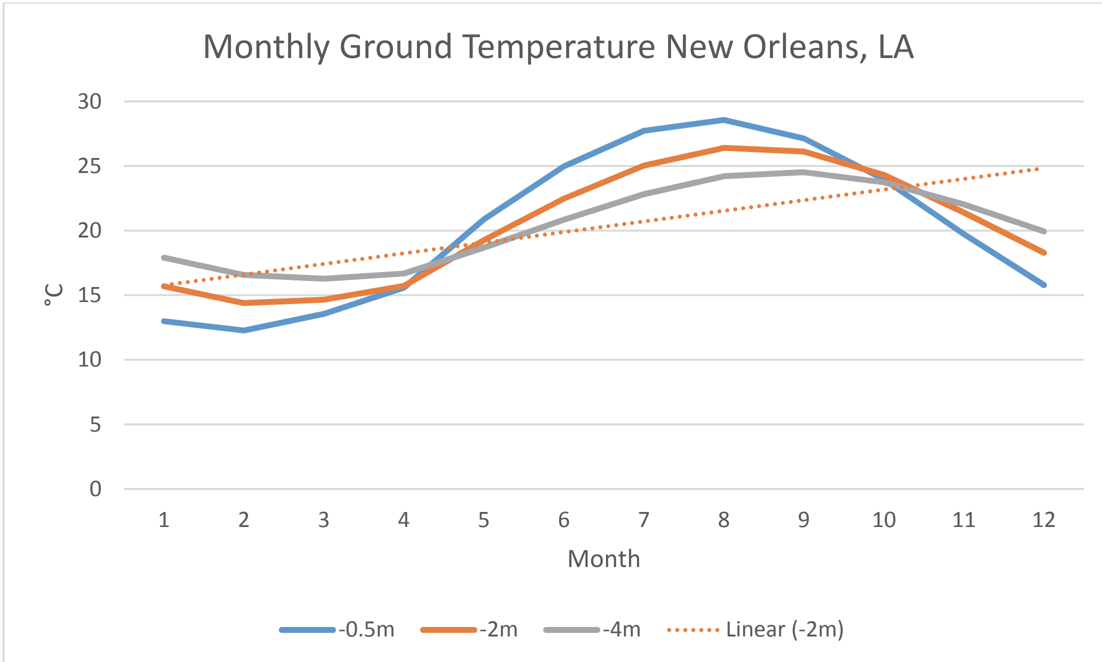


Figure 45. Monthly ground temperatures at 3 different depths in New Orleans, LA.

Simulation Model Diagrams

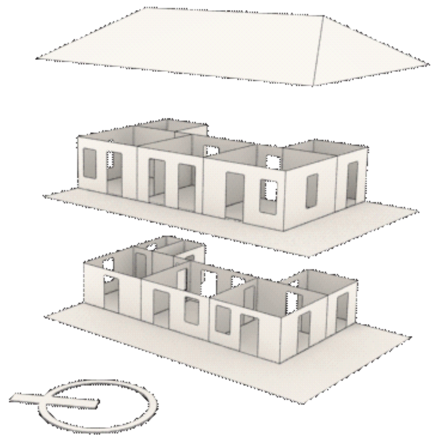


Figure 46. Exploded Axon diagram illustrating the 3D centerline model used in the baseline energy simulations.

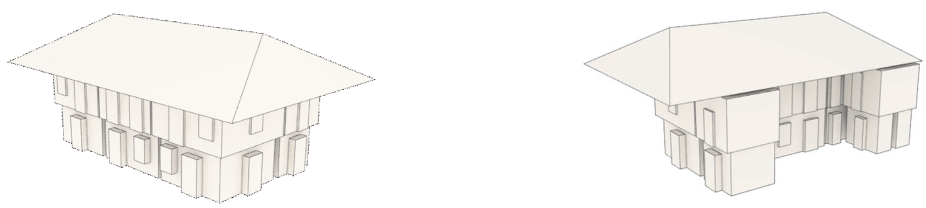


Figure 47. Interior model used for indoor CFD simulations.

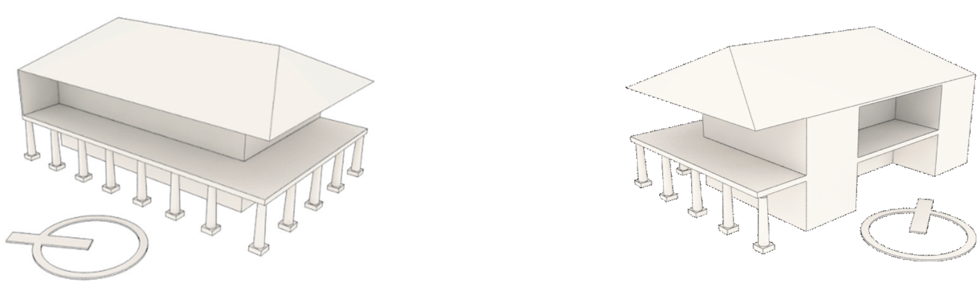


Figure 48. Site CFD Analysis Model.

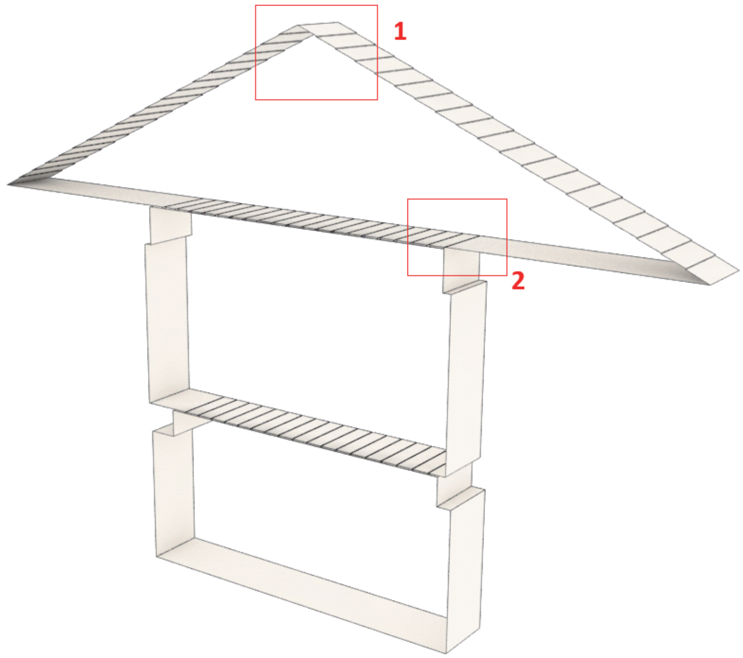


Figure 49. Interior section model used for night flush CFD simulation.

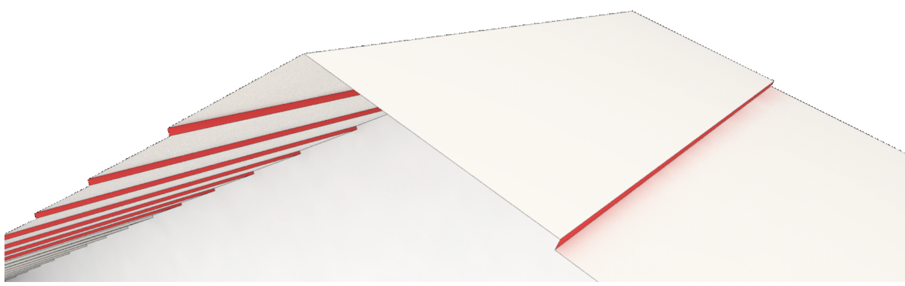


Figure 50. Detail 1 of Interior section model used for night flush CFD simulation illustrating gap spaced slate roof tiles.

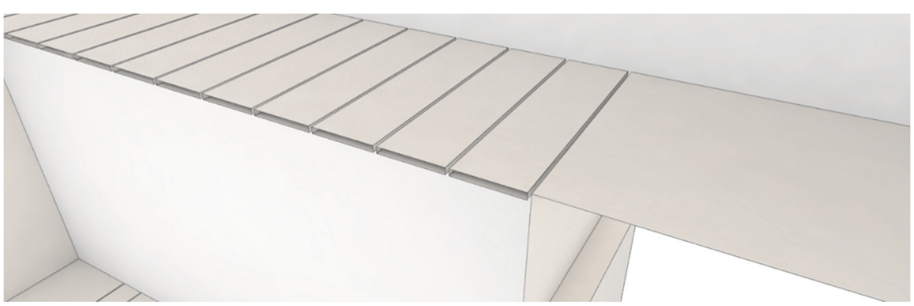


Figure 51. Detail 2 of Interior section model used for night flush CFD simulation illustrating gap spaced flood boards.

Appendix II: CFD Simulation Parameter Summary

Global Variables

Pitot House, New Orleans, LA

(29.981971, -90.089104)

GMT -6

Terrain Type

Country: Open, scattered objects generally less than +10m high

Fair Weather Conditions (Fluent)

Gravity -9.80665m/s

Materials Used

Masonry

Density - 2600 (kg/m3)

Cp Specific Heat - 900 (j/kg-k)

Thermal Conductivity – 1.00 (w/m-k)

Absorption Coefficient - 0 (1/m)

Scattering Coefficient - 0 (1/,)

Scattering Phase Function - isotropic

Refractive Index – 1 (constant)

Slate

Density - 2950 (kg/m3)

Cp Specific Heat - 760 (j/kg-k)

Thermal Conductivity – 2.01 (w/m-k)

Absorption Coefficient - 0 (1/m)

Scattering Coefficient - 0 (1/,)

Scattering Phase Function - isotropic

Refractive Index – 1 (constant)

Ansys Fluent Settings: Site

TABLE 1: Units

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

TABLE 2: Model

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Evan\Box Sync\backup\2016 Thesis HSPV\CFD\SITE_files\dp0\FFF\DM\FFF.agdb
Type	DesignModeler
Length Unit	Meters
Bounding Box	
Length X	35.781 m
Length Y	16.772 m
Length Z	56.071 m
Properties	
Volume	32579 m^3
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	91823
Elements	499663
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes

Temporary Directory	C:\Users\Evan\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE 3: Geometry

Object Name	*Shell*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	0.1
Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Reference Frame	Lagrangian
Material	
Fluid/Solid	Defined By Geometry (Fluid)
Bounding Box	
Length X	35.781 m
Length Y	16.772 m
Length Z	56.071 m
Properties	
Volume	32579 m^3
Centroid X	12.104 m
Centroid Y	8.5216 m
Centroid Z	-1.1024 m
Statistics	
Nodes	91823
Elements	499663
Mesh Metric	None

TABLE 4: Coordinate Systems

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	

X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

TABLE 5: Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity
Relevance Center	Medium
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Slow
Span Angle Center	Medium
Num Cells Across Gap	Default (3)
Proximity Size Function Sources	Faces and Edges
Proximity Min Size	0.10 m
Max Face Size	Default (1.70960 m)
Max Size	Default (3.41910 m)
Growth Rate	Default (1.20)
Minimum Edge Length	0.1270 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Assembly Meshing	
Method	None
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	CFD

Element Midside Nodes	Dropped
Straight Sided Elements	
Number of Retries	0
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Default (9.e-002 m)
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (5.e-002 m)
Statistics	
Nodes	91823
Elements	499663
Mesh Metric	None

TABLE 6: Mesh Controls

Object Name	*Automatic Method*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Automatic
Element Midside Nodes	Use Global Setting

Ansys Fluent Settings: Ground Floor

TABLE 1: Units

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

TABLE 2: Model

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Evan\Box Sync\backup\2016 Thesis HSPV\CFD\SITE_files\dp0\FFF-3\DM\FFF-3.agdb
Type	DesignModeler
Length Unit	Meters
Bounding Box	
Length X	8.6868 m
Length Y	2.7083 m
Length Z	15.545 m
Properties	
Volume	234.35 m^3
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	34772
Elements	175144
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes

Temporary Directory	C:\Users\Evan\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE 3: Geometry

Object Name	*Shell*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	0.1
Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Reference Frame	Lagrangian
Material	
Fluid/Solid	Defined By Geometry (Fluid)
Bounding Box	
Length X	8.6868 m
Length Y	2.7083 m
Length Z	15.545 m
Properties	
Volume	234.35 m^3
Centroid X	8.1519 m
Centroid Y	1.3452 m
Centroid Z	2.0052 m
Statistics	
Nodes	34772
Elements	175144
Mesh Metric	None

TABLE 4: Coordinate Systems

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	

X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

TABLE 5: Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6: Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity and Curvature
Relevance Center	Medium
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Slow
Span Angle Center	Fine
Curvature Normal Angle	Default (18.0 °)
Num Cells Across Gap	Default (3)
Proximity Size Function Sources	Faces and Edges
Min Size	Default (4.489e-003 m)
Proximity Min Size	Default (4.489e-003 m)
Max Face Size	Default (0.44890 m)
Max Size	Default (0.897790 m)
Growth Rate	Default (1.20)
Minimum Edge Length	0.15240 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2

Inflation Algorithm	Pre
View Advanced Options	No
Assembly Meshing	
Method	None
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	CFD
Element Midside Nodes	Dropped
Straight Sided Elements	
Number of Retries	0
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Default (4.0401e-003 m)
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (2.2445e-003 m)
Statistics	
Nodes	34772
Elements	175144
Mesh Metric	None

TABLE 7: Mesh Controls

Object Name	*Automatic Method*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Automatic
Element Midside Nodes	Use Global Setting

Ansys Fluent Settings: Second Floor

TABLE 1: Units

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

TABLE 2: Model

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Evan\Box Sync\backup\2016 Thesis HSPV\CFD\SITE_files\dp0\FFF-4\DM\FFF-4.agdb
Type	DesignModeler
Length Unit	Meters
Bounding Box	
Length X	5.334 m
Length Y	3.0734 m
Length Z	15.291 m
Properties	
Volume	247. m^3
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	18012
Elements	88179
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes

Temporary Directory	C:\Users\Evan\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE 3: Geometry

Object Name	*Shell*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Reference Frame	Lagrangian
Material	
Fluid/Solid	Defined By Geometry (Fluid)
Bounding Box	
Length X	5.334 m
Length Y	3.0734 m
Length Z	15.291 m
Properties	
Volume	247. m^3
Centroid X	-2.6879 m
Centroid Y	4.2441 m
Centroid Z	-23.291 m
Statistics	
Nodes	18012
Elements	88179
Mesh Metric	None

TABLE 4: Coordinate Systems

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	

X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

TABLE 5: Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6: Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Fine
Initial Size Seed	Active Assembly
Smoothing	Low
Transition	Slow
Span Angle Center	Coarse
Curvature Normal Angle	Default (70.3950 °)
Min Size	Default (2.4064e-003 m)
Max Face Size	Default (0.240640 m)
Max Size	Default (0.481270 m)
Growth Rate	Default (1.20)
Minimum Edge Length	0.128020 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	2
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Assembly Meshing	

Method	None
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	CFD
Element Midside Nodes	Dropped
Straight Sided Elements	
Number of Retries	0
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Default (2.1657e-003 m)
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (1.2032e-003 m)
Statistics	
Nodes	18012
Elements	88179
Mesh Metric	None

TABLE 7: Mesh Controls

Object Name	*Automatic Method*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Automatic
Element Midside Nodes	Use Global Setting

Ansys Fluent Settings: Night Flush Section Model

TABLE 1: Units

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

TABLE 2: Model

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Evan\Box Sync\backup\2016 Thesis HSPV\CFD\SITE_files\dp0\FFF-5\DM\FFF-5.agdb
Type	DesignModeler
Length Unit	Meters
Bounding Box	
Length X	12.283 m
Length Y	8.8297 m
Length Z	1. m
Properties	
Volume	50.399 m^3
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	9162
Elements	41722
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes

Temporary Directory	C:\Users\Evan\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE 3: Geometry

Object Name	*Shell*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	0.1
Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Reference Frame	Lagrangian
Material	
Fluid/Solid	Defined By Geometry (Fluid)
Bounding Box	
Length X	12.283 m
Length Y	8.8297 m
Length Z	1. m
Properties	
Volume	50.399 m^3
Centroid X	32.416 m
Centroid Y	4.3491 m
Centroid Z	21.023 m
Statistics	
Nodes	9162
Elements	41722
Mesh Metric	None

TABLE 4: Coordinate Systems

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	

X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

TABLE 5: Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6: Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Fine
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Slow
Span Angle Center	Medium
Curvature Normal Angle	Default (45.0 °)
Min Size	Default (2.2132e-003 m)
Max Face Size	Default (0.221320 m)
Max Size	Default (0.442650 m)
Growth Rate	Default (1.20)
Minimum Edge Length	1.241e-002 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	2
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Assembly Meshing	

Method	None
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	CFD
Element Midside Nodes	Dropped
Straight Sided Elements	
Number of Retries	0
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Default (1.9919e-003 m)
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (1.1066e-003 m)
Statistics	
Nodes	9162
Elements	41722
Mesh Metric	None

Ansys Fluent Settings: Gable Roof Massing Study

TABLE 1: Units

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

TABLE 2: Model

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Evan\Box Sync\backup\2016 Thesis HSPV\CFD\SITE_files\dp0\FFF-7\DM\FFF-7.agdb
Type	DesignModeler
Length Unit	Meters
Bounding Box	
Length X	35.781 m
Length Y	16.772 m
Length Z	56.071 m
Properties	
Volume	32383 m^3
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	74294
Elements	401601
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes

Temporary Directory	C:\Users\Evan\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE 3: Geometry

Object Name	*Shell*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Reference Frame	Lagrangian
Material	
Fluid/Solid	Defined By Geometry (Solid)
Bounding Box	
Length X	35.781 m
Length Y	16.772 m
Length Z	56.071 m
Properties	
Volume	32383 m^3
Centroid X	12.114 m
Centroid Y	8.5491 m
Centroid Z	-1.0313 m
Statistics	
Nodes	74294
Elements	401601
Mesh Metric	None

TABLE 4: Coordinate Systems

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	

X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

TABLE 5: Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity
Relevance Center	Medium
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Slow
Span Angle Center	Medium
Num Cells Across Gap	Default (3)
Proximity Size Function Sources	Faces and Edges
Proximity Min Size	0.10 m
Max Face Size	Default (1.70960 m)
Max Size	Default (3.41910 m)
Growth Rate	Default (1.20)
Minimum Edge Length	0.1270 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Assembly Meshing	
Method	None
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	CFD

Element Midside Nodes	Dropped
Straight Sided Elements	
Number of Retries	0
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Default (9.e-002 m)
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (5.e-002 m)
Statistics	
Nodes	74294
Elements	401601
Mesh Metric	None

TABLE 6: Mesh Controls

Object Name	*Automatic Method*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Automatic
Element Midside Nodes	Use Global Setting

Ansys Fluent Settings: Hip Roof Massing Study

TABLE 1: Units

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

TABLE 2: Model

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Evan\Box Sync\backup\2016 Thesis HSPV\CFD\SITE_files\dp0\FFF-8\DM\FFF-8.agdb
Type	DesignModeler
Length Unit	Meters
Bounding Box	
Length X	35.781 m
Length Y	16.772 m
Length Z	56.071 m
Properties	
Volume	32421 m^3
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	74055
Elements	400347
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes

Temporary Directory	C:\Users\Evan\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE 3: Geometry

Object Name	*Shell*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Reference Frame	Lagrangian
Material	
Fluid/Solid	Defined By Geometry (Solid)
Bounding Box	
Length X	35.781 m
Length Y	16.772 m
Length Z	56.071 m
Properties	
Volume	32421 m^3
Centroid X	12.112 m
Centroid Y	8.5481 m
Centroid Z	-1.0264 m
Statistics	
Nodes	74055
Elements	400347
Mesh Metric	None

TABLE 4: Coordinate Systems

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	

X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

TABLE 5: Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity
Relevance Center	Medium
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Slow
Span Angle Center	Medium
Num Cells Across Gap	Default (3)
Proximity Size Function Sources	Faces and Edges
Proximity Min Size	0.10 m
Max Face Size	Default (1.70960 m)
Max Size	Default (3.41910 m)
Growth Rate	Default (1.20)
Minimum Edge Length	0.1270 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Assembly Meshing	
Method	None
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled

Shape Checking	CFD
Element Midside Nodes	Dropped
Straight Sided Elements	
Number of Retries	0
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Default (9.e-002 m)
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default (5.e-002 m)
Statistics	
Nodes	74055
Elements	400347
Mesh Metric	None

TABLE 6: Mesh Controls

Object Name	*Automatic Method*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Automatic
Element Midside Nodes	Use Global Setting

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