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AC/DC: Let There Be Hybrid Cooling

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by

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For my parents (with love).

…and those about to rock.

Acknowledgements

Much gratitude to my thesis chair, Dan Powers, for his firm guidance, not just throughout my thesis, but also through the numerous obstacles I often made for myself during my time at SACD. Thanks to Rick Rados for always having the answer. The issues discussed relating to the roles of air conditioning versus passive cooling in the past fifty years helped me to understand my thesis' place in the timeline of cooling. To Stan Russell for his understanding in this not becoming a design-build project. However, the experience gained on-site as to how a building is put together has been invaluable in visualizing and illustrating how these concepts could translate into architectural space and form. Thank you and appreciation to Ricky Peterika, for too many things to mention, but most pertinent to this thesis, for showing me how to make the gardens of the "garden classroom" work.   Thank you to Alison and Nicole, for constructing a model in six hours, and to Luciano Esposito, for his late-night laser work. Thanks for the last minute help from Brandon Bartle, Mark Perret, Nate Boyd, Thao Nguyen, Jessica Gardberg and Leo Morantin. I would like to give a big thank you to Sasha Dalla Costa for her constant support, making me look good in the jury room and keeping me well-fed during my crazy hours.

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ABSTRACT

In today's increasingly energy conscious society, the methods of providing thermal comfort to humans are constantly under scrutiny. Depending on the climate, and the comfort requirements of the occupants, buildings can be designed to heat and cool occupants with passive methods, as well as mechanical methods. In the subtropics, where buildings often need to be heated in the winter and cooled in the summer, a synthesis of these two methods would be ideal. However, there is a disconnect between the integration of passive cooling and mechanical air conditioning, in subtropical architecture.

A study of user attitudes, based out of Australia, found that, "Central control of temperatures has been used to cut demand by preventing users from altering thermostats and other parts of the building for microclimate control. In particular, windows are sealed to prevent tampering."[1] Reliance on air conditioning has the everyday person convinced that if we save energy in the right places, we can use air conditioning as much as we like. The same study goes on to state, "Air-conditioning has been assumed to replace the need for climate design features in buildings creating poor thermal design and high energy use."[2] This can be most clearly seen in our public buildings. Fully conditioned buildings pump cool air into sealed envelopes, adjusting the

thermostat to regulate thermal comfort year-round, often in a climate in which mechanical air conditioning is needed only four months of the year, and during the warmest hours of the day. Inversely, ventilated buildings provide passive cooling in a climate in which the temperature and humidity are often too high for thermal comfort during the same four months of the year.

In his book Natural Ventilation in Buildings, Francis Allard points out that the global energy efficiency movement, begun in the early 1990s, has now emerged as a concept that incorporates active air conditioning and site-specific climate design of buildings into one holistic approach.[3] However, these buildings exist in more dry and temperate climates, and do not fully apply to the subtropics as cooling models. A model is needed for subtropical architecture allowing a building to reach both ends of the spectrum; from natural ventilation, through mechanical ventilation, to mechanical air conditioning. The goal of this thesis is to design a hybrid model for subtropical architecture which maximizes the use of natural and mechanical ventilation, and minimizes the use of mechanical air conditioning. The vehicle for this explanation is the design of an educational facility.

Research of thermal comfort needs for occupants in the subtropics was accompanied with observation studies. This research was compared with case study, site and program analysis. The analysis was supplemented by a handbook of passive and mechanical cooling which was compiled to aid in establishing cooling strategies for the design process. The implementation of the research and analysis was brought to a conclusion that successfully achieved the goals of this thesis. By using passive methods to lower the temperature of the air surrounding the classroom buildings, the incoming air used to cool the occupants reached temperatures low enough to be considered comfortable inside the classrooms.

Subtropical Hot, Humid Climates

Systems of classifying the earth's climatic zones have been categorized by many, but the most widely accepted system is the Koppen-Geiger climate classification. Based upon the relation of climate to vegetation, the system defines cities such as Tampa, Washington D.C., Hong Kong and Milan as humid subtropical climates. Typically located on the southeastern edges of continents, the vegetation is lush, and fairly cloudy skies often cause strong glare of diffused sunlight.

The two climatic factors that have the biggest impact on subtropical regions are the ambient air temperature, which is the air temperature of one's surroundings, and relative humidity, which is the percentage of water vapor that exists in the air. The average temperatures of regions within this climate can vary by more than ten degrees, and are often affected by proximity to bodies of water and topography of natural land features. In many ways the humid subtropics are similar to tropical climates closer to the equator. For example, both climates experience very high temperature and humidity levels. Temperatures can reach as high as the low 90s in the summer, and feel even hotter, due to the humidity. The relative humidity hovers at 70 to 80 percent

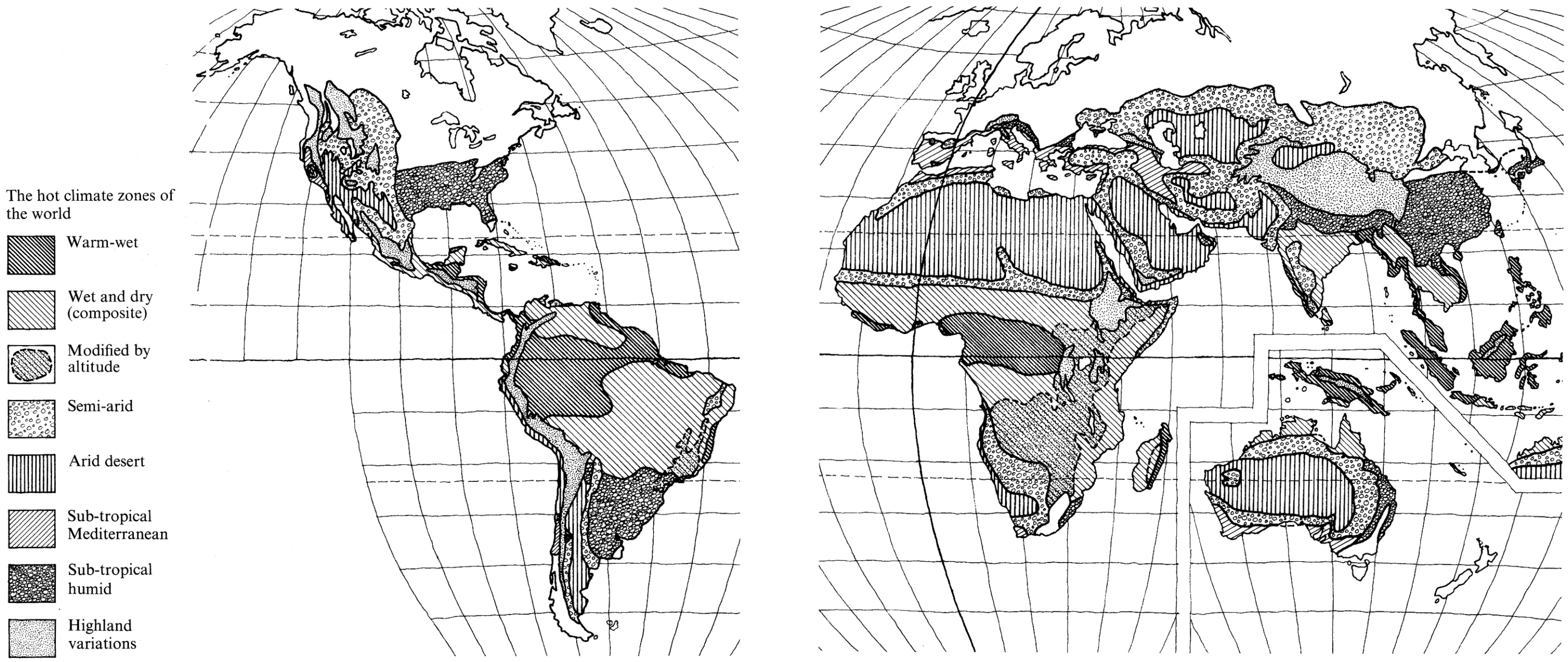


Fig. 1. Hot climate zones of the world.[1]

in the summer during the days, and does not deviate much in the evenings. However, unlike the tropics, subtropical climates also have a cool season. For example, in North America the cool season stretches from mid-November through mid-March, and temperatures can drop as low as 25 degrees Fahrenheit. The relative humidity also drops in the cool season to between 40 and 70 percent. It is because of these characteristics that the humid subtropics are often considered a hybrid climate: too hot and humid to be classified as temperate, but not consistently hot and humid enough to be classified as tropical.

High precipitation is common of the humid subtropics with the most amount of rain falling from late May to early September in North America. In these months, afternoon showers can be expected almost every day. The hurricane and monsoon seasons bring the highest concentration of rains and occasional flooding, depending on the topography and saturation of the ground.[2] Though subtropical regions closer to the poles of the earth are affected by the prevailing westerlies, the trade winds prevail in the majority of subtropical climates. Because these hot humid regions are generally found along continental edges, many areas benefit from onshore breezes generated by the difference in temperatures of land and sea.[3]

Thermal Comfort and the "Comfort Zone"

One of the most relentless pursuits of mankind has been the pursuit of comfort. Human comfort is built upon health and well-being, which is most powerfully influenced by climate. Terry S. Boutet, in his book Controlling Air Movement, describes the relevance of health and climate in ancient and modern times, "Comfort and health have been, and always will be, influenced by climate. Hippocrates, in about 400 B.C., wrote that, 'Whoever would study medicine aright must learn of the following subjects. First he must consider the effect of each of the seasons of the year and the difference between them. Secondly, he must study the warm and the cold winds, both those which are common to every country and those in peculiar to a particular locality. Lastly, the effect of the water on the health must not be forgotten. Thus, he would know what changes to expect in the weather and, not only would he enjoy good health himself for the most part, but he would be very successful in the practice of medicine. If it should be thought that this is more of the business of the meteorologist, then learn that astronomy plays a very important part in medicine since the changes of the seasons produce changes in the mechanism of the body.' Climate and health are still vital issues among modern doctors, as Sir Leonard Hill pointed out in a report to the Medical Research Council, 'The changing play of light, of cold and warmth, stimulate the activity and health of the mind and body. Monotony of occupation and external conditions for long hours destroy vigour and happiness of, and bring about the atrophy of disuse in, men.'"[1]

Comfort is both psychological and physiological, encompassing not only the limits of an environment in which no discomfort occurs, but extending beyond that boundary to the limits of satisfaction. Because of this, thermal comfort differs from comfort in that it lacks the emotion and excitement of the human experience. Thermal comfort can be defined as, ". . . the condition which produces minimal activity of the thermoregulatory mechanisms of the body."[2] Thus, it is the emotional aspect of human comfort that makes for a full, rounded experience, and should be the vantage point from which the thermal qualities of an experience are viewed.

In his book, Design with Climate, Victor Olgyay proposes a method of designing for humans within their respective climates. Through analysis of a varied set of studies conducted in relation to humans and their perceived levels of comfort, Olgyay assembled a Bioclimatic Chart. The underlying concept of the Bioclimatic Chart is to establish a comfort zone whose perimeter represents the limits of a human's comfort within a specific climate.[3] Since the publication of the Bioclimatic Chart, many others have published charts based on a similar theme. The studies researched in the creation of most of these charts incorporated both physiological and psychological responses to climate conditions in a variety of environments. The comfort zone is different for every individual, and is affected by factors such as age, sex and acclimatization. An example of acclimatization would be the altering of an individual's comfort zone from one environment to the next, such as from a dry, temperate climate to a hot, humid climate. All of these factors contribute to varied definitions of the comfort zone, further proving the subjective nature of comfort. For example, the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) defines the comfort zone as, ". . . the range of conditions in which more than 50 percent of the persons tested felt comfortable."[4] S.F. Markham's definition, mentioned by Olgyay, ranges from 60 to 76 degrees Fahrenheit, with relative humidities at noon varying from 40 to 70 percent.[5]

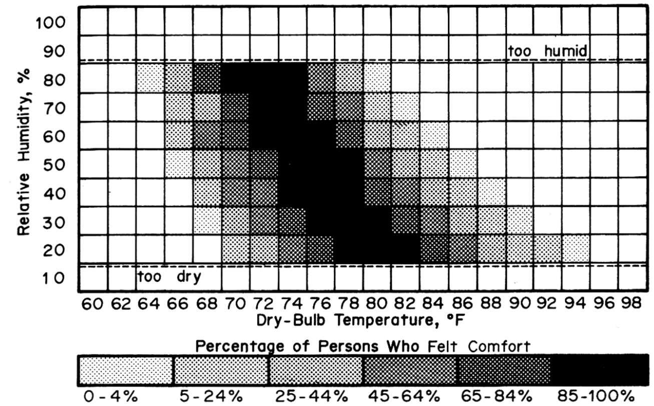


Fig. 2. Range of conditions which provide comfort according to ASHRAE.[6]

The six main factors affecting comfort in humans are ambient air temperature, solar radiation, humidity, air movement and velocity, clothing, and the metabolic rate of the body. The ambient air temperature is the baseline from which the five other factors relate. The radiant temperature is measured from the surfaces surrounding the individual, and a difference between ambient and radiant temperatures can be used to balance one another and increase comfort. Humidity can greatly increase or decrease the loss of heat from the body, which affects comfort more directly than radiant temperature. Air movement enables the body to lose heat through convection or evaporative cooling. As air velocity increases, so does the rate of heat loss from the body. When the ambient air temperature is below the temperature of the human body, air movement will always have a cooling effect. When the ambient air temperature is above the

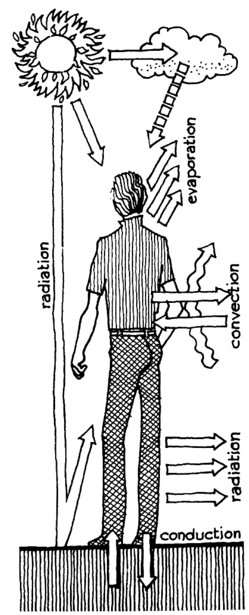


Fig. 3. Thermal Exchange of the human body.[7]

temperature of the human body, the air movement will have a warming and a cooling effect, but the cooling effect will always be greater until the ambient air temperature reaches 104 degrees. Clothing decreases the evaporative cooling effect of the body and prevents heat loss through convection. Densities of fabrics and amount of body coverage are the contributing factors. The metabolic rate is affected by body weight and levels of activity, and is the factor that most directly affects body heat levels. As the body's level of activity increases, so does the need for cooling.[8]

The Human Comfort Chart has been established as a combination of previous comfort charts, in order to supply the architect with a source that displays the factors of human comfort in terms easily understood. Developed by Boutet, this chart simplifies the process of analyzing a climate's comfort issues, thus assisting the architect in understanding which climate responsive strategies are needed from the outset of the design process. The comfort zone found within this chart contains separate summer and winter comfort zones, as well as an overlapping comfort zone of greater size, afforded by the implementation of ventilation. Depending on the climatic conditions, the ambient air temperature may need to be lowered, the humidity may need to increase, the humidity may need to decrease, or the individual may need the supply of air movement. The Human Comfort Chart will be used, for the purpose of this thesis, to analyze the comfort issues found within the climate of the project site. The ventilated comfort zone will serve as a foundation from which subjective comfort levels

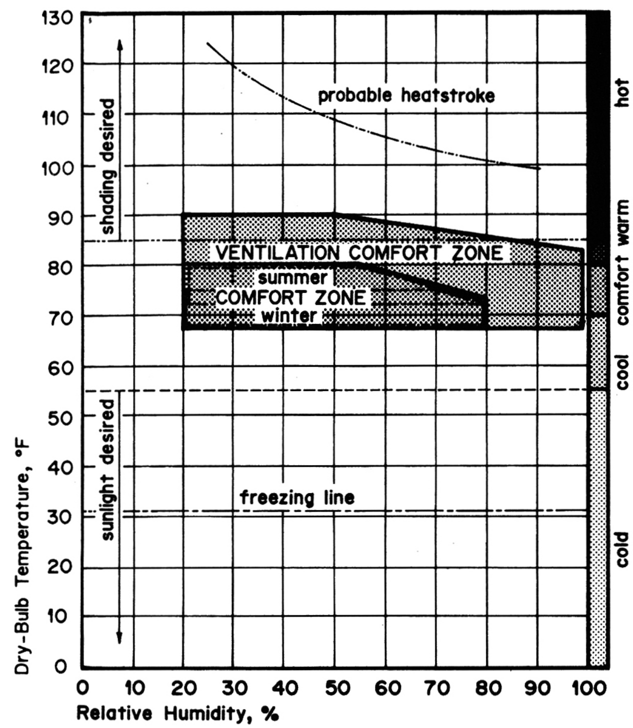


Fig. 4. The Human Comfort Chart developed by Terry Boutet.[9]

can be assumed to exist.[10]

The Importance of Air Movement in Hot, Humid Climates

In the summer months of subtropical climates, temperatures often reach highs that cause the human body to perspire. Additionally, relative humidity levels can reach levels leaving moisture on the skin and clothing of occupants. Air movement uses the perspiration and moisture as an advantage of cooling. The movement of air across the skin and clothing increases both the rate and sensation of cooling as the moisture is evaporated. This process is commonly referred to as evaporative cooling. In hot, humid climates, cross-ventilation can be utilized as a method of cooling occupants up to a certain temperature limit, assuming a relatively high air velocity. Since, in most cases, the air used to ventilate an interior space comes from the exterior environment, the limit is based upon the outdoor air temperature. If one assumes a maximum air speed between 1.5 and 2.0 meters per second, then the maximum temperature limit for which outdoor air can be used to cross-ventilate an interior space is between 82.4 and 89.6 degrees Fahrenheit. The maximum air speed has been established as the threshold at which loose papers, such as the worksheets and book pages students would review in class, begin to fly around.[1] Similarly, if the same velocity of air movement can be induced by the stack effect, or with the supplement of a fan, the same results can be achieved.

Fig. 5. Ventilation caused by the stack effect.[2]

For the purpose of this thesis, there are three main forms of air movement. The first is natural ventilation, which uses the forces of the wind to move air through a space. Cross-ventilation is an example of natural ventilation. The second form of air movement is induced ventilation, which is based on changes in temperature and pressure. Changes in temperature and pressure can cause air to rise or sink, which is referred to as buoyancy. A solar chimney is a good example of induced ventilation. The last form of air movement is forced ventilation, which relies on the assistance of mechanical means to move air at a higher velocity than that of the existing natural conditions.[3]

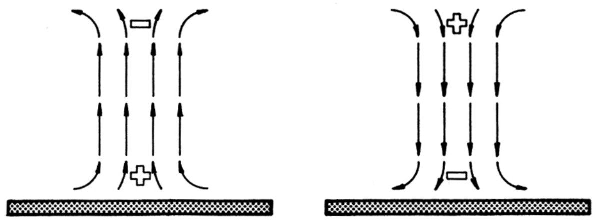


Fig. 6. Buoyancy is caused by variations in air density due to changes in air temperature. Air pressure always moves from positive to negative.[4]

Meso-climate and Microclimate

The climate of the subtropics can be analyzed at two different scales. The meso-climatic scale is the broader scale, and consists of data that is recorded for an entire city or district. The data often includes monthly weather patterns of characteristics such as average maximum temperatures, average minimum temperatures, average relative humidity, prevailing wind directions, amount of precipitation, and the sun's path. More specific meso-climatic data covers observations recorded hourly and averaged over the period of a month.[1]

The microclimate scale is specific to a building site and its immediate context, such as the surrounding buildings and streets.[2] Microclimatic data is observed and recorded by the architect, and is extremely important in its influence of the design process. Site-specific conditions demanding analysis include sun and shade, wind patterns, reflectivity of surrounding surfaces, and the effects of thermal mass on the site. Additionally, ambient air temperature and relative humidity should also be recorded. While the latter two may seem redundant, the truth is that the meso-climatic and microclimatic data do not always match. Contextual influences can cause an increase or decrease in temperature and humidity. Consequently it is imperative to make consistent observations throughout specific areas of the site. Certain areas of the site may

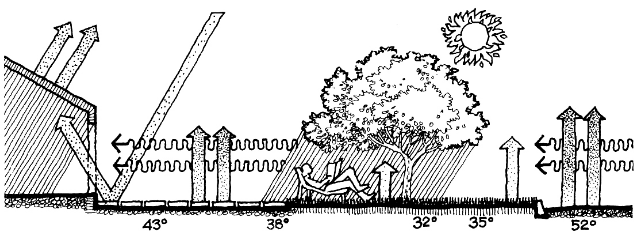


Fig. 7. The temperatures of a microclimate are greatly affected by the surrounding context.[3]

be shaded during the morning, and then exposed to the sun in the afternoon. These variations can have a significant effect on the shape and orientation of proposed buildings during the design process. The purpose of comparing the ambient air temperature and relative humidity recordings to the meso-climatic data is to understand the patterns of difference between the two. Since most architects do not have an entire twelve months to understand the site at its hottest and coldest, conclusions can be inferred from the differences between the two forms of data. Although computer programs may be able to model sun and shade patterns, among other characteristics, the knowledge gained by physically placing one's self at the site to experience the same conditions one will be designing for is invaluable.

The purpose of the selected case studies is to understand the range of methods used in educational architecture for cooling in hot, humid climates. From the most typical local example of air conditioned "big box" enclosure, through air conditioned enclosures separated by open-air circulation, to the bare-bone example of natural and mechanical ventilation, these case studies serve to explain which cooling method is best utilized for specific spaces in school buildings.

School of Architecture and Community Design

University of South Florida

Tampa, Florida

H. Leslie Walker and Associates – Architects, 1965

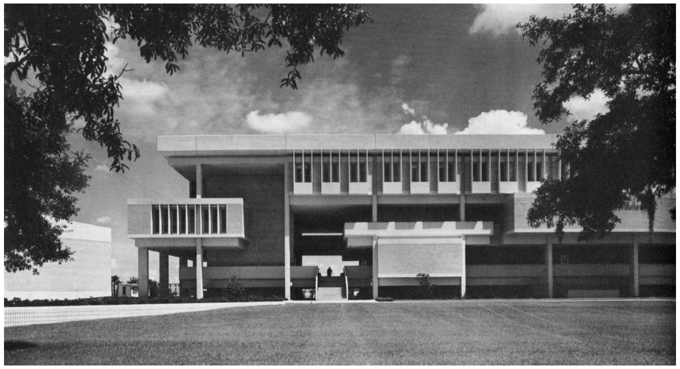


Fig. 8. Photo just after completion showing dark shadows as a result of the deep recesses afforded by the design.

The HMS Building which houses the School of Architecture and Community Design is an excellent example of the institutional architecture of the 1960s that was constructed in the Gulf Coast Region. Using a concrete column and beam framework, the building demonstrates Modernist sensibilities in its technological use of cantilevered enclosures to create shaded paths, and the separation of enclosed spaces to create covered breezeways. It was constructed just prior to the energy crisis of the 1970s under the reality that energy was cheap, thus the enclosed classrooms maximized air conditioning efficiency as sealed envelopes without any windows.

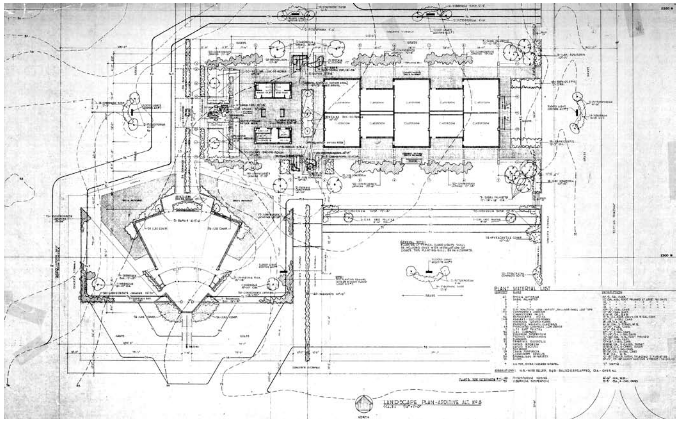


Fig. 9. Original landscape plan showing the anticipated use of vegetation as a way too cool the edges of the building.

The HMS building lies at the air conditioned end of the spectrum for the selected group of case studies. While it does provide covered open-air circulation, similar to Denham Oaks Elementary School, the air movement within these breezeways is unable to penetrate into the fully enclosed classrooms. The purpose of this case study is twofold. One function is to understand the amount of surface area hidden from direct sunlight, as well as indirect heat. By minimizing surfaces exposed to the hot, humid climate, the

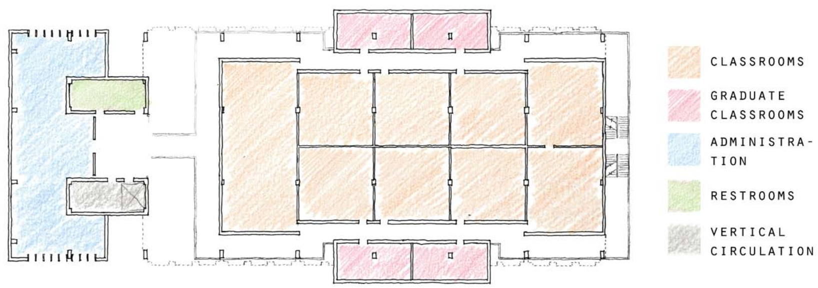


Fig. 12. Functions of spaces, 3rd floor.

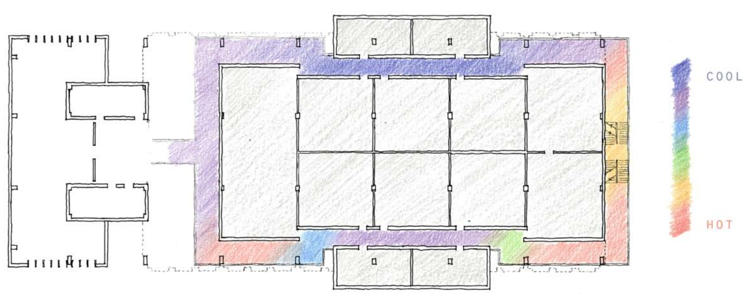


Fig. 11. Thermal zones, Fall and Spring, 6-10 a.m., 3rd floor.

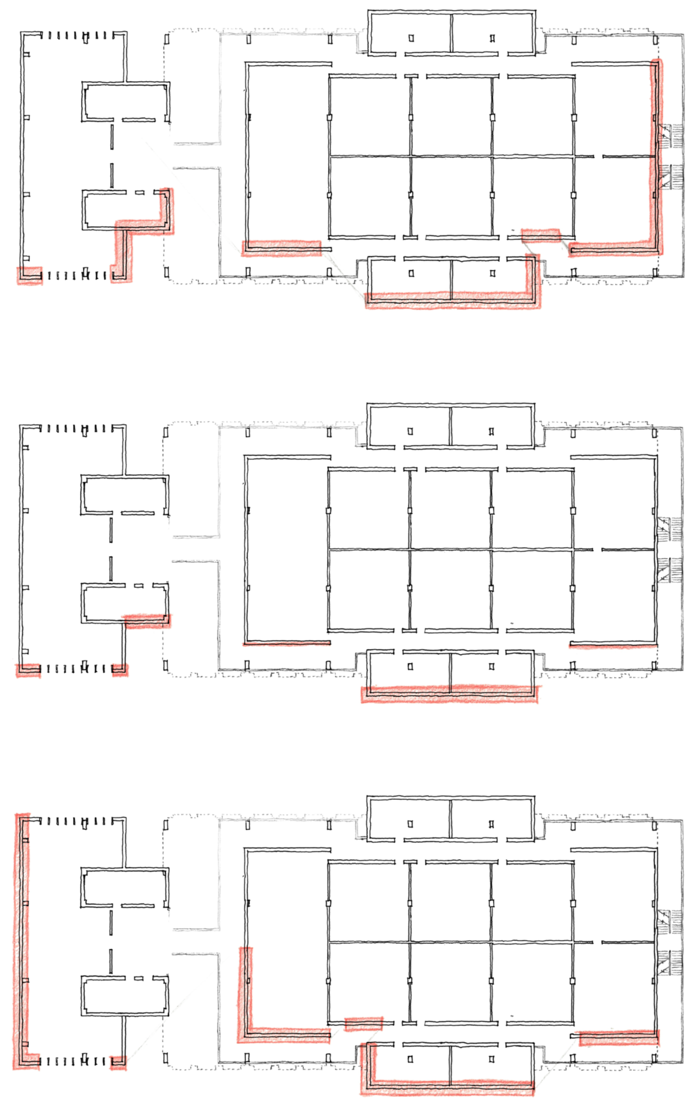


Fig. 10. Surfaces affected by direct solar heat gain, Fall and Spring.

efficiency of conditioned spaces of the building is maximized. The second function is to examine how these surfaces could be cooled with the same wind currents that could naturally and mechanically ventilate interior spaces with the addition of wall openings. If the thermal perception of naturally cooled exterior surfaces can be related to surfaces felt within interior spaces, then the thermal qualities of interior surfaces can begin to shape and organize interior spaces.

The design approach of HMS is a variation on the principles of a dogtrot house, applied to a larger scale structure. As such, all of the open-air circulation paths serve as breezeways. The vertical circulation, restrooms and administrative offices are pulled to the west and separated from the classrooms on the lower levels creating a "dogtrot" covered by the fourth floor. The circulation balconies circling the third floor provide shade to the paths and building surfaces of the second and first floors, while the cantilevered volumes provide shade along the north and south circulation paths of the third floor. Recessed from the encircling balconies, the building envelope of the first, second, and third floors is completely finished in brick. No windows are to be found on these levels. The classrooms within this envelope were designed to be fully air conditioned spaces. The fourth floor is an air conditioned enclosure which spans the entire length and width of the building. Sun-shaded, operable windows can be found along the north and south façades of this level.

Despite the designer's use of overhangs and recesses to provide surface

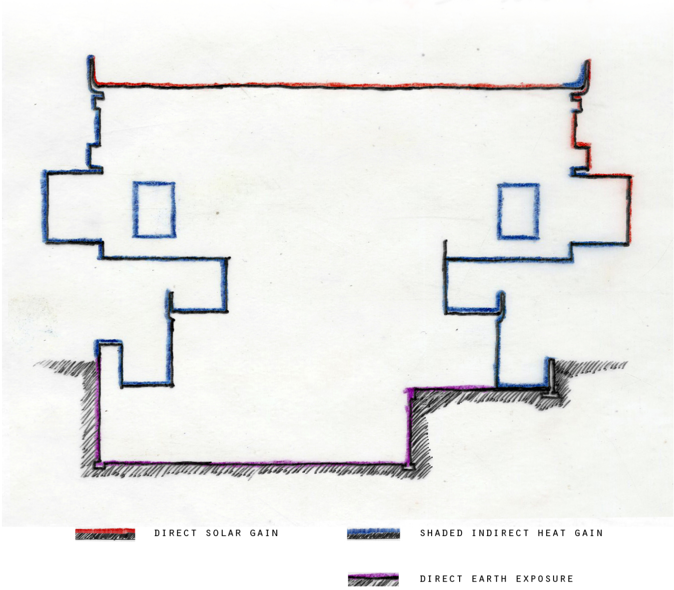


Fig. 14. Exposed surfaces section.

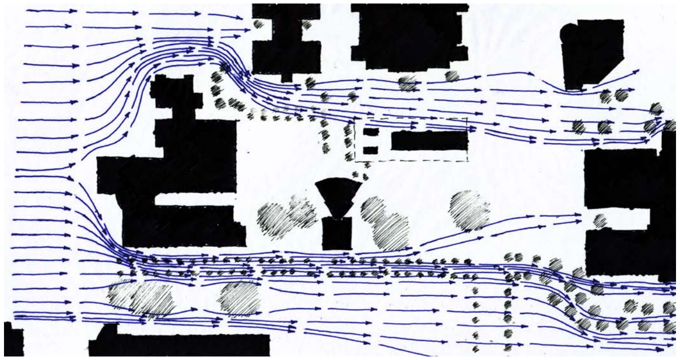


Fig. 13. Wind diagram depicting westerly winds.

shading, as well as paths for air movement, the building takes a bipolar stance of extreme contrast between interior and exterior. The building informs its inhabitants that the natural air is meant to be kept out of the classrooms at all times. Unfortunately, all other relationships with the world outside suffer just as severely. Daylight, the sound of birds, the scent of trees, as well as the feel of

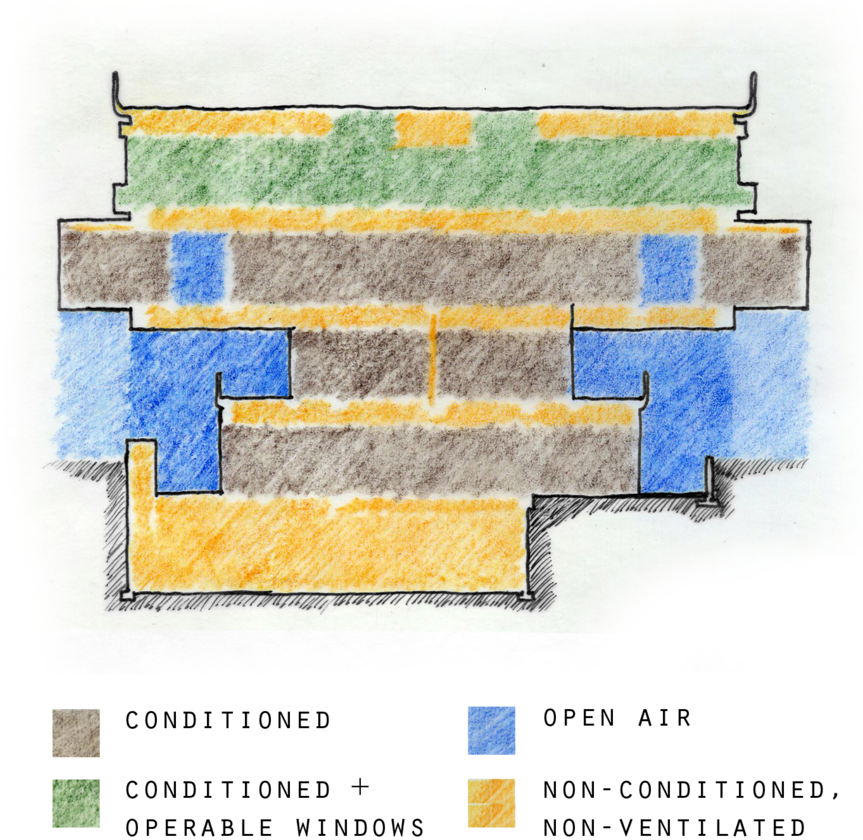


Fig. 16. Cooling methods section.

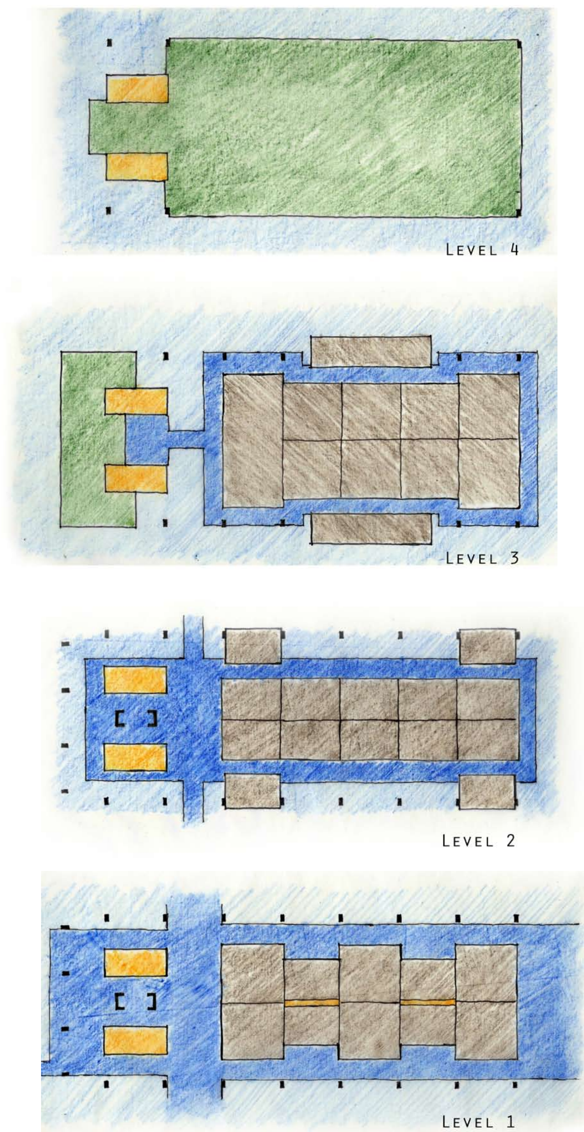


Fig. 15. Cooling methods plans.

natural air, all cease to exist within the classrooms. This case study serves as not only a study of air movement and heat gain of surfaces, but also as an inspiration to break down barriers between interior and exterior spaces through a range of secondary and tertiary spaces leading from open space to enclosure within the sense of the classroom, thus collapsing the previous notions of interior versus exterior.

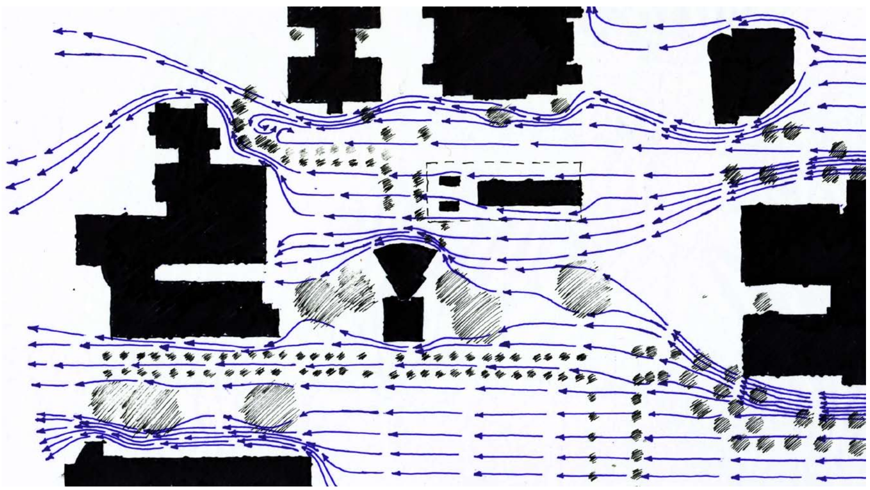


Fig. 17. Wind diagram depicting easterly winds.

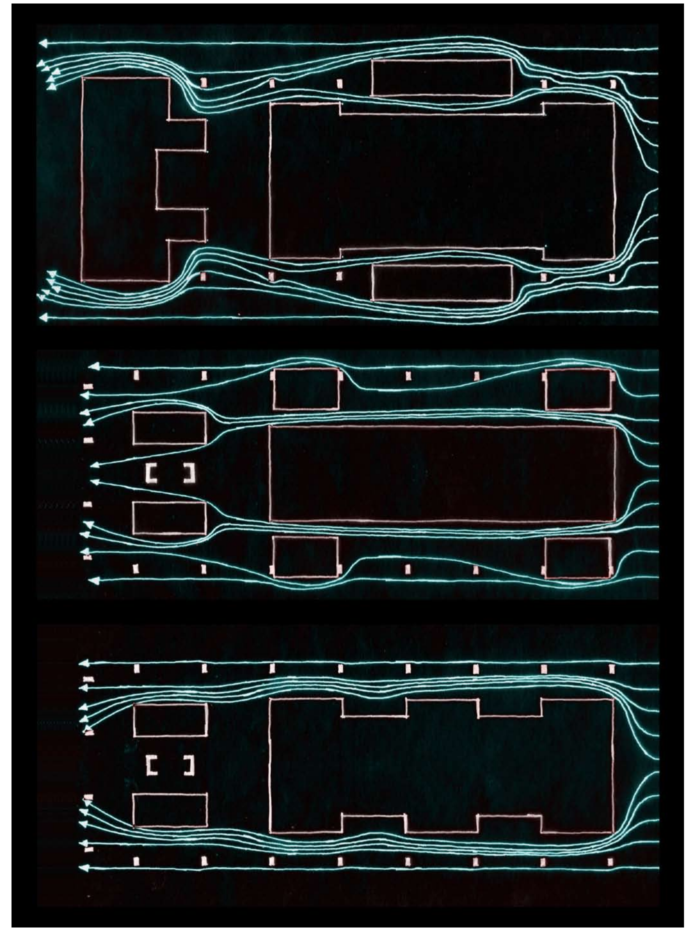


Fig. 18. Westerly wind plan diagrams of levels 1-3.

Marrkolidjban Outstation School

Central Arnhem Land, Northern Territory, Australia

Troppo Architects, 1992

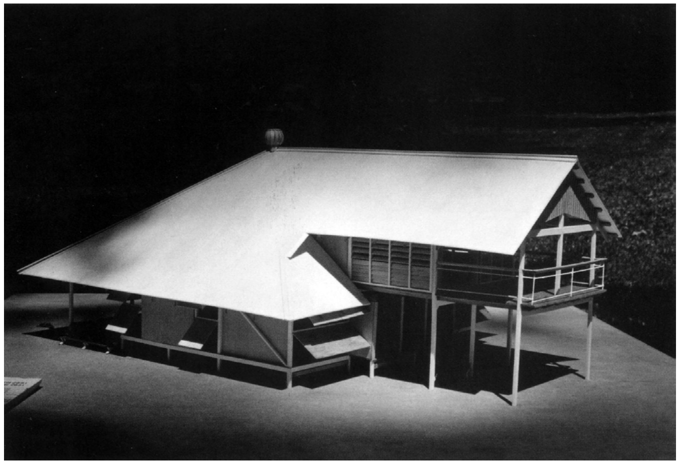


Fig. 19. Original model showing metal roof providing a large area of shade. The operable louvered wall panels can be seen, allowing occupants to have complete control over the degree to which the space is cooled by outside air.[1]

The Marrkolidjban Outstation School is located near the northern coast of Australia in a climate similar to the hot, humid climate of Tampa, with the exception being the dry season that can be found in Arnhem Land. Despite this difference in humidity and rainfall for certain portion of the year, the Outstation School utilizes the simplest strategies maximizing natural and mechanical ventilation in a contemporary architectural model. As such, this case study will be used as a starting point for the design and construction of the full-scale inhabitable space. Furthermore, these basic methods are relevant and extremely applicable to the subtropics. The most important lesson derived from this case study is the lack of distinction between interior and exterior space afforded by the abundant number of exterior walls that function as large louvers

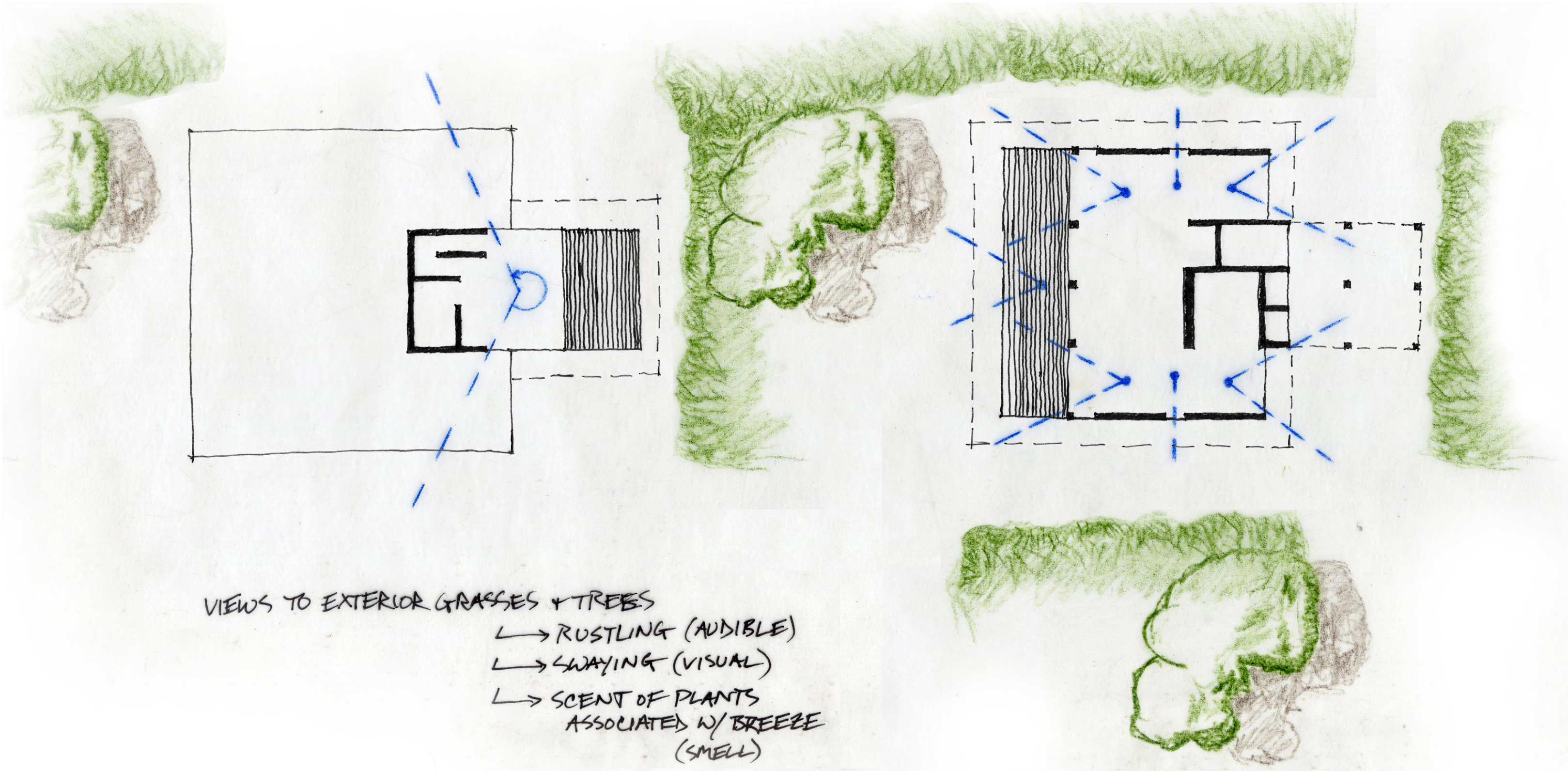


Fig. 20. Sensory connection to exterior.

and retractable doors, and the intermediate semi-enclosed spaces created as a result of the louvers and doors being open. The sensorial connection to the surrounding field allows the inhabitants to not only hear, but also see the breeze as it moves across the field carrying the scent of the tall grass and trees. If the interior classrooms of school buildings offered a greater sense of openness to exterior spaces through the blending of interior and exterior spatial qualities, the perception of thermal qualities would be amplified.

The design approach of Troppo Architects is based around four fundamental architectural principles for tropical buildings: the promotion of cooling breezes; ventilation by convection; reducing radiation of heat, and; the sheltering of walls and openings.[2] Most inspiring, though, is how cooling breezes are promoted in the Outstation School. As in many tropical and subtropical regions, orientation, elevation and the plan form of the building are key elements. But it is the treatment of potential barriers that allows the ventilation to pass through the building, cooling all of the indoor spaces. The layout consists of very few interior walls, and the exterior walls consist of operable louvres and shutters from the floor to the underside of the roof. Solid interior partitions are oriented parallel with the passage of the prevailing wind.

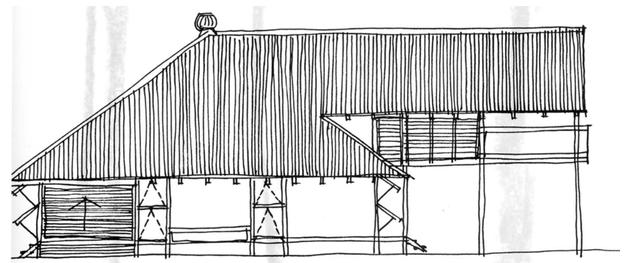


Fig. 21. Original elevation.[3]

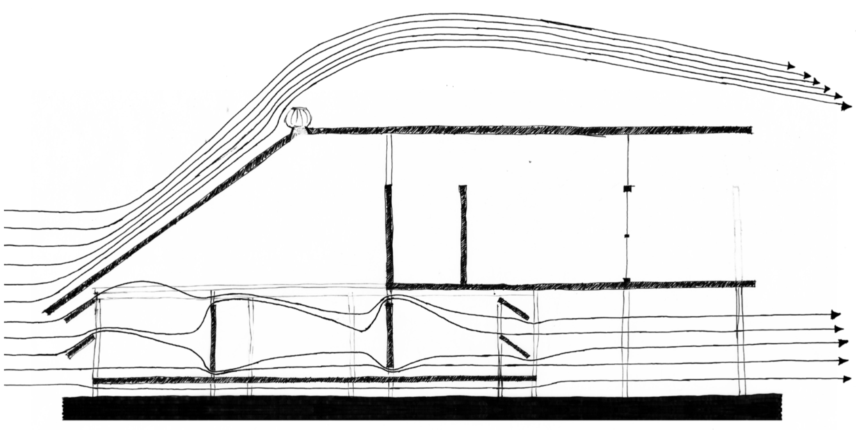


Fig. 22. Wind section diagram.

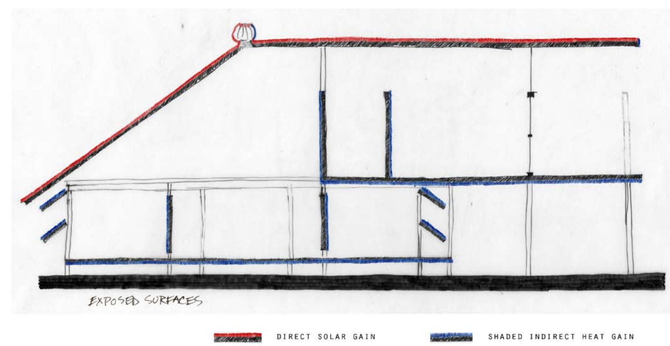


Fig. 23. Exposed surfaces section.

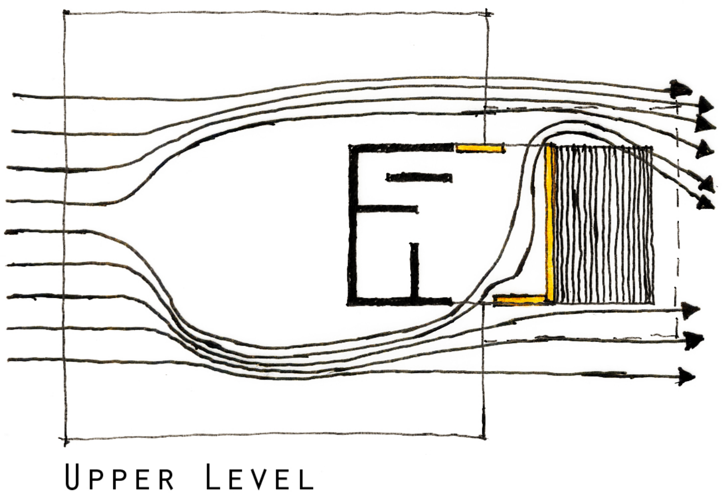


Fig. 25. Wind plan diagrams of level 2 partially open.

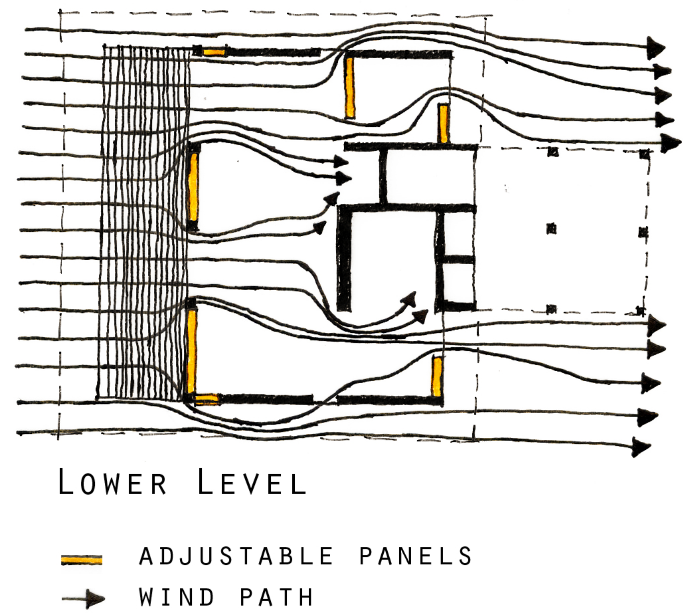


Fig. 26. Wind plan diagrams of level 1 partially open.

As the passage of air moves inside the building, internal partitions raised above the floor and stopped short of the ceiling allow air flow to continue above and below those partitions that would otherwise impede air movement. The roof pitch rises one and a half times the height of the walls, encouraging air stratification within the main space. A rotary vent rests atop the centered pitch of the main space aiding in the exhaust of rising hot air and inducing cool air into the classroom at the inhabitants' level. These principles provide a basis for the design of school buildings in terms of presentation towards prevailing winds, the treatment of potential barriers and the incorporation of supplementary means

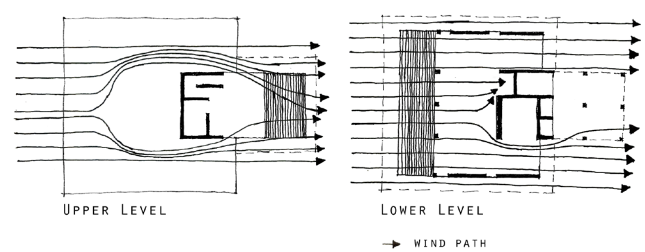


Fig. 24. Wind plan diagrams of levels 1 and 2 fully open.

of air movement. The Marrkolidjban Outstation School, demonstrates how the role of the human, and his or her perception and control of thermal comfort can become a tactile part of the learning process in school buildings.

The Outstation School is at the natural ventilation end of the spectrum for the selected group of case studies. Whereas the other cases consisted of air conditioned interior spaces, this building is void of a mechanical air conditioning system, and is designed to blur the perception between interior and exterior. Unlike the large building square footages of the other case studies, this school is no more than 1,300 square feet in floor area. The Outstation School is the only structure that makes up the campus, and is surrounded by tall grass and trees. Despite the positive qualities of this case study, the openness of the structure translates to a building that is neither tightly sealed, nor materially thick. This poses problems such as lack of security, lack of insulation, and the potential for air leakage when considered as a model to be adapted for hybrid cooling.

Denham Oaks Elementary School

Land O' Lakes, Florida

Rowe Architects Incorporated, 1993

Denham Oaks Elementary School is located just north of greater Tampa, surrounded by suburban single-family homes. The site consists of a small oak preserve to the north, to which the school's L-shaped layout opens onto, and recreational fields to the northwest. Based upon the idea of creating a series of neighborhoods along the reach of both arms of the L, individual garden courts provide air movement between the larger built volumes of the campus while also creating a sense of community among the students of each court. In addition to exterior air movement, all of the campus classrooms, which are designed to be fully air conditioned, also feature operable clerestory windows that allow for natural ventilation. This case study implies a hybrid system of cooling, and yet school buildings such as this one, located in subtropical

Fig. 27. Plan of Denham Oaks Elementary School. This illustrates the relationship between garden courts, classrooms and oak preserve beyond.

climates, rarely utilize natural ventilation. However, if the perception of thermal comfort of the inhabitants within the classroom, for example, can be expanded to include sensorial cooling elements of a greater space, such as the court and preserve beyond, then the perception of thermal comfort will more likely be satisfying.

Denham Oaks demonstrates a range of thermal zones from exterior to interior through the use of garden courts, unique because the most efficient passively cooled courtyards are typically found in dryer climates. By opening up one side of the courtyard to the preserve, and allowing exterior covered pathways between buildings to be unobstructed, air flows through all four courts capturing both easterly and westerly breezes. In addition, the low one-story sectional quality of the campus allows air to move over one arm of buildings and back down to ground level before crossing the other arm of the campus, again, affording all four courts good air movement. Wrapping three sides of the garden court, covered pathways provide shade with varying degrees of openness, not only lowering the inhabitant's temperature, but the ambient air temperature as well. Secondary gardens exist off of these circulation pathways, marking the entrance to the classrooms. The sense of spatial limits of the garden reaches beyond the physical garden to include the pathways, secondary gardens, and oak preserve beyond. Unfortunately, this sense of a greater space does not extend to the classrooms. The walls of the campus buildings serve to maximize functional wall space, and minimize the amount of natural daylight. As a result,

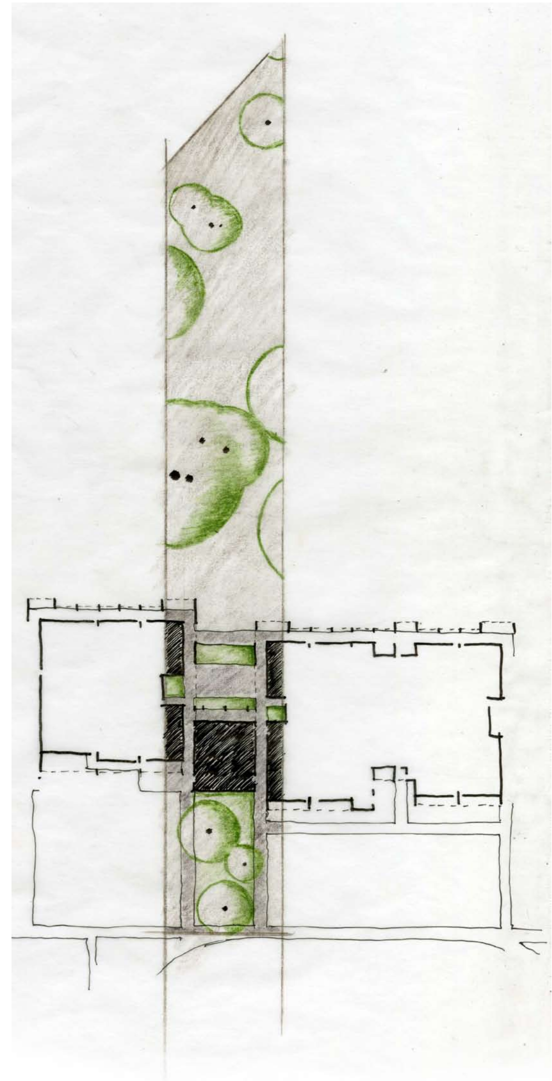


Fig. 28. Perception of expanse of garden court.

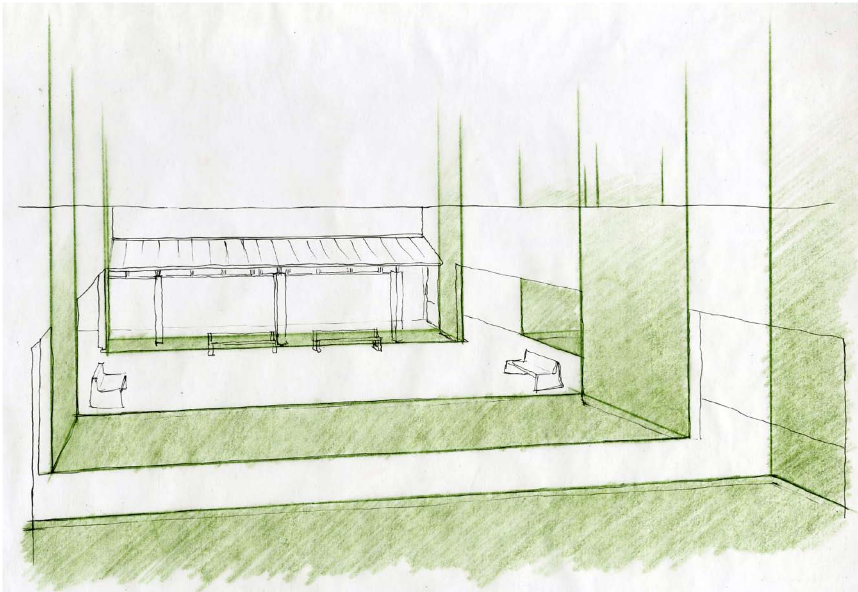


Fig. 29. Areas of vegetation within the garden court.

all windows are placed high and views to the exterior give no sense of a greater whole. Thus, Denham Oaks lies in the crossroads of the selected case studies. While it does provide air conditioned enclosures utilizing open-air circulation, it has the ability to function as a passively cooled school.

This campus design suggests the possibilities of the court as a source of the perception of thermal comfort. By creating a strong sensorial connection to the court, the classroom becomes a part of the court. Views must be created to the greater space described as the garden court, but more importantly an abundance of elements are needed within the garden court providing a sense of

Fig. 30. Sectional study of garden court.

sound, smell, taste and touch in association with the breeze that naturally and mechanically cools the classrooms. This case study will serve as a jumping off point for the implementation of garden courts that provide the perception of thermal comfort to interior classrooms through sensorial elements integrated into the architecture of the spaces.

"Natural ventilation relies on the quality of the external environment of the building to provide clean, fresh air to service the air quality and cooling needs of the building and its occupants."[1] During the Industrial Revolution, the air quality used to supply natural ventilation to buildings within major cities was heavily polluted. This problem, coupled with the noise pollution of downtowns, became the catalyst for the development of forced ventilation, which is ventilation by mechanical means.[2] A mechanical ventilator simply consists of a motor-driven fan that either exhausts air from an interior space, or induces air from an exterior space.[3] With the advent of mechanical ventilation, buildings no longer required large openings in the building envelope to allow for natural ventilation. Filters removed the pollutants from the air as it was mechanically pulled into the building through small punctures in the exterior walls, floors and roof, providing fresh air. The small number and size of the mechanical ventilation openings enabled the architect to exclude the noise and filth of the city from the interiors of urban buildings.[4]

Up until this point in time, naturally ventilated buildings in hot, humid climates such as those in the South Pacific, the Caribbean and the Gulf Coast typically featured large openings, and, in the case of the dwellings of primitive peoples, the elimination of walls altogether. The air movement through the interior spaces provided evaporative cooling for the inhabitants and the lack of enclosure was almost a necessity of the climate.[5] However, Willis Carrier developed a way to not only mechanically move air, but to cool and dehumidify it, as well. His air conditioning system finally made a controllable, cool, dry, interior environment a reality.[6] In the 1950s and 1960s, the mechanical service disciplines came together as one integrated heating, ventilation and air conditioning, also known as HVAC. This merging of disciplines allowed the services to be better coordinated within the design of the building, and increased the acceptance of this new technology. The act of creating a cool, dry, thermal environment within a building, despite the temperature and humidity outside, became a progressive and desired ideal.[7]

The architect ultimately designs for the potential inhabitants of the space. As the installation of air conditioning has spread throughout public and private buildings, a large population has been affected by this technology. Richard Hyde, in his book Climate Responsive Design, provides a list of common justifications by the designer, and criticisms by the users, of air conditioning in buildings. One justification of installing air conditioning is the ability to maximize the potential built area of a site through the elimination of open spaces such as courtyards, no longer needed to access natural ventilation. Another justification is the freedom to site a building, shade a building, and shape a building in any way desired, since the climate design factors will not be used to cool the building. A third reason is the hope of improving attendance and attracting new users to buildings such as schools, offices and shopping malls through the perception of a comfortable place to work or an afternoon oasis. The fourth reason is the necessity to provide fresh, cool air to spaces such as auditoriums in which a large number of users, in close proximity, require air to not only cool the large amount of heat created from the number of bodies, but also to flush out the poor quality air surrounding the users.[8] These justifications illustrate the freedom, hope and necessity of air conditioning to the architect as a design tool.

The list of criticisms by the users of air conditioned buildings, compiled by Hyde, is provoked by an increasing awareness of energy efficiency and human well-being. One of the main criticisms is the over-use of recycled air in HVAC systems to lessen energy consumption, which affects users' health and contributes to sick building syndrome. Second, high "life-cycle energy costs and negative environmental impacts" are created due to the abuse of air conditioning capabilities, and ignorance of climate design factors such as shading, shaping and naturally ventilating a building, when possible. Another major criticism is the shifting of temperature control to a central location within a building by removing control of localized thermostats and operable windows from the users, especially in buildings originally designed to be thermally controlled locally. The last main criticism is the long-term effects of living and working within climatically controlled environments for the majority of day and night, “it is postulated that this will reduce occupants’ physiological thermo-regulatory mechanisms, increasing the risk of climatic stain when returning to warmer external conditions.”[9]

Societies in warm climates have indulged in the use of a machine that will cater to their thermal wishes, or rather, what their thermal wishes are speculated to be. The air conditioner, acting as a “mechanical servant”, has given users the ability to exist, for the large majority of our daily lives, in the temperature and humidity of our liking. But what happens when the majority of a building’s users are not in control of their surrounding temperature and humidity?[10]

Hyde further points out, “It is evident that whilst these concerns are about the design issues associated with air conditioning there is also strong criticism placed on the management of these systems. This stems from the practice, akin to ‘climate determinism’, of using constant prescribed temperatures and humidity day in, day out and throughout the year. The result is the building is disengaged from the place in which it is located and from the natural cycle, promoting in humans a range of behavior similar to that of sensory deprivation. This is indicated in feedback from one user survey of air conditioned buildings.”[11] Two of the problems described in the feedback suggest that the occupants were not happy having their localized thermal environment controlled by a central source, and that the transition between interior and exterior could be uncomfortable due to the large temperature and humidity differences. The survey also showed that there is little preference for an air conditioned building over a non-air conditioned building, and that preference is based on climatic experience.[12]

Despite studies such as this, ASHRAE has pursued a standardized thermal range for building interiors. This idea, in which the occupant does not feel too hot or too cold, is the underlying theme behind thermal neutrality. Proponents of thermal neutrality believe the thermal qualities of interior spaces should be so perfectly suitable that they go unnoticed. Thermal neutrality stems from the concept of the comfort zone, and has served as an attempt by organizations such as ASHRAE to objectify a subjective concept.[13] According to Victor Olgyay, "…conditions wherein the average person will not experience the feeling of discomfort can constitute the perimeter of the comfort zone."[14] The comfort zone differs from thermal neutrality in the sense that the comfort zone is unique to every individual, whereas thermal neutrality is a method universally applied to occupants despite their varying individual comfort zones. Olgyay describes a report of lightly clothed, sedentary individuals, stating that the British comfort zone lies between 58° and 70°F; the comfort zone in the United States lies between 69° and 80°F; and in the tropics it is between 74° and 85°F. Regional acclimatizations such as these, in addition to age and sex, are the major factors that influence individual variations in the comfort zone.[15]

The thermal sense that determines the limits of one's comfort zone expands well beyond the boundaries of neutrality. Simple pleasures can be had with all five senses, and though not typically included within those five, the thermal sense can be just as enjoyable. In fact, it is often sensory experiences along the limits of one's thermal comfort zone that are the most pleasing. Lisa Heschong states,"…there seems to be a simple pleasure that comes with just using it, letting it provide us with bits of information about the world around, using it to explore and learn, or just to notice. The stone is cool; yes, it feels cool when I touch it; perhaps it has been in the shade for awhile. The coffee cup is warm; it warms my hands. There is something very affirming of one's own life in being aware of these little pieces of information about the world outside us. When the sun is warm on my face and the breeze is cool, I know it is good to be alive."[16] Humans enjoy a range of temperatures, especially contrasts. Take for example, the alternating repetition of heat and cool from the intermittent shade of tree canopies when walking along a tree-lined path. Each moment of sunlight refreshes the desire for the moment of shade, and, conversely, each moment of shade refreshes the desire for a moment of sunlight. This is experienced in much the same way that one's palate is cleansed during a proper meal.

The range of temperatures typically experienced in non- or poorly air conditioned settings is often discouraged by proponents of a thermal uniformity, commonly referred to as a steady-state approach. The steady-state approach advocates a lifestyle in which the moments in-between air conditioned spaces are viewed as negative, uncomfortable, or an inconvenience of thermal stress. Those in-between moments are, of course, the moments one is able to interact with the world outside. The moment one leaves their air conditioned car to walk into their air conditioned office is an example of the in-between moment, or the break in the steady-state.[17] Once inside the office or home, another major issue persists, which is the relationship of the steady-state to the functions and habits of the various interior spaces. The use of air conditioning in this steady-state mode is eliminating the thermal qualities previously tied to specific spaces and their uses. Spaces, within the home, where families once gathered for desirable thermal qualities to relax in the evening are gathering places no more. The family has been stretched throughout the house, inconsequential of the thermal qualities of the spaces occupied by each family member because the thermal qualities are the same for every space.

The contemporary issues of climate determinism, thermal neutrality and the steady-state approach apply to a variety of public buildings. It is the author's opinion that these issues stem from an abuse and over-reliance on air conditioning in buildings. Limiting the use of air conditioning in a building to the times of the year in which thermal comfort of occupants cannot be achieved by passive means will drastically improve energy efficiency, greatly reduce greenhouse emissions, and benefit the well-being of the occupants. Also of great benefit, and of specific interest to this thesis, will be the renewed sense of purpose, through thermal qualities, of spaces associated with the maximization of passive cooling and air movement. The idea of the thermal place as a reason for occupants to come together will create a sense of community and shared experience, reinforcing the ritual of gathering.

Currently, the majority of schools within Tampa, Florida are equipped with centrally located HVAC systems that supply and exhaust cooled or heated air to and from the individual classrooms and other spaces. In a conversation with a substitute teacher who has been assigned to a number of different local schools, it was stated that the majority of classrooms rely on air conditioning year-round, with the exception of those winter months when heat is needed. Most classrooms provide daylight through windows along one side of the classroom, typically located at the top of the wall, but much fewer amount feature operable windows. Classrooms with operable windows are seldom opened to provide natural ventilation to the interior spaces.[1] There seems to be a general perception amongst those in control of the cooling systems that when the option to cool classrooms by non-conditioned methods is present, it is often viewed as incomparable to the cooling sensation provided by air conditioning. This architectural project has three main goals. The first is to maximize the annual time window of evaporative cooling of occupants throughout the spaces of school buildings located in hot, humid climates through natural and induced ventilation methods such as cross-ventilation and buoyancy. Additionally, forced ventilation, such as the use of fans, will supplement passive methods, when needed. The second is to minimize the reliance on air conditioning systems within interior spaces of school buildings in hot, humid climates. The third is to facilitate the localized control of microclimates within the school building.

The scope of this thesis encompasses designing the masterplan for a primary school campus with the intention of specifically focusing on the microclimate of a selected classroom community within the school. The masterplan is the configuration of major spaces and functions of the building program within the site. Designing a masterplan will acknowledge the importance of air movement throughout the campus that can be captured to provide natural and induced ventilation for the buildings and occupants. Climate responsive strategies of wind and solar orientation must first be established in the siting of the structures before exploring the design of individual classroom communities. The purpose of selecting one classroom community as the focus of achieving the goals listed above is to positively affect the perception of students where the majority of their time is spent; in the classroom.

The project is located near the Gulf Coast of Florida in the city of Tampa. Tucked into the northeast portion of the Hillsborough Bay, the city is surrounded on three sides by water. With the city of Tampa's coldest month's mean temperature recorded at 60.8 degrees Fahrenheit, and the warmest month's mean temperature recorded at 82.5 degrees Fahrenheit, the city falls within the Koppen Climate Classification of humid subtropical. The number of homes with school aged children in the Channel District is five percent greater than the rest of Tampa, and the area is known to have a large percentage of young couples, implying the need for a local primary school.[2]

The garden classroom is the conceptual basis underlying the architectural solution of this thesis. This concept can be distilled to creating garden spaces within and surrounding classrooms and classroom communities to provide positive, thermal qualities of human comfort to their occupants. For the purpose of this thesis, garden spaces are defined as non air conditioned spaces consisting of natural features, such as plants, and man-made features, such as sun screens. The gardens increase the perception of human comfort, and facilitate the maximization of natural and induced ventilation of classroom communities in two main ways.

The first positive comfort quality of garden spaces is the connection of air movement, such as a breeze, to other senses affected by the garden, through what the author is terming sensory association. Sensory association is based upon the experiences of an individual, and how those experiences influence the mental connections made between each of the five senses and the thermal sense. For example, the scent of coffee, for many, often has a sensory association with heat. As a result, this connection between the sense of smell and one's thermal sense can produce a psychological sensation of warmth in an individual.[1] The thermal sense is often, mistakenly associated with the sense of touch. However, the two differ greatly, since the human body senses heat loss and gain without ever touching an object.[2] While the ability of the human psyche to alter the physical cooling of one's body is negligible, the perception of cooling can be greatly influenced psychologically and create greater levels of comfort for occupants. In The Japanese House and Garden, Tetsuro Yoshida tells of a variety of methods used in Japanese households to create a sense of coolness in the minds of residents. In the warmest times of the year, images of waterfalls and mountain streams are displayed. Yoshida goes on to describe, "People like to hang a lantern or a wind chime under the roof of the veranda. The lightly swaying lantern or the ringing of the bell gives a suggestion of refreshing coolness." An awareness of air movement also persisted in Persian gardens, where fragrant plants often provided a pleasant scent with the breeze.[3] One can imagine sitting in a room within a Persian household, invigorated by the scent of jasmine as a gentle wind slips through the window from the garden. As months go by, this repeated experience forms a sensory association between the scent of the jasmine and the cooling sensation of the breeze. This relationship between the human psyche and the physical act of cooling the body is what makes human comfort, human.[4]

The second positive comfort quality of garden spaces is to serve as a buffer, softening the thermal transition between interior spaces such as classrooms and exterior spaces such as hallways and courtyards. This reduces the amount of thermal stress on the human body often experienced in hot, humid climates when moving from cool conditioned spaces to the outdoors on a hot day. In a study carried out by Nasser Al Hemiddi, under the direction of Baruch Givoni, surface and air temperatures at three feet above ground were measured, based on a variety of ground treatments. The results showed that on clear, hot summer days, there was a difference of up to 6 degrees Fahrenheit between the temperature above exposed pavement, and the temperature above the ground shaded by "a high and dense shrub fence." Additionally, not only was the air under the shrub cooler, but the shrub also provided shade from solar heat gains to a nearby wall.[6] Thus, the temperature of the air decreases as it moves from the garden and into the classroom. The manner in which a garden space accomplishes this depends on a variety of factors, such as the height, density, and location of trees, shrubs, vines, and groundcover. The vegetation of a garden guides and reflects the path of air movement, and can increase or decrease the air velocity based on the shape and density of the plants. Also, trees, shrubs, vines, and groundcover all act as natural air filters, improving the air quality.[7]

By layering garden spaces, and thinking of the classroom as a garden itself, a variety of thermal zones can be created, each with its own sensory associations. Because every individual's past experiences are unique, each occupant's sensory associations are unique as well. By incorporating gardens of varied thermal qualities and sensory associations into the design of classroom communities, students and teachers will have the ability to find a space in the

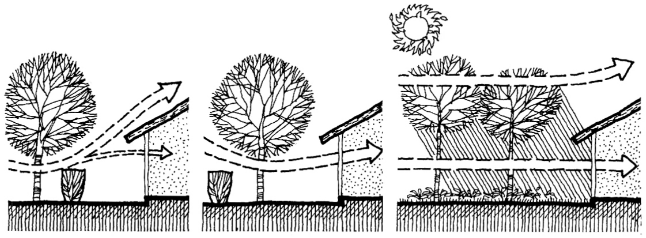


Fig. 31. Diagram illustrating the cooling potential of trees and shrubs. Vegetation can be used as a passive means of directing air, as well as cooling air, along its path into a building.[5]

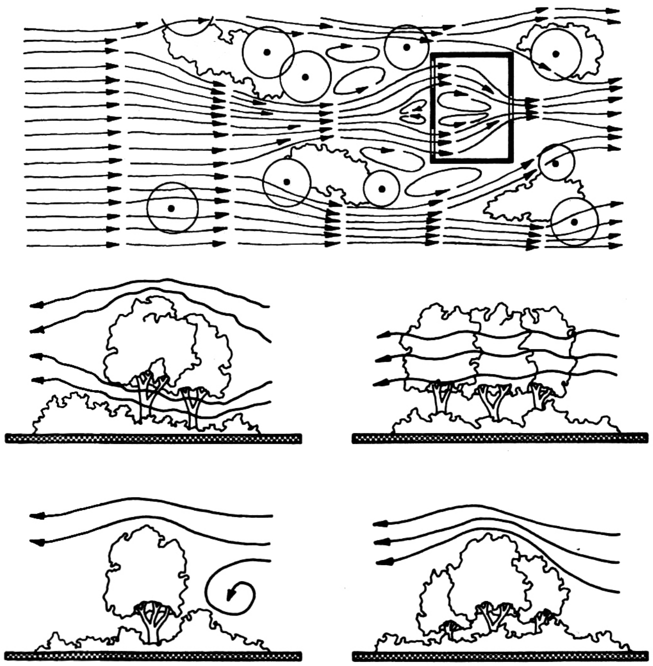


Fig. 32. Diagram illustrating the positive influences vegetation can have on air movement. Grass, shrubs and trees can all provide guidance, filtration, obstruction and deflection of air patterns.[8]

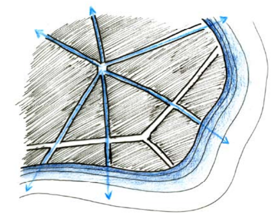
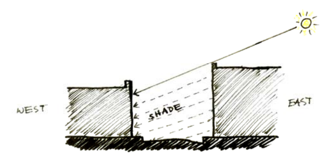
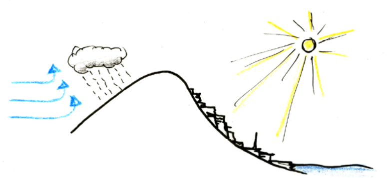
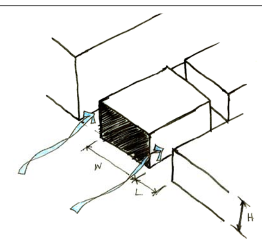
garden classroom that suits their comfort needs.

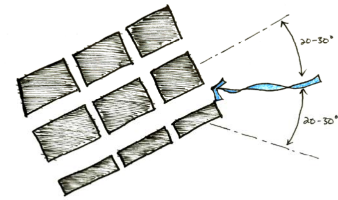
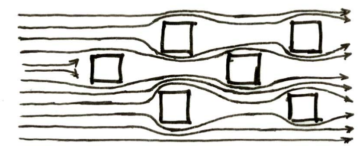
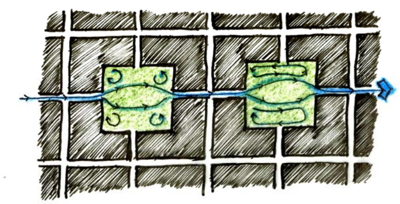
The variables throughout this thesis will be researched via architectural case studies, observation studies, site analysis, and program analysis. The case studies will demonstrate the positive and negative characteristics of passively and mechanically cooled educational buildings in subtropical hot, humid climates. The three case studies will focus on air movement around the building envelope, air movement through interior spaces, direct and indirect solar heat gain of building surfaces, the role of vegetation in the perception of cooling, and how these factors relate to the function of the architectural spaces. The observation studies will analyze human interaction within the open-air breezeway of an educational building, demonstrating thermal factors that affect how individuals choose their location within a space to achieve comfort. In addition, a handbook of hybrid cooling will be compiled, based on the most pertinent factors to creating a passive and mechanically cooled educational building in a subtropical hot, humid climate.

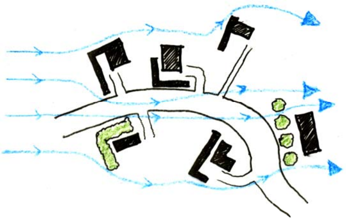
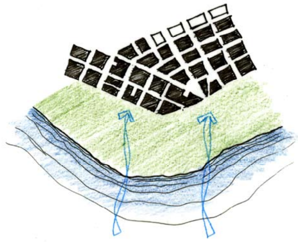
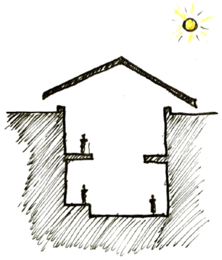
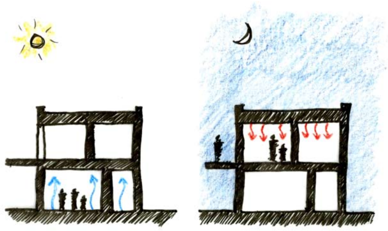
The project will be designed based upon meso-climatic and microclimatic site analysis, and the formulation of a building program. The meso-climatic data will be used to understand the monthly weather patterns of Tampa. The microclimatic data will consist of observation studies conducted at the site to understand the ambient air temperature, relative humidity, sun and shade, perception of air movement, reflectivity of surrounding surfaces, and effects of thermal mass on the site. Next, a conceptual program will be created to determine the microclimate-responsive solutions specific to unique areas of the site. This program will be based upon the observation studies conducted on the site, as well as methods from the handbook of hybrid cooling. In order to establish a scale for the school campus and classroom communities, a functional program will be created, based on a maximum number of students. From the integration of these two programs and analysis taken from the site, the masterplan for the primary school campus will be designed. Conclusions made from the case studies and human observation studies will further supplement the design of the masterplan and classroom communities.

The Passive and Mechanical Cooling Handbook is a compilation of cooling approaches and methods, each accompanied by a brief written description and diagram. The purpose of the handbook is to provide the designer with the basic knowledge of passive and supplemental cooling concepts. It can be used as a reference tool, as well as a starting point for architectural projects. The handbook is divided into three sections. The first section, building groups, lists methods of locating, sizing and orienting building groups to maximize their passive cooling potential. This section applies predominantly to the meso-climatic scale. The second section, buildings, lists concepts and architectural features that can maximize the passive cooling potential of individual buildings and spaces. This section applies to the microclimatic scale. The third section, supplementing passive systems, lists methods of mechanically moving air to aid in the cooling process. This section also applies to the microclimatic scale. The concepts described were assembled from G.Z. Brown and Mark DeKay’s book, Sun, Wind and Light: Architectural Design Strategies. The hope is that, by presenting them in an approachable format, architects will be able to incorporate these ideas from the start of the design process.

Fig. 33. Passive and Mechanical Cooling Handbook.[1]

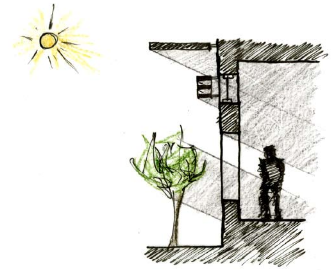
Building Groups	
Radial Ventilation Corridors Spaces between buildings are organized in a radial pattern to facilitate cool air drainage and the evening's thermal currents.	
Shared Shade Siting buildings to take advantage of the shade created by each other, as well as the shade created by surrounding the surrounding context.	
Topographic Microclimates Placing buildings on areas of the site that take advantage of unique microclimatic elements, such as wind currents, due to the topography.	
Loose Urban Patterns Providing ample space between buildings to facilitate air movement.	

Breezy Streets Orienting streets or pathways to take advantage of the prevailing winds.	
Dispersed Buildings Providing wide, open spaces to maximize exposure to breezes.	
Interwoven Buildings and Planting Cooling spaces through air movement and shade by designing plantings and vegetation around and within buildings.	
Interwoven Buildings and Water Cooling spaces through air movement and humidification by designing water features around and within buildings.	

Windbreaks Deflecting and capturing wind with elements such as walls, rows of bushes, and rows of trees.	
Green Edges Cooling and humidifying moving air with irrigated vegetation.	
Overhead Shades Protect outdoor spaces, and interior spaces along the outer-edge of buildings, from direct solar gain.	
Buildings	
Migration of Occupants Interior and exterior spaces, designed to function as warmer or cooler spaces, can provide extended durations of comfort. Occupants can move from one space to another based upon the respective comfort level.	

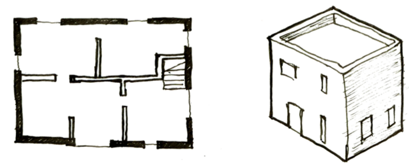
Layer of Shades

Architectural shading elements such as a trellis and roof overhangs can provide protection from the summer sun. Louvres can provide sun protection from the lower winter sun.



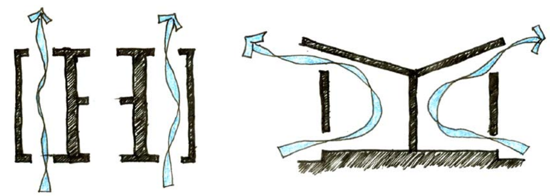
Clustered Rooms

The surface area of a building’s skin can be minimized if occupant spaces can be consolidated into one building, as opposed to three or four. As a result, heat loss and gain is minimized.



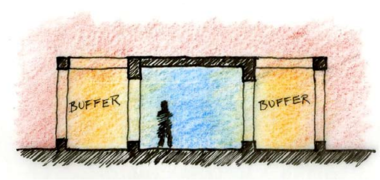
Permeable Buildings

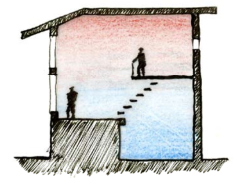
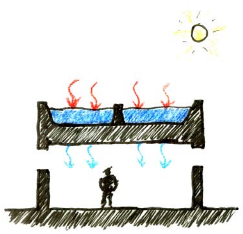
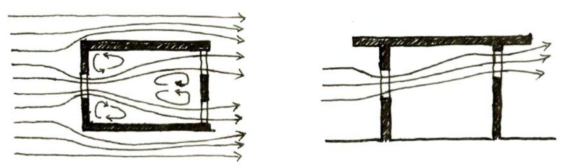
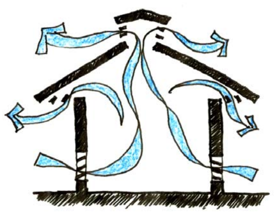
Open floor plans and sections encourage air movement such as cross-ventilation and the stack effect.

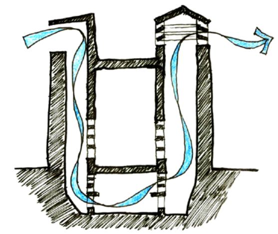
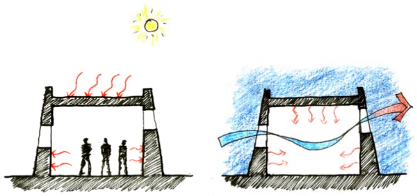
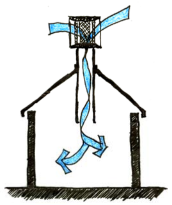
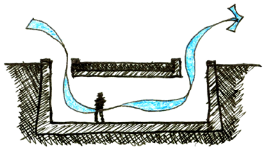


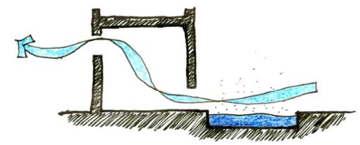
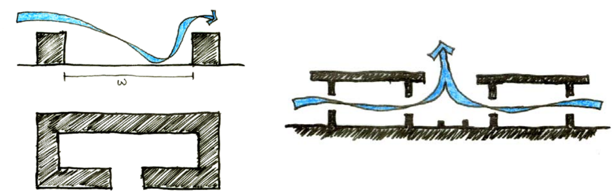
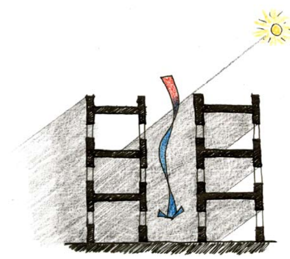
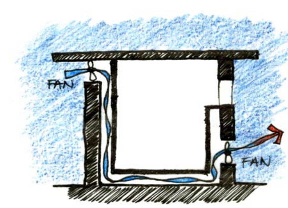
Buffer Zones

Interior and exterior spaces, whose function can handle greater variations in temperature, can be located between protected rooms and the exterior climate.



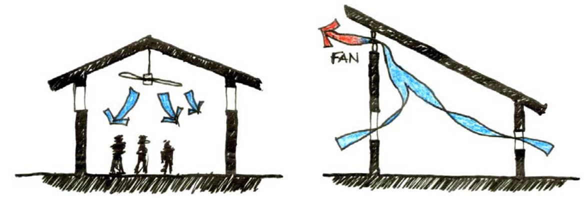
Stratification Zones Interior and exterior spaces, can be located at different heights to take advantage of the differences in temperature occuring, due to the stratification of the air.	
Roof Ponds A shallow layer of water contained on the roof of a building can lessen the impact of solar heat gain.	
Cross-ventilation The location of openings on opposite sides of a space allows air to move through the space, cooling the occupants as a result of pressure differences.	
Stack-ventilation The location of openings along the lower and upper edges of a space allows hot air to rise and exit, while cool air enters and cools occupants as a result of air temperature and density.	

Wind Catchers Towers capture winds moving at higher altitudes, unobstructed by the surrounding context, which then flow down the tower and into the interior spaces. The tower also functions in the opposite fashion by allowing air to flow up the tower and escape out the top. Both methods provide air movement through the interior spaces, cooling the occupants.	
Night Cooled Mass In climates in which the ambient air temperature is cooler in the evenings than in the daytime, thermal mass that absorbs heat during the day radiates the heat into the interior in the evening. Consequently, the loss of heat in the evening means that the wall remains cool for most of the day.	
Evaporative Cooling Towers Moist pads located at the inlet of the tower enables the air to cool as it is humidified. Due to the greater density of the now cold air, the air flows down into the space, cooling the occupants.	
Earth Edges Entire spaces, or just a portion of the space, can be built into the earth to lessen the impact of solar heat gain during the day. The thermal mass of the earth also helps to regulate temperatures in the evening, leading to a more thermally balanced space from day to night.	

Water Edges Water features surrounding buildings can cool breezes through humidification as they enter the interior, as well as encourage air movement.	
Breezy Courtyards By maintaining open pathways for air to enter and exit courtyards, the courtyard can function as a space of cooling, and also as a space to redirect breezes to interior spaces.	
Shady Courtyards Tall and narrow, these courtyards provide shade, especially at the lower levels, and can be used as cold air sinks.	
Supplementing Passive Systems	
Mechanical Mass Ventilation Fan-assisted means of ventilating thermal mass can aid in the removal of heat from the mass, during evening hours, in areas with poor natural air movement.	

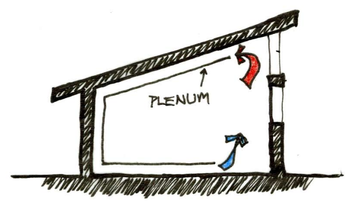
Mechanical Space Ventilation

Fan-assisted means of ventilating spaces and occupants can increase the rate of cooling in areas with poor natural air movement.



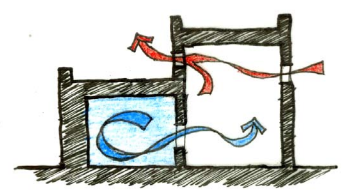
Ducts and Plenums

Cool air can be carried to spaces for ventilation through ducts and plenums.



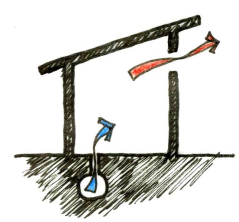
Passive Buffer Zones

Air temperatures of outside air are lowered through buffer zones that serve as intermediary spaces, which can cool the air through a variety of passive methods before entering an interior space.



Earth-Air Heat Exchangers

The temperature of air traveling through pipes in the ground can be lowered due to the often cooler temperatures of the earth during the day.



Meso-climatic Analysis

For the purpose of this thesis, all climatological data is sourced from the National Climatic Data Center. The source data, referred to as climatological normals, is compiled by the NCDC into average values for each meteorological element over a period of 30 years. The normals organized and published by the NCDC for the city of Tampa come from the climate recording station located at Tampa International Airport. Although this station is located approximately six miles from the site, this data gives an accurate description of the meso-climate of Tampa.

Geographically found at Latitude 2756’50”N 8227’31”W, the city of Tampa is at the southernmost cusp of the North American subtropics. Characterized by milder winters than its northern subtropical counterparts, the abundance of water helps to lessen the extremes of summer and winter often attainable in a subtropical climate. The prevailing winds in Tampa are known as easterlies, which come from the east, but westerly winds often make their presence in the afternoon and evening time throughout the year. Prevailing

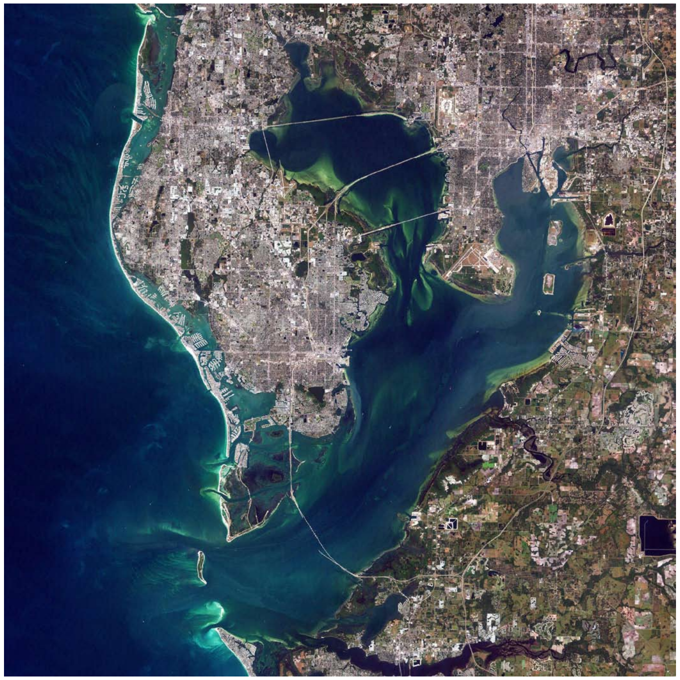


Fig. 34. NASA Landsat image of the Tampa Bay area.

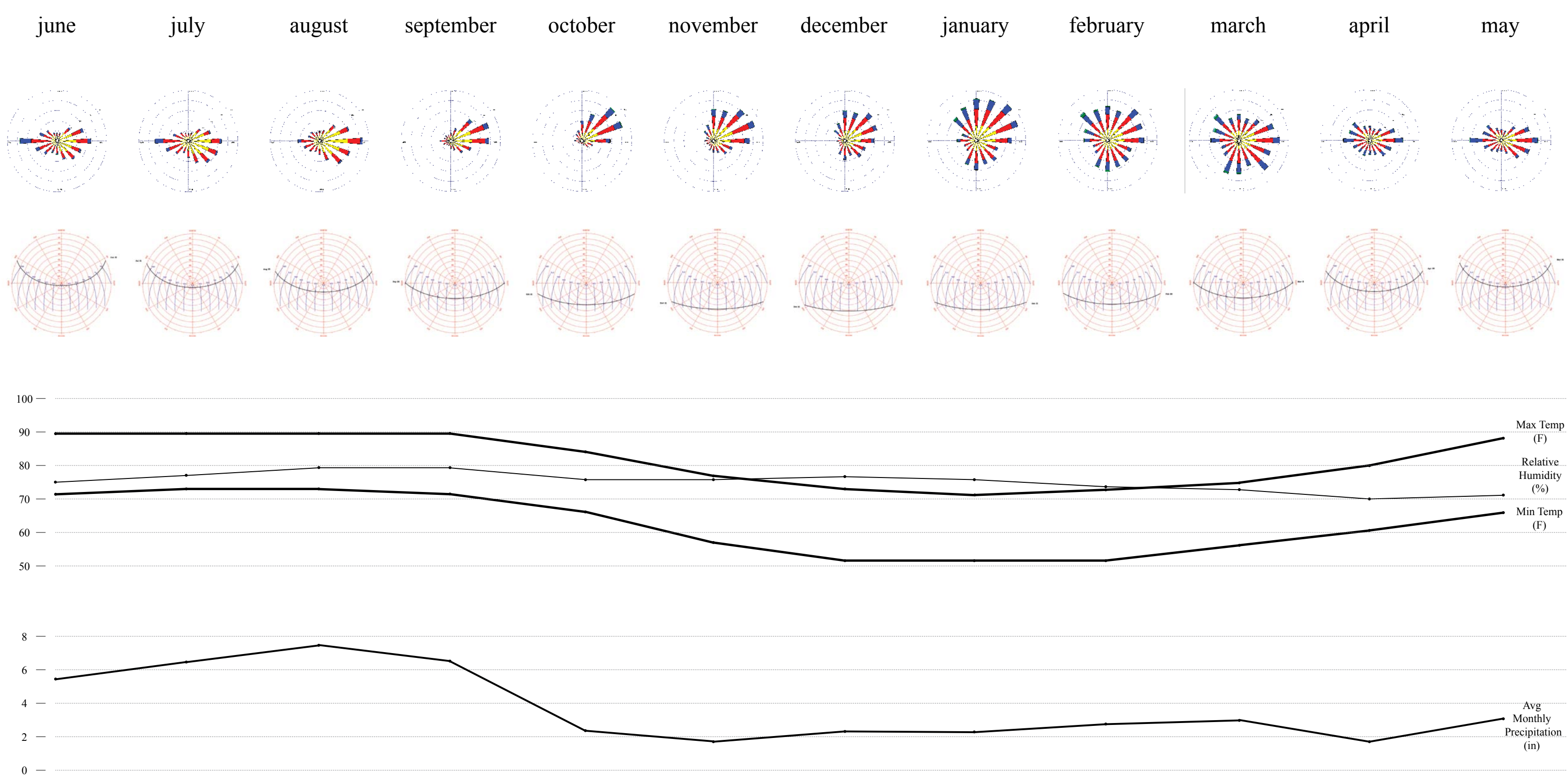


Fig. 35. Meso-climatic chart for the city of Tampa.

winds are often determined by the direction from which the highest number of wind gusts, for the longest duration, occur. However, as evidenced in the monthly wind rose plots, months such as January, February and March also contain comparable winds from almost every direction. The average monthly wind speed varies from 5.7 to 8.2 miles per hour, which is a sufficient range of speed to provide comfort ventilation to occupants. Because the city is located in the Northern Hemisphere, June produces the highest sun angle with the longest duration of daylight hours, and December contains the lowest sun angle with the shortest duration of daylight hours. Maximum annual temperatures seldom reach above 90 degrees and below 70 degrees Fahrenheit in the summer, and the winter temperatures rarely rise above 70 degrees or drop below 50 degrees. Summer temperatures in Tampa infrequently climb above 90 degrees because of the afternoon sea breeze. Another afternoon occurrence that prevents climbing summer temperatures is the afternoon thunderstorms which seem to happen almost every day. The late-day release of precipitation helps temperatures to drop to the 70s. The frequency of thunderstorms, and the winds associated with them, suggests a need for architecture that protects occupants from the rain, while sustaining natural ventilation of the occupants. Tampa's average relative humidity reaches from 70 percent in April to 79 percent in August and September. Daily summer humidity patterns often start out around 87 percent at midnight, increase further to 90 percent at sunrise, and then drop to around 63 percent in the afternoon.

In order to understand when, and which, cooling strategies will be emphasized for the design of this project, the annual, as well as daily, interval requiring cooling must be defined. Additionally, the moments requiring the greatest amount of cooling must be established. The method used to interpret the climatological data is based on a method developed by Boutet. Derived from the Human Comfort Chart, he constructed a Temperature and Humidity Matrix to quantify the times of a month in which human comfort occurs. The matrix also helps the designer to understand how often the given climate falls outside of the comfort zone, and what those climate conditions are. Daily observations, recorded at three-hourly intervals, were tabulated on the Temperature and Humidity Matrix, based on the number of occurrences. The totals were then converted to percentages of time, with the duration of time being the respective month. For example, the climate in Tampa during the month of November, 2007, fell within the comfort zone 34 percent of the month, which was one of the highest comfort zone percentages that year. For 27 percent of the month the climate was cool, 17 percent of the month the climate was cool and humid, and 8 percent of the month it was comfortable, yet humid. The monthly percentages were compiled into a Climate-Comfort Analysis Chart to understand how often the Tampa climate affords comfort, and how often heating, cooling, humidification, and dehumidification measures need to be taken.

Heating is most needed during January and, especially February, during which temperatures fall within the cool and cold zones 85 percent of

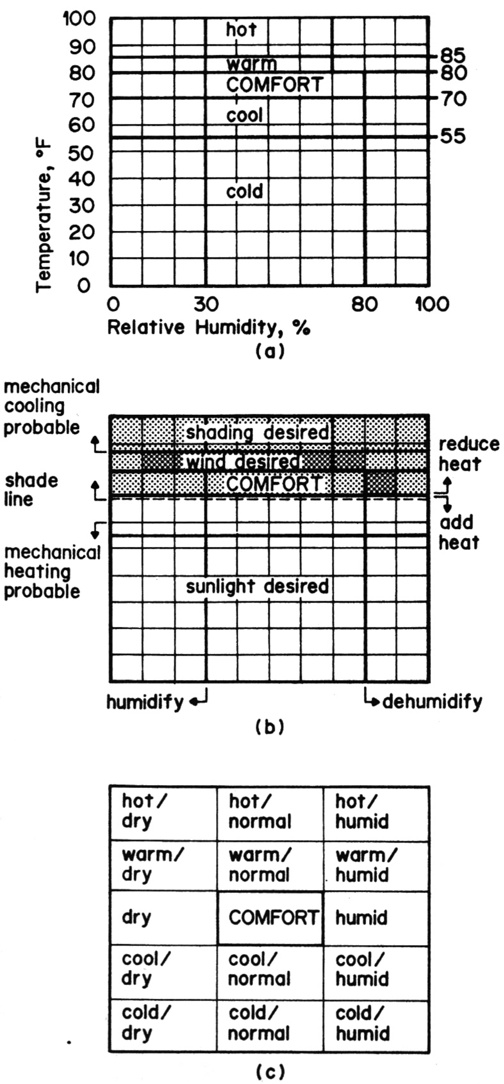
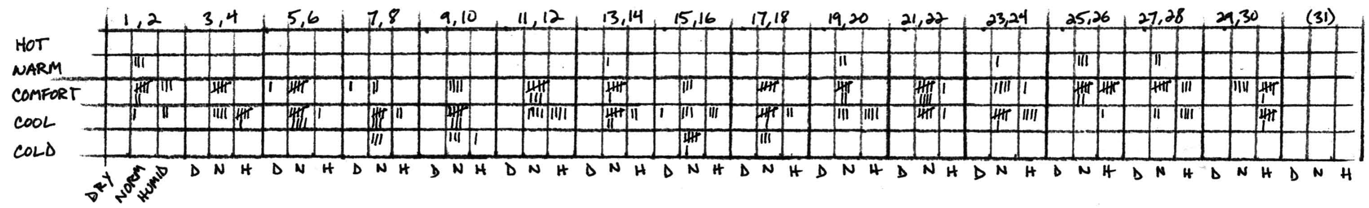


Fig. 36. The temperature and humidity chart converted to a 15 cell Temperature and Humidity Matrix.[1]



NOVEMBER

hot/ dry	hot/ normal	hot/ humid
warm/ dry	warm/ normal	warm/ humid
dry	COMFORT	humid
cool/ dry	cool/ normal	cool/ humid
cold/ dry	cold/ normal	cold/ humid

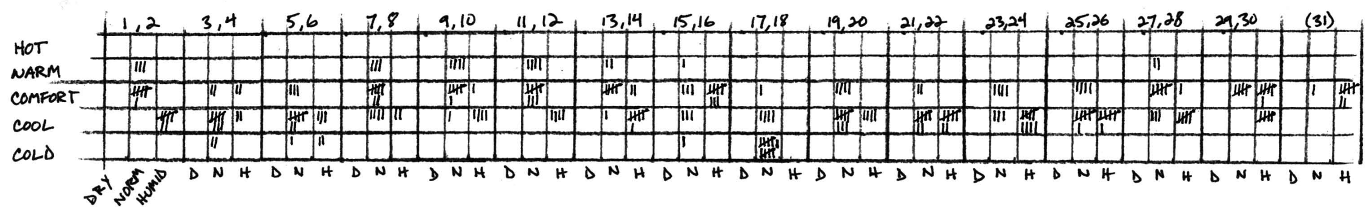
Hourly Totals

	12	
2	81	19
1	66	42
	15	1

➡

Percentage of Time

	5	
1	34	8
1	27	17
	6	1



DECEMBER

hot/ dry	hot/ normal	hot/ humid
warm/ dry	warm/ normal	warm/ humid
dry	COMFORT	humid
cool/ dry	cool/ normal	cool/ humid
cold/ dry	cold/ normal	cold/ humid

Hourly Totals

	19	
	66	27
	55	64
	15	2

➡

Percentage of Time

	7	
	27	11
	22	26
	6	1

Fig. 37. Example of the hourly totals of temperature and humidity for November and December.

the time. Throughout the year, the climate is rarely dry enough to require humidification. High humidity, on the other hand, does persist year-round with the lowest percentages being the spring months of March, April and May. Consequently, these months, as well as November and December, tend to have higher percentages of temperature and humidity within the comfort zone. These matrices can be misleading, however. For example, according to the Climate-Comfort Analysis Chart, the matrix for May contains the highest comfort zone percentage of 2007. At 44 percent, the matrix would lead one to believe that a day spent in Tampa, during the month of May, would be more comfortable than one spent during the month of November. However, upon viewing the Summary by Hour Charts for May and November, it is apparent that the daytime temperatures of May do not fall within the comfort zone, and yet the November daytime temperatures do. In fact, it is the nighttime temperatures of May that fall within the comfort zone, while the daytime temperatures imply a need for shade and air movement. Because of this, it is the author's opinion that the Climate-Comfort Analysis Chart must be viewed in tandem with the Summary by Hour Chart for any given month, which is an average of the three-hourly observations for that month, displayed over a period of twenty-four hours.

According to the Climate-Comfort Analysis Chart, July and August contain the greatest percentages of time that cooling is needed. The pairing of data from both charts show that the month which requires the greatest amount of cooling is August. August averages the least number of hours under 80 degrees

JANUARY

	Dry	Normal	Humid
Hot			
Warm		1	1
Comfort		21	12
Cool	1	27	20
Cold	1	13	3

FEBRUARY

	Dry	Normal	Humid
Hot			
Warm	1	1	
Comfort	1	9	3
Cool	1	31	22
Cold		22	9

MARCH

	Dry	Normal	Humid
Hot			
Warm	1	11	
Comfort	1	33	5
Cool	2	24	15
Cold	1	6	1

APRIL

	Dry	Normal	Humid
Hot	1	2	
Warm	1	12	1
Comfort	2	29	6
Cool	1	29	13
Cold		2	1

MAY

	Dry	Normal	Humid
Hot	2	15	
Warm	1	21	1
Comfort		44	8
Cool		7	1
Cold			

JUNE

	Dry	Normal	Humid
Hot		22	2
Warm		13	18
Comfort		18	25
Cool			2
Cold			

JULY

	Dry	Normal	Humid
Hot		31	6
Warm		5	34
Comfort		6	18
Cool			
Cold			

AUGUST

	Dry	Normal	Humid
Hot		38	6
Warm		2	29
Comfort		3	22
Cool			
Cold			

SEPTEMBER

	Dry	Normal	Humid
Hot		27	2
Warm		11	14
Comfort		12	34
Cool			
Cold			

OCTOBER

	Dry	Normal	Humid
Hot		17	
Warm		12	10
Comfort		19	37
Cool		4	1
Cold			

NOVEMBER

	Dry	Normal	Humid
Hot			
Warm		5	
Comfort	1	34	8
Cool	1	27	17
Cold		6	1

DECEMBER

	Dry	Normal	Humid
Hot			
Warm		7	
Comfort		27	11
Cool		22	26
Cold		6	1

Fig. 38. Climate-Comfort Analysis Chart.

JANUARY

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			62	55	58	78
02			61	54	57	78
03			61	54	57	79
04			60	53	57	79
05			60	53	56	79
06			59	52	56	79
07			59	52	56	79
08			59	53	56	80
09			61	53	57	76
10			64	53	59	70
11			67	54	60	64
12			69	54	61	62
13			70	54	61	59
14			71	53	61	56
15			71	53	61	56
16			70	54	61	57
17			70	54	61	59
18			67	54	60	63
19			66	54	59	67
20			65	54	59	69
21			64	54	58	71
22			63	54	58	74
23			62	54	58	76
24			62	54	58	77

FEBRUARY

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			57	50	53	79
02			56	50	53	81
03			55	49	52	81
04			55	48	52	80
05			55	48	52	80
06			54	48	51	80
07			54	48	51	80
08			55	48	52	78
09			58	49	54	72
10			61	49	55	66
11			64	49	56	60
12			66	48	57	56
13			67	49	58	55
14			68	49	58	54
15			68	48	58	53
16			68	49	58	54
17			66	48	57	56
18			65	49	56	59
19			62	49	55	64
20			61	49	55	67
21			60	50	55	71
22			59	50	54	73
23			58	50	54	75
24			58	50	54	78

MARCH

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			64	55	59	72
02			63	54	58	73
03			62	54	58	76
04			62	54	57	76
05			61	54	57	78
06			61	53	57	78
07			61	54	57	79
08			63	55	59	75
09			67	55	60	65
10			71	54	61	58
11			73	53	62	52
12			75	54	63	49
13			77	53	63	45
14			77	51	62	42
15			78	51	62	41
16			78	51	62	41
17			76	51	62	44
18			74	52	62	48
19			71	52	61	54
20			69	53	60	59
21			68	54	60	62
22			67	54	60	65
23			66	55	60	68
24			65	55	59	70

APRIL

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			66	57	61	72
02			66	57	61	74
03			65	57	60	76
04			64	57	60	77
05			64	56	60	77
06			64	56	60	77
07			65	56	60	75
08			68	57	62	69
09			71	56	62	60
10			73	55	63	56
11			75	55	64	52
12			77	55	64	49
13			78	54	64	47
14			79	55	65	46
15			78	54	64	46
16			78	54	64	47
17			76	54	63	48
18			74	54	63	51
19			72	54	62	57
20			70	55	62	62
21			69	56	61	65
22			68	56	61	67
23			68	57	61	69
24			67	57	61	70

MAY

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			72	62	66	71
02			71	62	66	73
03			71	62	65	74
04			70	62	65	76
05			69	62	65	78
06			69	62	65	78
07			71	62	66	74
08			74	62	67	66
09			77	62	68	60
10			79	61	68	54
11			81	60	68	50
12			84	59	68	45
13			85	58	69	42
14			86	58	69	40
15			86	58	69	40
16			85	58	68	40
17			84	58	68	42
18			82	58	67	45
19			80	58	67	50
20			78	59	67	54
21			76	61	67	59
22			75	61	67	63
23			74	62	67	66
24			73	62	66	68

JUNE

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			77	70	72	80
02			76	70	72	82
03			76	70	72	83
04			76	70	72	83
05			75	70	72	84
06			75	70	72	85
07			77	71	73	82
08			79	71	74	76
09			81	71	74	72
10			83	71	75	68
11			84	71	75	65
12			86	70	75	60
13			87	70	75	58
14			87	70	75	57
15			86	69	75	58
16			86	69	75	59
17			84	69	74	61
18			83	69	74	63
19			82	69	73	66
20			80	70	73	72
21			79	70	73	74
22			78	70	73	76
23			78	70	73	78
24			77	70	72	79

JULY

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			80	73	75	79
02			79	73	75	80
03			79	73	75	81
04			79	73	75	81
05			79	73	75	81
06			79	73	75	81
07			81	74	76	79
08			82	74	76	75
09			84	74	77	72
10			86	74	78	68
11			87	74	78	66
12			87	74	78	65
13			87	73	77	63
14			87	73	77	63
15			87	73	77	63
16			87	72	77	63
17			86	72	76	64
18			85	72	76	65
19			84	71	75	67
20			82	72	75	73
21			81	72	75	74
22			81	72	75	76
23			80	73	75	78
24			80	73	75	79

AUGUST

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			81	74	76	80
02			80	74	76	81
03			80	74	76	82
04			79	73	75	83
05			79	73	75	84
06			79	73	75	84
07			80	74	76	84
08			82	74	77	77
09			85	74	77	71
10			87	74	78	67
11			88	74	78	63
12			89	73	78	60
13			90	73	78	59
14			89	72	77	59
15			90	72	77	58
16			90	72	77	57
17			89	72	77	59
18			87	72	77	63
19			85	72	76	67
20			83	73	76	72
21			82	73	76	75
22			82	73	76	76
23			81	73	76	77
24			81	73	76	78

SEPTEMBER

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			78	72	74	82
02			77	72	73	83
03			77	71	73	84
04			76	71	73	85
05			76	71	73	85
06			76	71	73	85
07			77	71	73	84
08			79	72	74	78
09			82	72	75	72
10			84	72	76	68
11			86	72	76	63
12			87	71	76	59
13			88	71	76	57
14			87	71	76	58
15			87	71	76	59
16			86	71	76	61
17			85	71	75	63
18			84	71	75	65
19			82	71	74	70
20			81	71	74	72
21			80	71	74	75
22			79	71	73	77
23			79	71	74	78
24			78	71	74	80

OCTOBER

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			75	69	71	81
02			74	68	70	81
03			74	68	70	83
04			74	68	70	83
05			74	68	70	84
06			74	68	70	84
07			74	68	70	85
08			75	69	71	82
09			78	69	72	75
10			81	70	73	70
11			82	69	74	65
12			84	69	74	62
13			85	69	74	60
14			85	68	74	59
15			85	68	74	58
16			84	68	74	59
17			83	68	73	61
18			81	68	72	64
19			79	68	72	70
20			78	68	71	72
21			77	68	71	75
22			77	68	71	76
23			76	68	71	77
24			76	68	71	79

NOVEMBER

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			63	56	59	77
02			63	56	59	78
03			62	56	59	79
04			62	55	58	80
05			62	55	58	80
06			61	55	58	80
07			61	54	57	79
08			63	55	59	77
09			67	55	60	67
10			71	55	62	60
11			73	56	63	56
12			75	56	64	52
13			76	55	64	50
14			77	55	64	50
15			77	55	64	50
16			76	55	64	51
17			74	55	63	54
18			71	56	62	60
19			69	56	61	65
20			68	56	61	67
21			67	56	61	70
22			66	56	60	71
23			65	56	60	73
24			64	56	60	75

DECEMBER

HOUR (LST)	CEILOMETER	EFF CLD AMT	DRY BULB	DEW POINT	WET BULB	RELATIVE HUMIDITY
01			65	58	61	79
02			64	58	60	81
03			63	57	60	82
04			62	57	60	84
05			62	57	59	85
06			62	57	59	85
07			62	57	59	85
08			62	57	59	84
09			65	58	61	80
10			69	59	63	72
11			71	59	64	66
12			74	59	65	61
13			75	59	65	59
14			75	59	66	58
15			76	58	65	56
16			75	58	65	56
17			74	58	65	59
18			71	59	64	66
19			69	59	63	70
20			68	59	63	74
21			67	59	62	75
22			66	59	62	77
23			66	59	62	78
24			65	59	61	79

Fig. 39. Summary by Hour Chart.

Fahrenheit in a twenty-four hour period, and the highest afternoon temperatures which reach 90 degrees. As such, this thesis will establish August as the month of peak cooling. The relative humidity within a twenty-four hour period during the summer months is typically highest when the temperature is lowest, and it is typically lowest when the temperature is at its highest. In comparing the Human Comfort Chart with the results found for these two months, the ventilation comfort zone increases the time spent within the comfort zone by only 5 percent in July, and 2 percent in August. However, with increased air movement, the temperature and humidity of the remaining 71 percent and 73 percent, respectively, in the hot and warm zones, can be greatly decreased. Shading of occupants, and the site, during the summer months can also drastically reduce the effective temperature.[2]

Due to the subtropical nature of Tampa's climate, the meso-climatic data illustrates the spectrum of occupant needs to be expected in relation to thermal comfort. Despite the fact that, for the majority of the year, cooling is required, the architecture of this thesis should be capable of adapting to the full range of climatic conditions characteristic of Tampa's climate. Whereas the cooling months require architectural interventions that maximize shade and air movement, the months of comfort imply an architecture that provides minimal interference with the exterior climate, and the heating months suggest an architecture that minimizes air movement and maximizes solar radiation. The months providing the most daytime comfort are March, April, November and

December. November has the greatest monthly percentage, but April contains the longest average duration of comfort throughout the day, with temperatures in the 70s from 9 a.m. to 8 p.m. February is, by far, the peak heating month, with temperatures considered cool or cold occurring 85 percent of the time. Additionally, February is characterized by the lowest average daytime and nighttime temperatures in a twenty-four hour period.

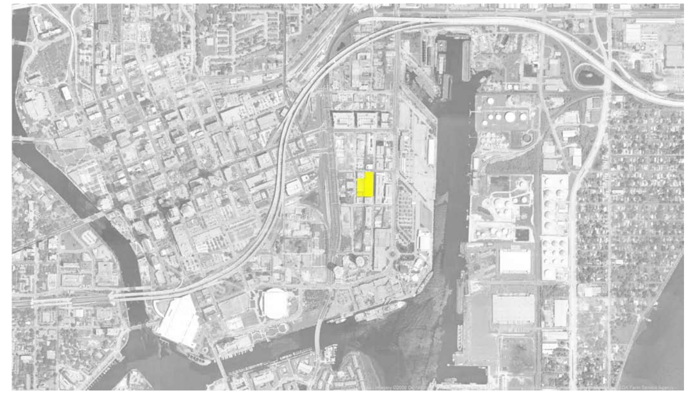


Fig. 40. Aerial view of the site in relation to downtown Tampa.

Fig. 41. Aerial view of the site in relation to immediate context.

Microclimatic Analysis

The site, located in the Channel District of Tampa's downtown, was selected for its hot and humid climate, urban context, proximity to natural water features, and growing community. Approximately 1000 feet from the Ybor Channel, the northernmost portion of waters associated with the Port of Tampa, the site has the capability to take advantage of winds generated by the difference in temperature between the land and the water of the channel. The surrounding buildings range in height from single-storey office buildings to eight-storey residential and mixed-use structures. Individual lots are designed with 0' setbacks, and most structures feature party walls, constructed on the property lines, allowing for increased density within city blocks. In addition to the winds created by the Ybor Channel, the man-made context of the urban environment also has a unique effect on the microclimatic characteristics, such as air movement, solar radiation, temperature and humidity, found at the

Fig. 42. View of the site looking southwest.

site. The building heights, proximities and densities all play major roles in the localized air movement, and the radiation of absorbed heat of asphalt streets, and reflectivity of concrete sidewalks and building surfaces, affect temperature, humidity, and levels of indirect light.[3]

In order to understand the physical factors having the most direct impact on the microclimate of the site, a series of Site Observation Studies were conducted. Due to the timing of this thesis, they began in November 2009, and ended in December of the same year. The studies focused on ambient air temperature, relative humidity, thermal zones, sun and shade, perception of air movement, perception of thermal comfort, absorptivity and reflectivity of surrounding surfaces, and radiation of thermal mass at the site. Each observation study lasted approximately 45 minutes, and the studies were specific to different times of the day and night. In addition, the temperature, humidity and wind direction recordings were compared with the climatological data recorded at Tampa International Airport for the same day and time. Despite the fact that these studies were conducted during the cooler and more comfortable months of the year, conclusions can be made about the microclimate of the site from the implications of the information gathered at the site.

The average ambient air temperature at the site was warmer than the temperature recorded at TIA, from noon to 5 p.m., by approximately 2 degrees Fahrenheit. The rest of the evening and early morning, the average observed

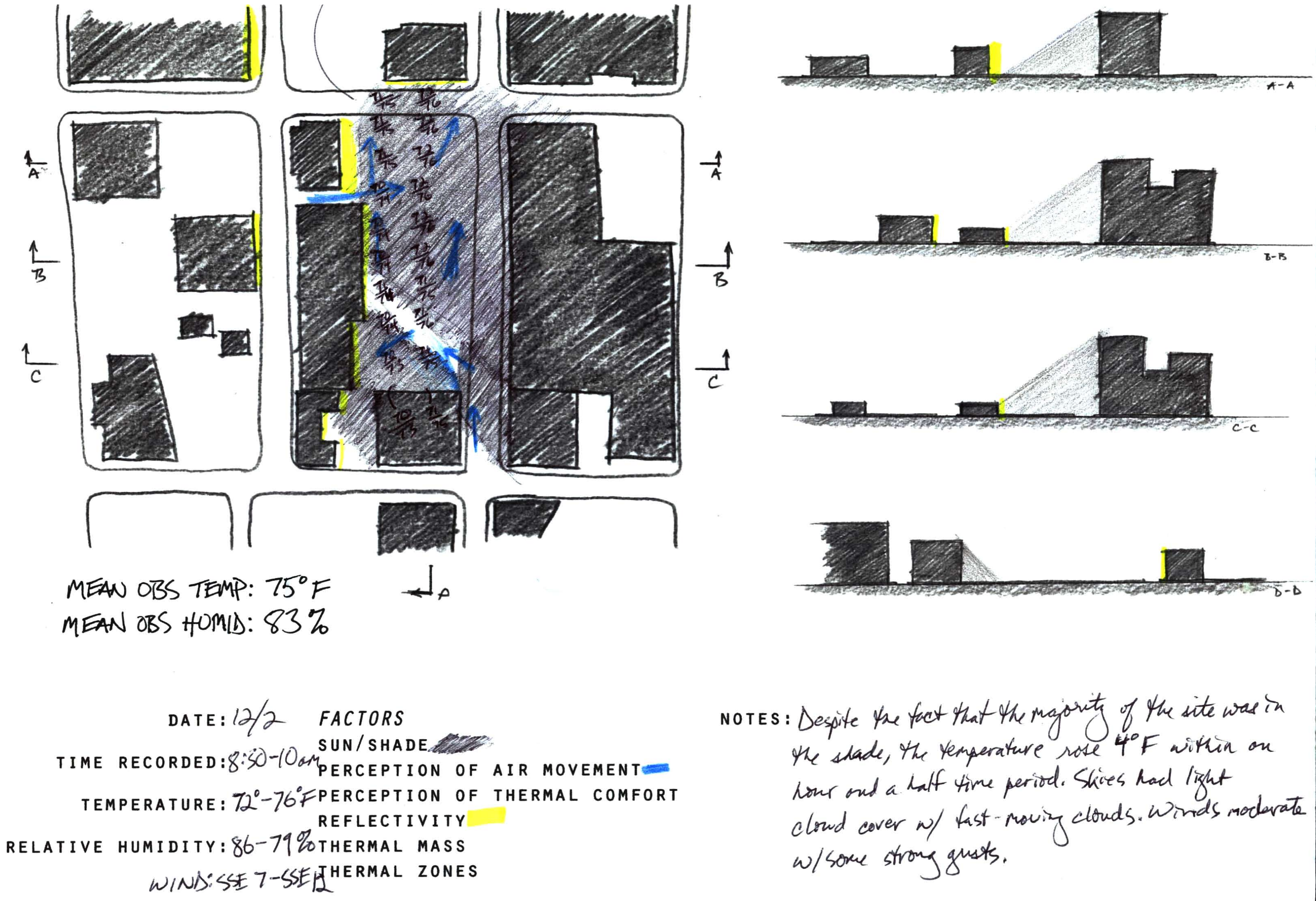


Fig. 43. Site Observation Study A.

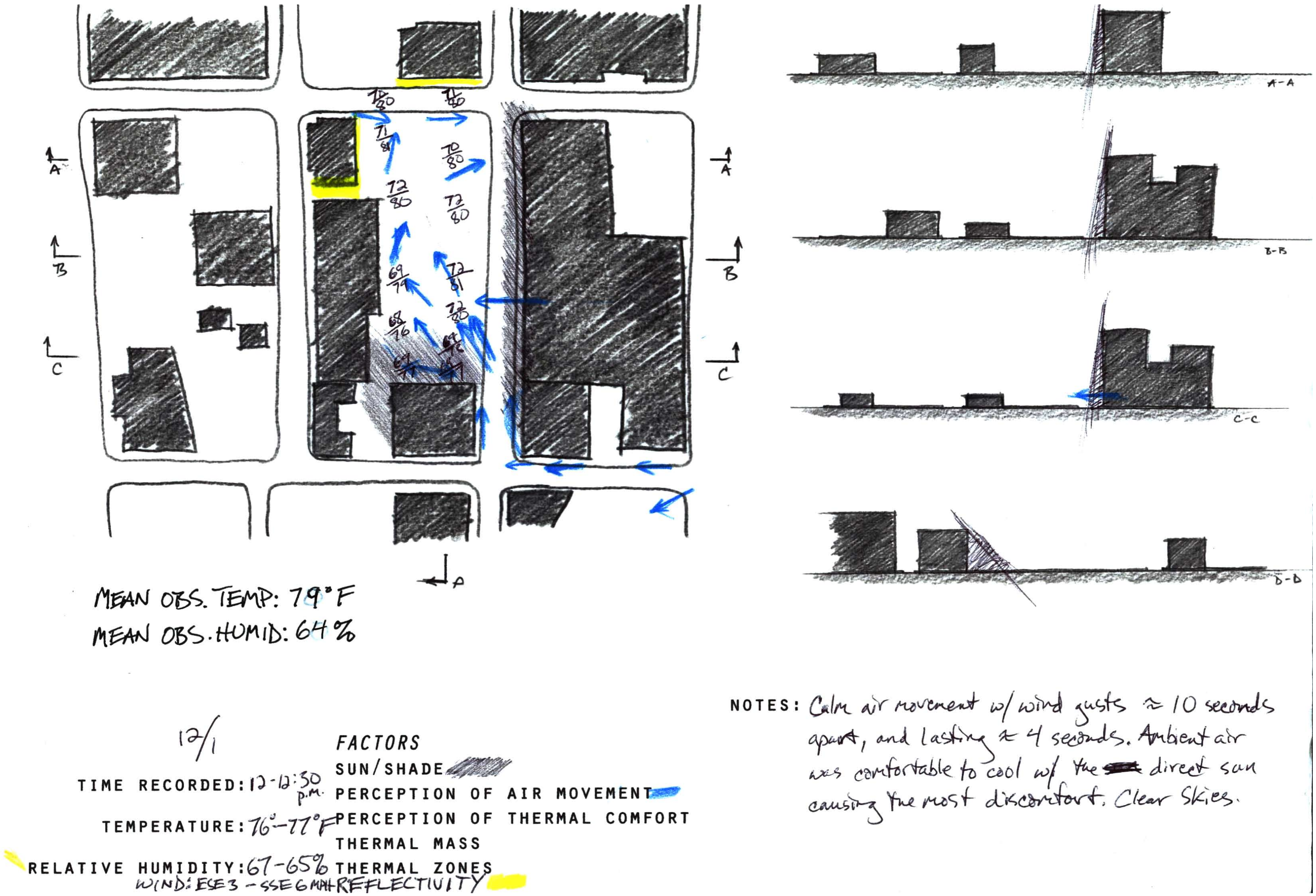


Fig. 44. Site Observation Study B.

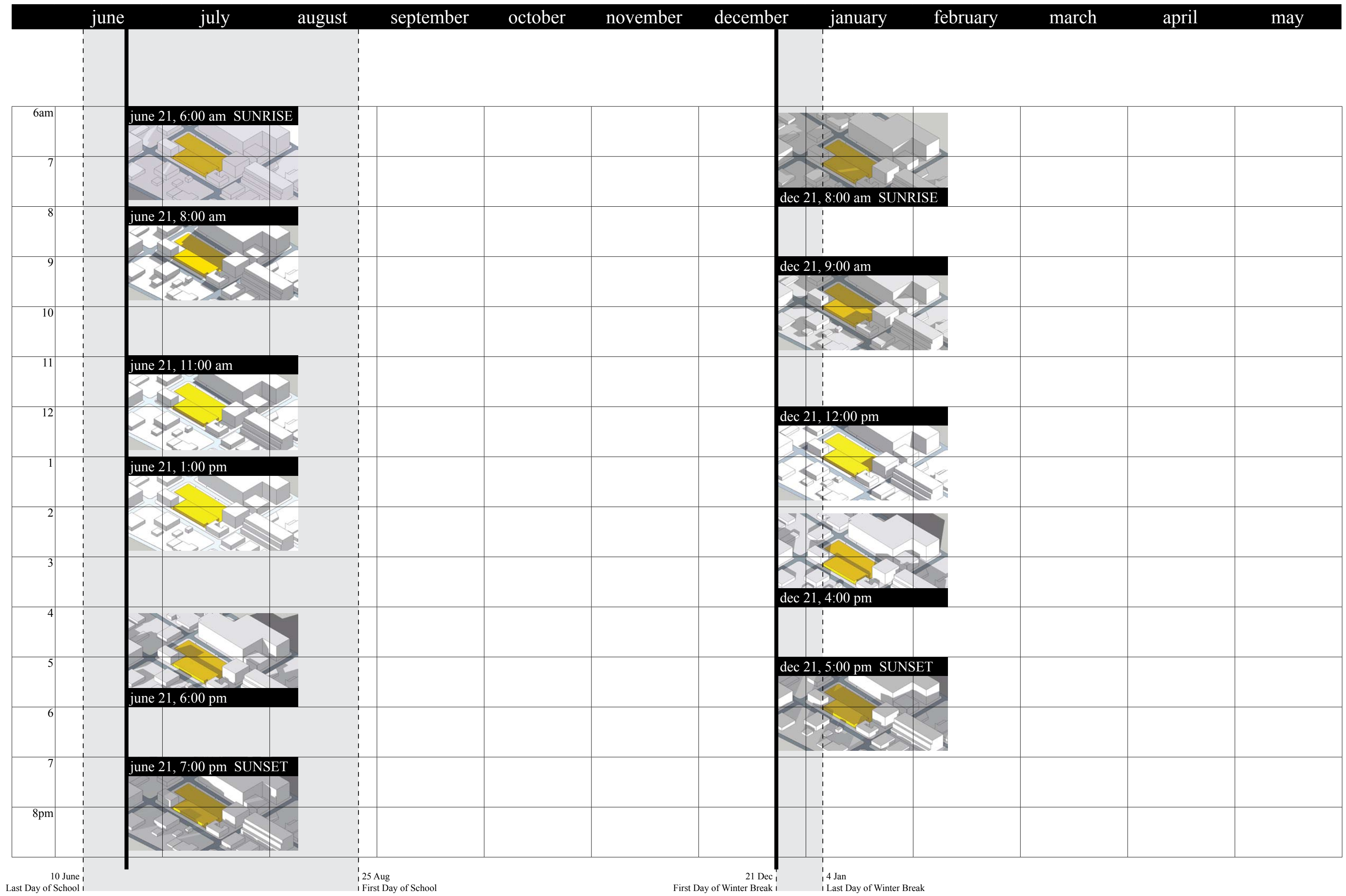


Fig. 45. Shade studies of the summer and winter sun in relation to the academic calendar.

temperatures and recorded temperatures were the same. Temperatures in areas of sun differed from temperatures in areas of shade by as much as 4 degrees. Areas of asphalt reached 3 degrees higher than areas of grass, during the late afternoon, and in the evening, radiated the solar transmission absorbed during the day to create temperature differences of a couple degrees. The observed analysis and hourly shade studies show that the majority of the site is shaded, primarily by the building to the east, until 10 a.m. in the summer, and 11 a.m. in the winter. The northern end of the site is shaded in the summer afternoons by the building to the northwest, and during the winter, shade from the building to the south moves across the southern portion of the site.

The wind moving through the site is affected most by the surrounding buildings, especially those to the east and south, due to their scale. Most of the time, wind gusts from any direction can be felt at any location on the site, however, calm areas do occur in specific locations when winds come from the east or south. For example, when the wind is blowing from any direction south of east and west, an area of calm can be found along the northern face of the building to the south of the site. Another example takes place when the wind blows from any direction east of north and south. In this case, the height and width of the building to the east of the site will oftentimes block a large area of wind and cause an area of calm on the western side of the building. However, wind moves through the vehicular circulation path which begins on the east side of the building, and pushes out into the site from the opening on the western side of the building. The difference in pressure causes the air to move at an increased velocity. This east-west wind corridor could be of great advantage if continued through the site. The streets connecting to the site also supply air movement at increased velocities via the urban wind corridor effect that results from the continuous surfaces of building facades lining the streets. The increased air velocities that exist around the site as a result of the urban context will be captured as much as possible to facilitate air movement within the site. Additionally, these increased air velocities will aid in creating pressure differentials in, and around, the site to encourage air movement in what would otherwise be areas of calm.

The northern party wall of the building to the south of the site is the only source of thermal mass, in addition to the soil of the site, itself. Temperatures were recorded along the face of the party wall, and a temperature difference of three degrees Fahrenheit was observed around 12 p.m. This was most likely due to the fact that the ground in front of the face of the wall had been in the shade all morning, as opposed to being caused by the wall's thermal mass properties, since the remainder of temperatures recorded in the shade was very similar. One can imagine, though, that if this party wall, and the air effectively surrounding it, were to remain shaded throughout the day, then the temperature difference would be greater during the evening. Furthermore, if the face of the wall was cooled as a means of structural ventilation in the evening, then the temperature difference would be greater during the day.

The reflectivity of surfaces on and surrounding the site varies with the position of the sun. The surface having the greatest reflective impact on the site is the west façade of the building to the east of the site. Roughly 85 percent of the surfaces on, and projecting from, the second through eighth floors of this façade are glass. These levels are the residential floors of the building, and feature balconies with glass enclosures and dividers, in addition to glass doors and windows. Solar radiation bounces off of these surfaces and onto the site after around 2 p.m. in the summer, and 1 p.m. in the winter. This indirect heat and light could cause temperatures to rise within the site, as well as visual distractions to occupants. Other surfaces reflecting solar radiation include the building to the northwest and the surrounding concrete sidewalks. The former has a direct impact on the site until 11 a.m. in the summer, and throughout the entire day during the winter. The latter could affect the project any time of day and year. Minimizing the effect of solar radiation on the proposed buildings and occupants will be an important factor in reducing the overall heat gains of this project. Lessening the heat gains will, in turn, decrease the cooling load required.

Program Analysis

The program of this project can be viewed in two different ways: conceptually and functionally. The conceptual program is based on creating the potential for air movement throughout the site. It consists of designing areas of varied air temperature and density, as well as captured breezes, to utilize buoyancy and pressure forces in creating air movement. The functional program is the number and size of spaces, as they relate to the occupants of the school.

Fig. 46. Functional Program.

Number of Spaces	Description of Area	Minimum Unit Sq Ft	Total Sq Ft	Student Stations Each	Student Stations Total
	KINDERGARTEN				
6	Classrooms	800	4800	18	108
6	Student Toilet Rooms	40	240		
3	Material Storage Rooms	120	360		
2	Teacher Planning Areas		400		
2	Activity Rooms	1130	2260		
	Subtotal		8060		
	PRIMARY				
18	Classrooms	800	14400	18	324
4	Teacher Planning Areas		800		
18	Student Toilet Rooms	40	720		
4	Activity Rooms	1130	4520		
	Subtotal		20440		
	INTERMEDIATE				
12	Classrooms	800	9600	22	264
3	Teacher Planning Areas		600		
12	Student Toilet Rooms (Boys/Girls)	40	480		
3	Activity Rooms	1130	3390		
	Subtotal		14070		
	MUSIC				
1	Classroom		1400		
1	Material Storage Room		100		
	Subtotal		1500		
	ART				
1	Kiln Room		55		
	Subtotal		55		

Number of Spaces	Description of Area	Minimum Unit Sq Ft	Total Sq Ft	Student Stations Each	Student Stations Total
	GIFTED CLASSROOMS				
1	Gifted Science Classroom		800		22
1	Gifted Math Classroom		800		22
2	Student Toilet Rooms (Boys/Girls)	40	80		
	Subtotal		1680		
	PHYSICAL EDUCATION				
1	Teacher Planning Area		100		
1	Material Storage Room		200		
1	Staff Shower/Toilet Room		50		
1	Fenced Storage Area		(225)		
1	Kindergarten/Primary Playcourt		TBD		
1	Intermediate Playcourt		TBD		
1	Kindergarten/Primary Turf Area		(22500)		
1	Intermediate Turf Area		(260000)		
	Subtotal		350		
	MEDIA CENTER				
1	Reading Room with Computer Lab Area		4000		
1	Technical Processing Room		250		
1	Teacher Workroom		250		
1	Staff Toilet Room		40		
1	Audio Visual (AV) Storage/CCTT Room		700		
1	Office		120		
	Subtotal		5360		
	ADMINISTRATION				
1	Administrative Reception		255		
1	Secretarial Area		450		

Number of Spaces	Description of Area	Minimum Unit Sq Ft	Total Sq Ft	Student Stations Each	Student Stations Total
1	Principal's Office		200		
1	Assistant Principal's Office		150		
1	General Office		150		
1	Data Processing Office		150		
1	Production/Workroom		200		
1	Conference Room		250		
2	Clinic Rooms	100	200		
2	Clinic Toilet/Shower Rooms	50	100		
1	Administrative Storage Room		200		
1	Records Room		200		
1	Textbook Storage Room		200		
2	Staff Toilet Rooms (Men/Women)	40	80		
	Subtotal		2785		
	GUIDANCE				
1	Reception/Secretarial Area		100		
2	Offices	150	300		
1	Group Activity Room		200		
	Subtotal		600		
	FOOD SERVICE				
1	Student Dining Room		3000		
1	Servery		575		
1	Chair Storage Room		150		
1	Kitchen		1000		
1	Receiving Area		25		
1	Kitchen Manager's Office		100		
1	Cooler		120		
1	Freezer		160		
1	Dry Storage Room		190		

Number of Spaces	Description of Area	Minimum Unit Sq Ft	Total Sq Ft	Student Stations Each	Student Stations Total
1	Faculty Dining Room		400		
2	Faculty/Staff Toilet Rooms (Men/Women)	40	80		
	Subtotal		5800		
	MULTI-PURPOSE				
1	Multi-Purpose Room		1700		
1	Stage		700		
1	Chair Storage Room		150		
1	Stage Storage Room		300		
2	Public Toilet Rooms (Boys/Girls)	200	400		
	Subtotal		3250		
	CUSTODIAL				
1	Central Receiving		200		
1	Custodial Office		100		
8	Service Closets	20	160		
2	Locker Rooms (Men/Women)	40	80		
2	Toilet Rooms (Men/Women)	40	80		
1	Flammable Storage Room		250		
1	Equipment Storage Room		250		
	Subtotal		1120		
	Net Subtotal		65070		
	Mechanical (%4)		2600		
	Subtotal:		67670		
	Circulation, Walls, etc. (%27)		18270		
	TOTAL GROSS:		**85940**	**S.S.:**	**740**

Fig. 47. Ground Floor Plan.

Fig. 48. Second Floor Plan.

10. PRIMARY

CLASSROOMS (18)
STUDENT TOILET ROOMS (18)
TEACHER PLANNING AREAS (4)
ACTIVITY ROOMS (4)

THIRD FLOOR PLAN

N

Fig. 49. Third Floor Plan.

11. INTERMEDIATE

CLASSROOMS (12)
STUDENT TOILET ROOMS (12)
TEACHER PLANNING AREAS (3)
ACTIVITY ROOMS (3)

12. GIFTED

GIFTED SCIENCE CLASSROOM (1)
GIFTED MATH CLASSROOM (1)
STUDENT TOILET ROOMS (4)

Fig. 50. Fourth Floor Plan.

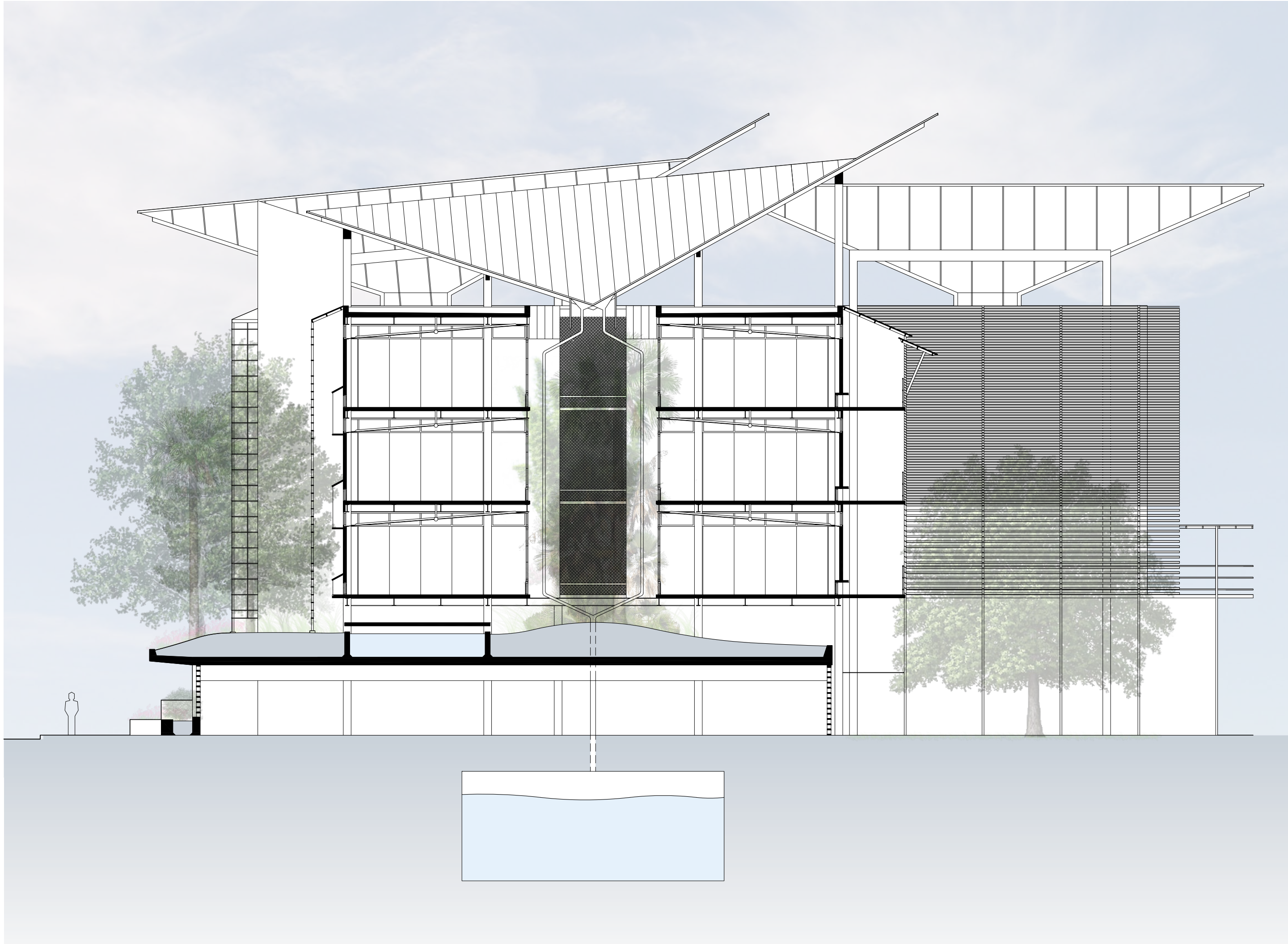


Fig. 51. Garden Classroom Section A-A.

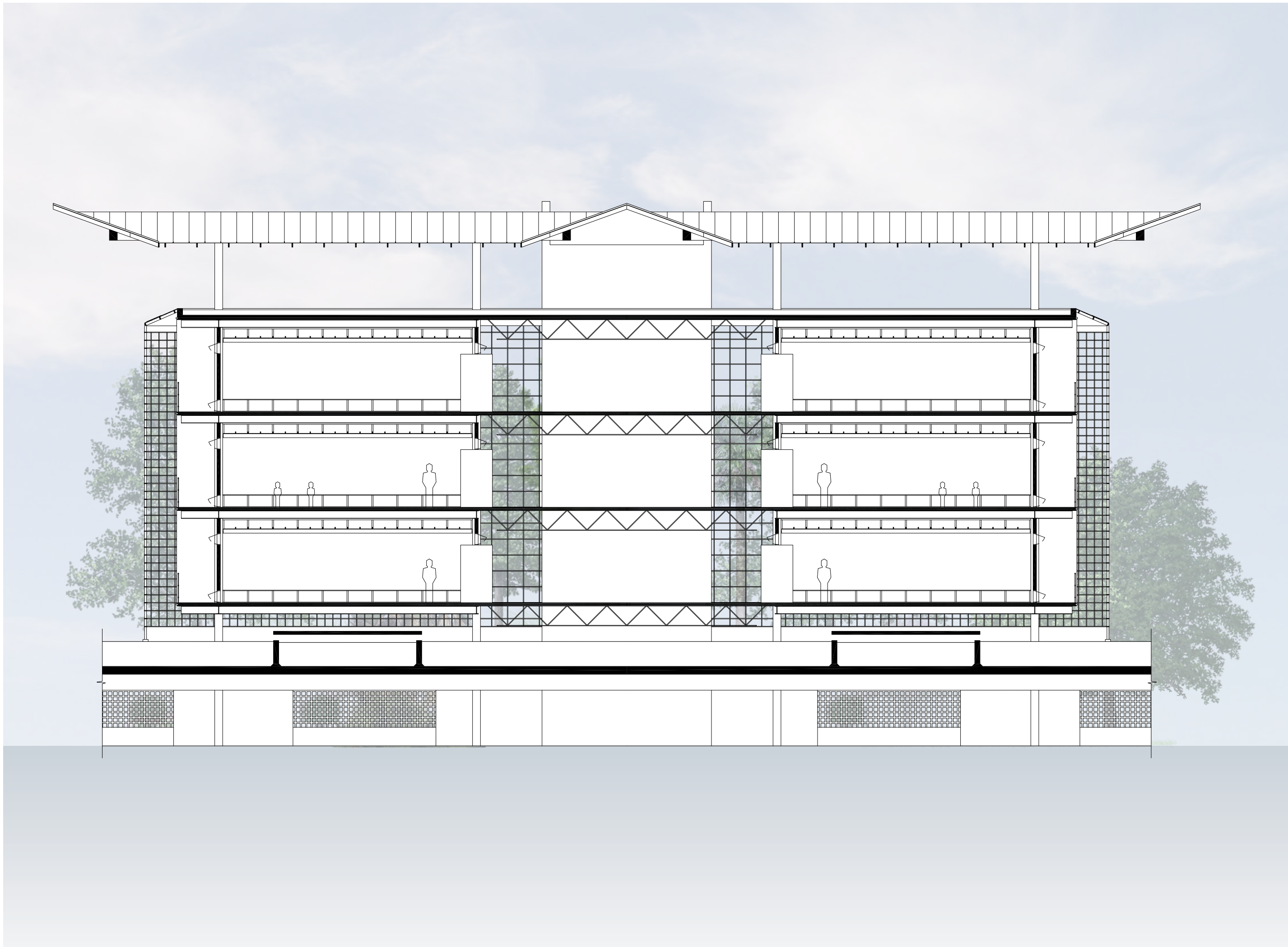


Fig. 52. Classroom Community Section B-B.

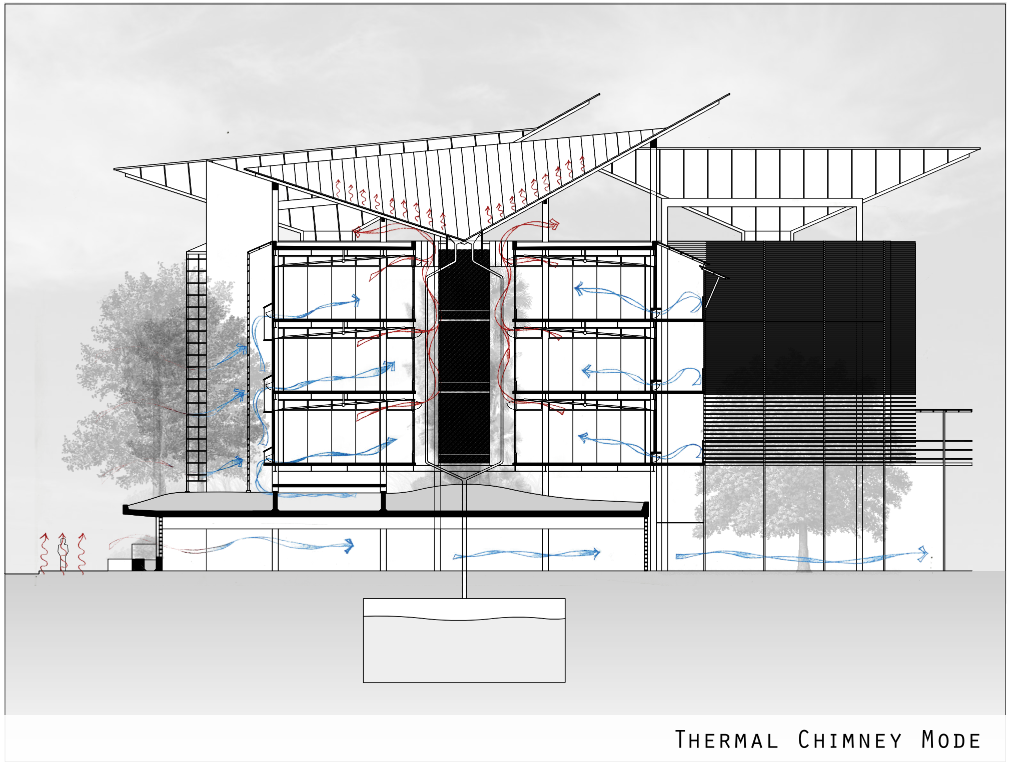


Fig. 53. Passive Cooling Mode: Thermal Chimney.

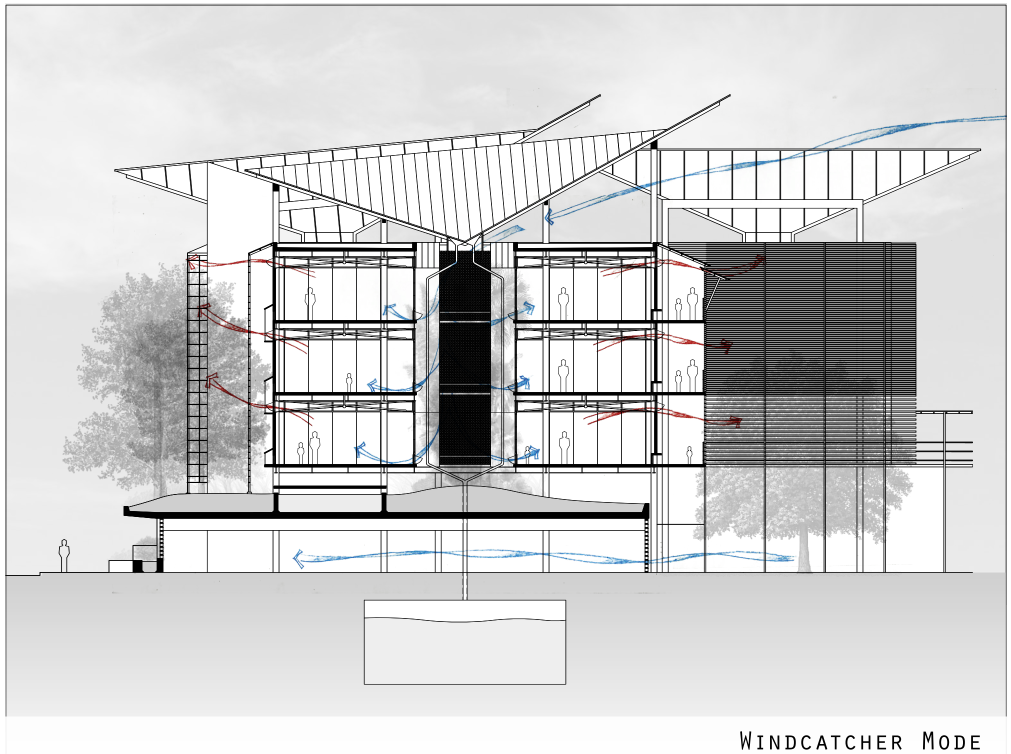


Fig. 54. Passive Cooling Mode: Windcatcher.

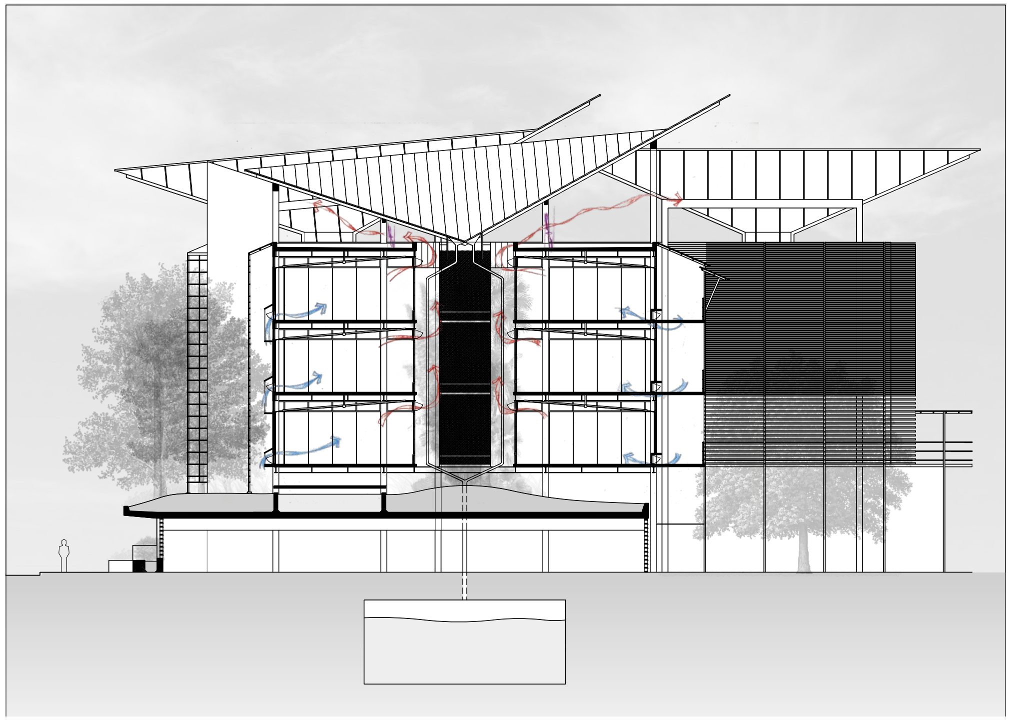


Fig. 55. Mechanically Assisted Cooling Mode: Thermal Chimney.

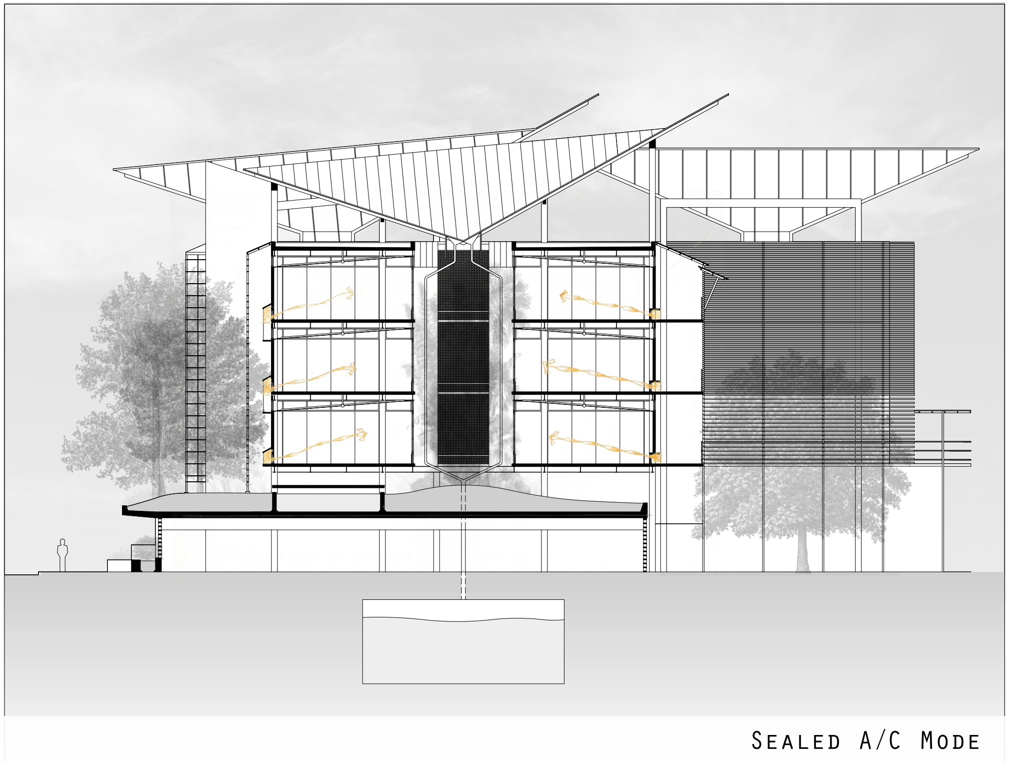


Fig. 56. Full Mechanical Cooling Mode: Air Conditioning.

Fig. 57. Sensory Dune: Grasses and Wildflowers.

Fig. 58. Planting Key A.

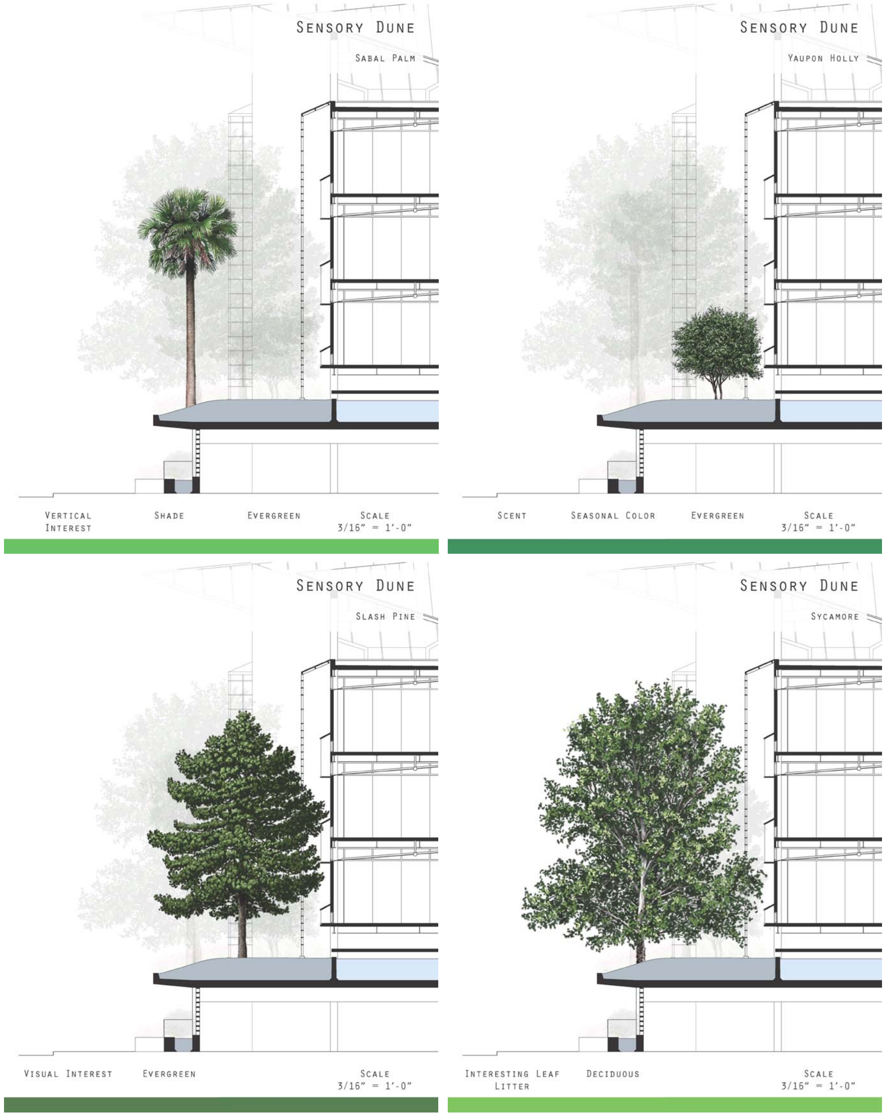


Fig. 59. Sensory Dune.

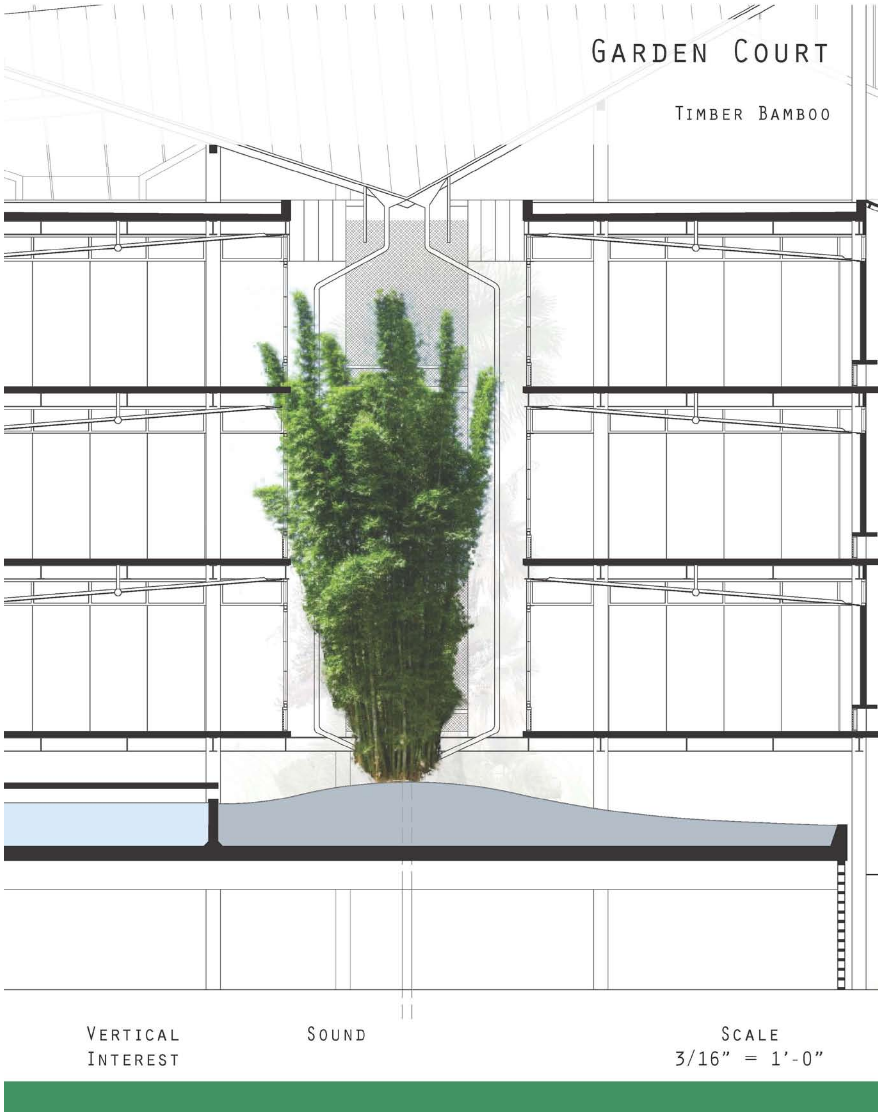


Fig. 60. Garden Court: Timber Bamboo.

Fig. 61. Planting Key B.

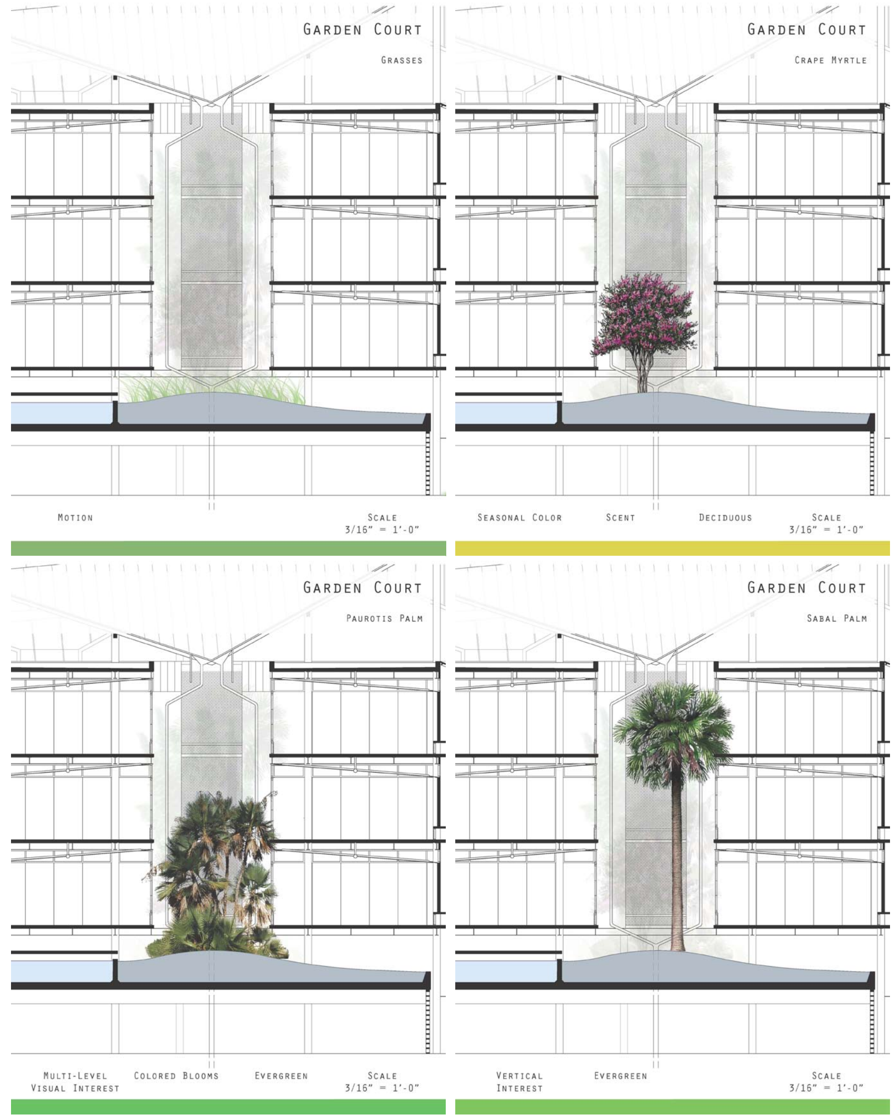


Fig. 62. Garden Court.

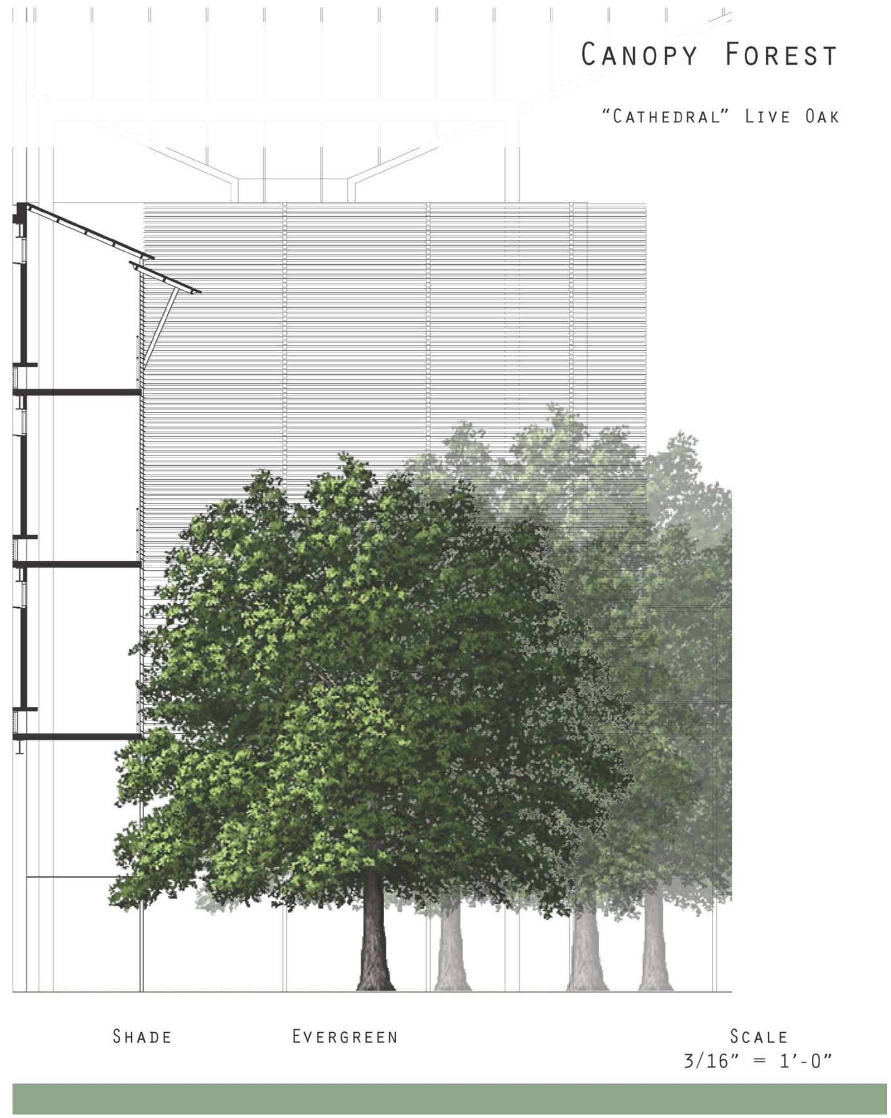


Fig. 63. Canopy Forest: Cathedral Live Oak.

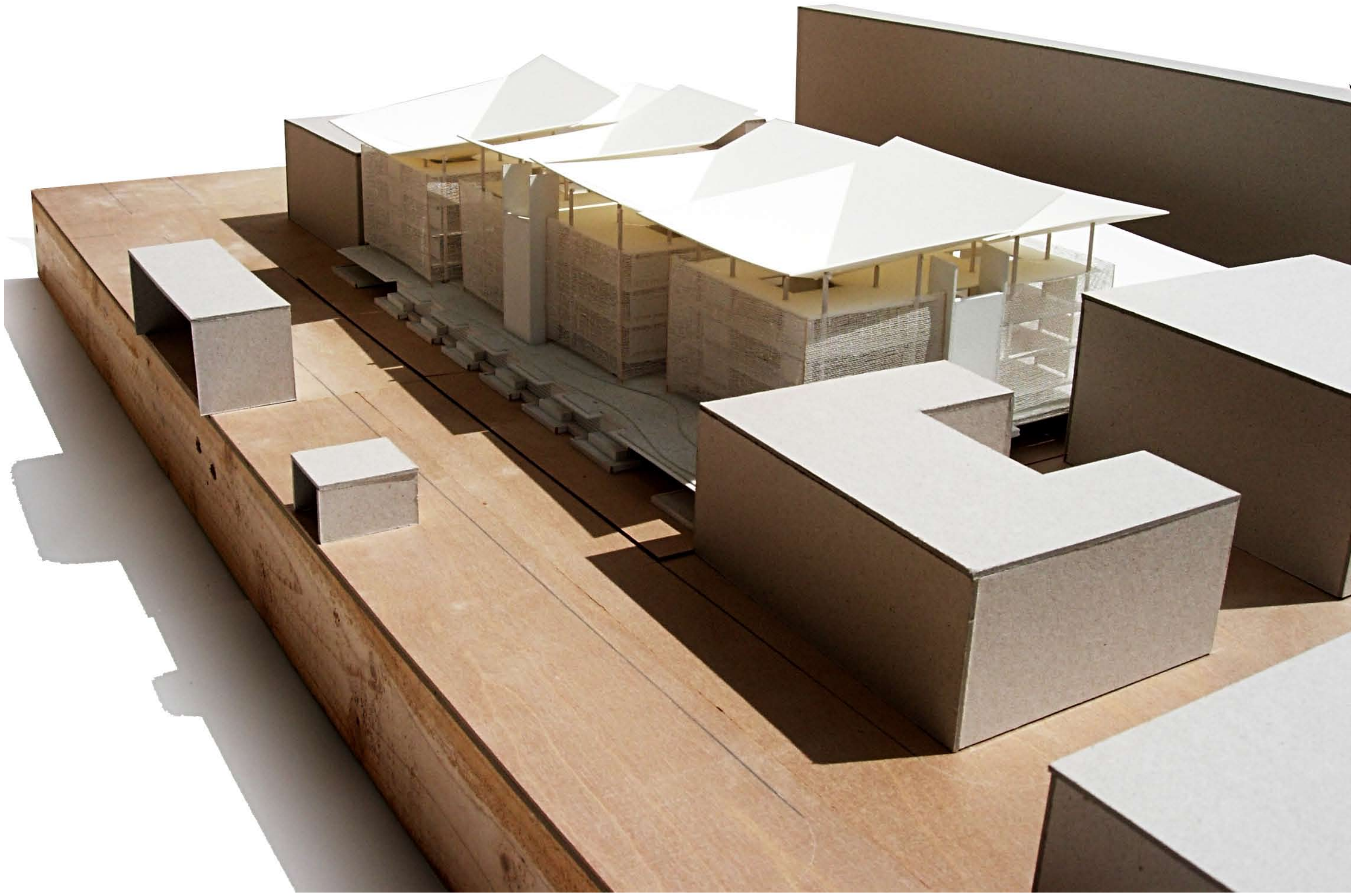


Fig. 64. Site model.

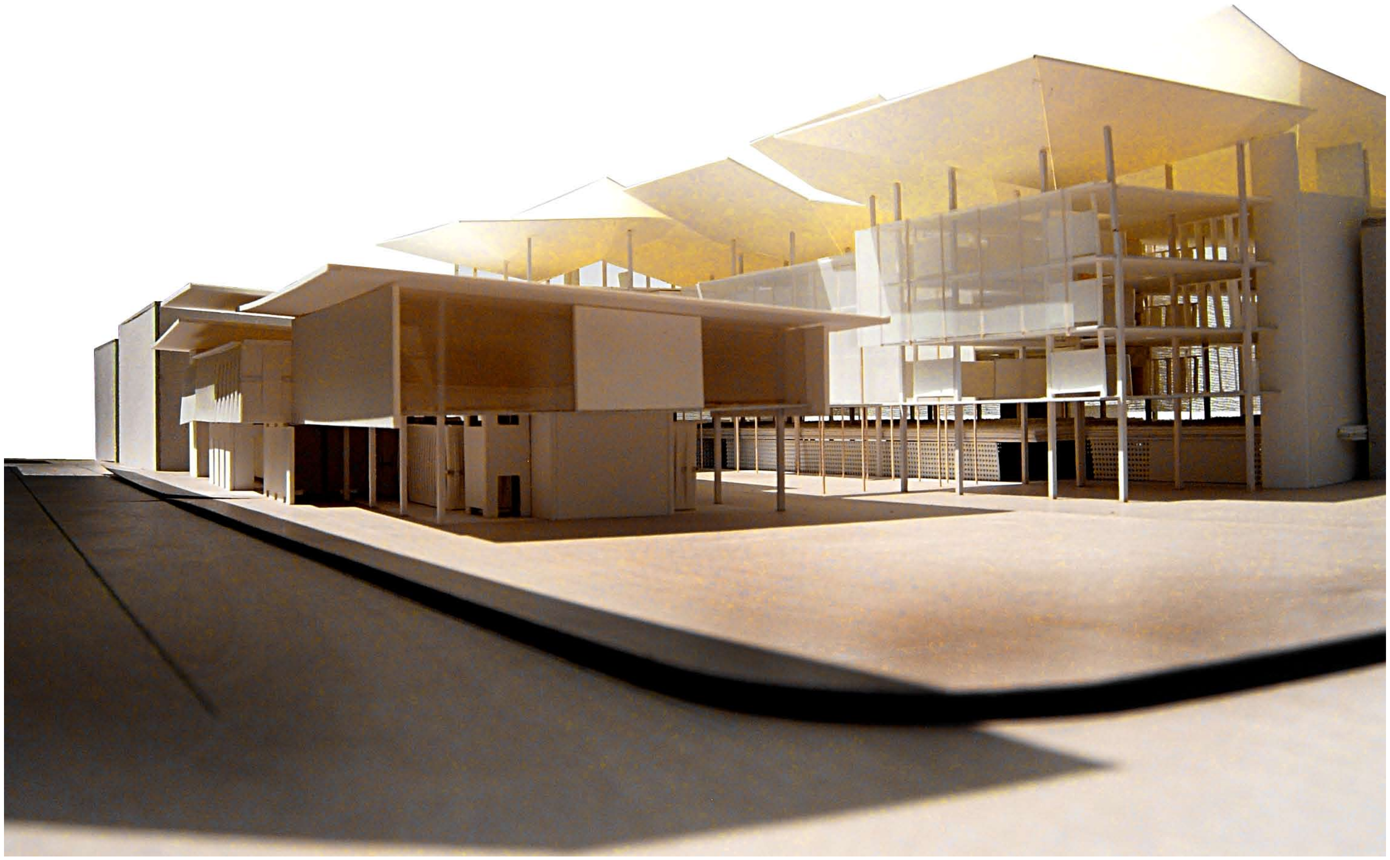


Fig. 65. View showing shade of deep roof overhangs.

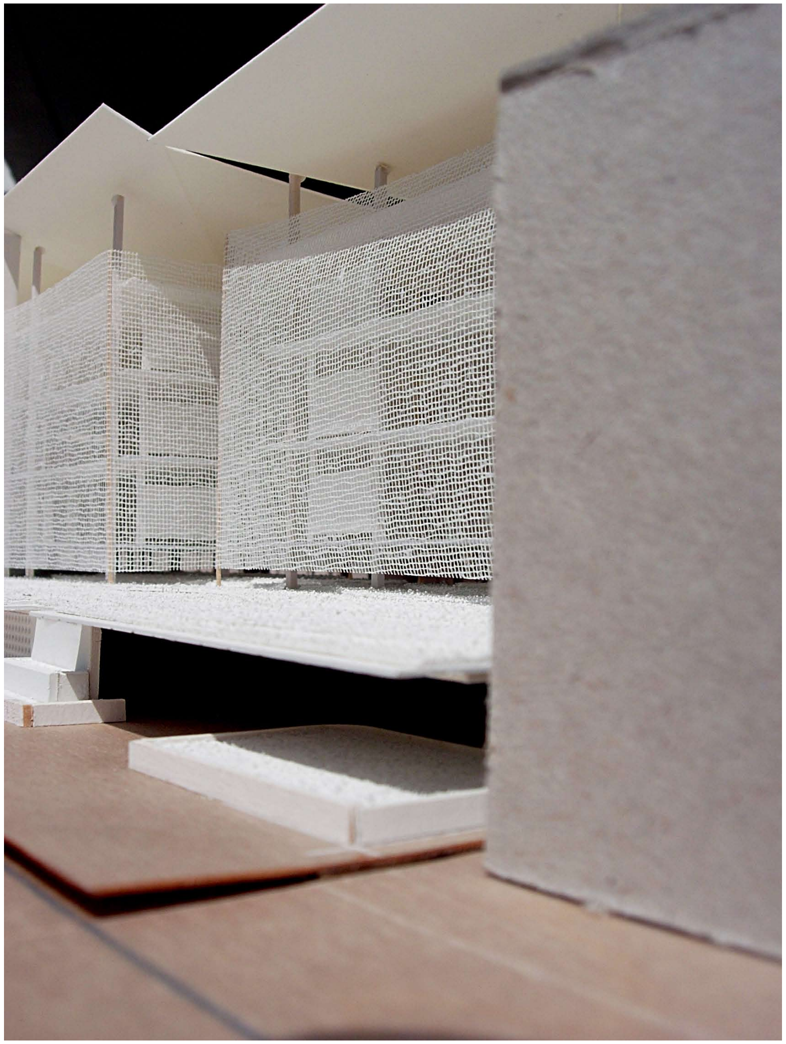


Fig. 66.	Parking garage, sensory dune and classrooms.

Fig. 67. View into canopy forest.

Fig. 68. Circulation paths looking over the shaded canopy forest.

Fig. 69. Section model showing the garden court.

Fig. 70. View of classrooms and circulation along east side.

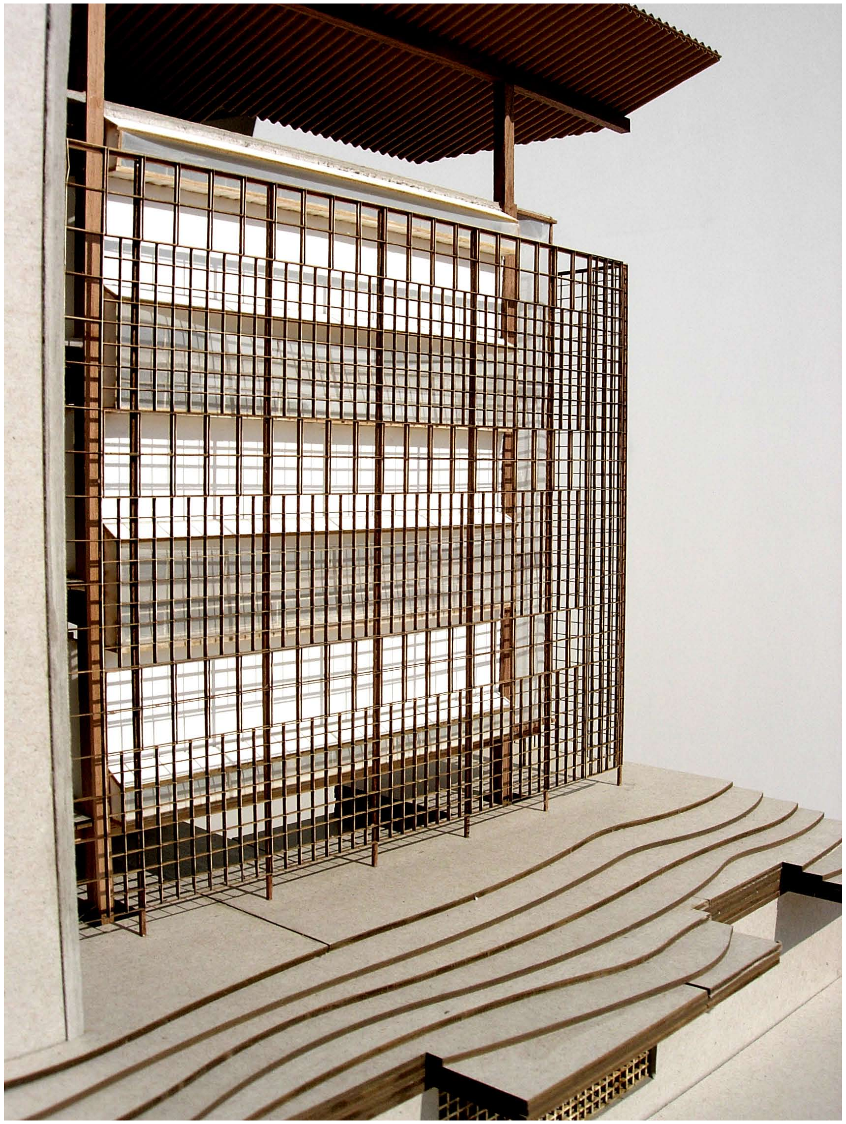


Fig. 71.   Foliage screen upon the sensory dune.

Fig. 72.   View of classrooms along the west side.

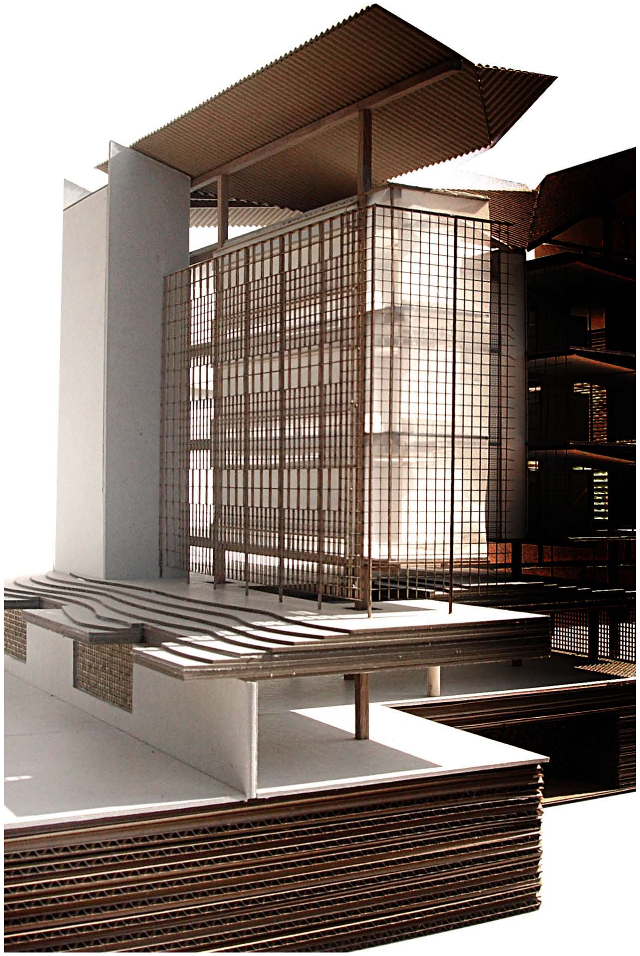


Fig. 73. View of southwest corner.

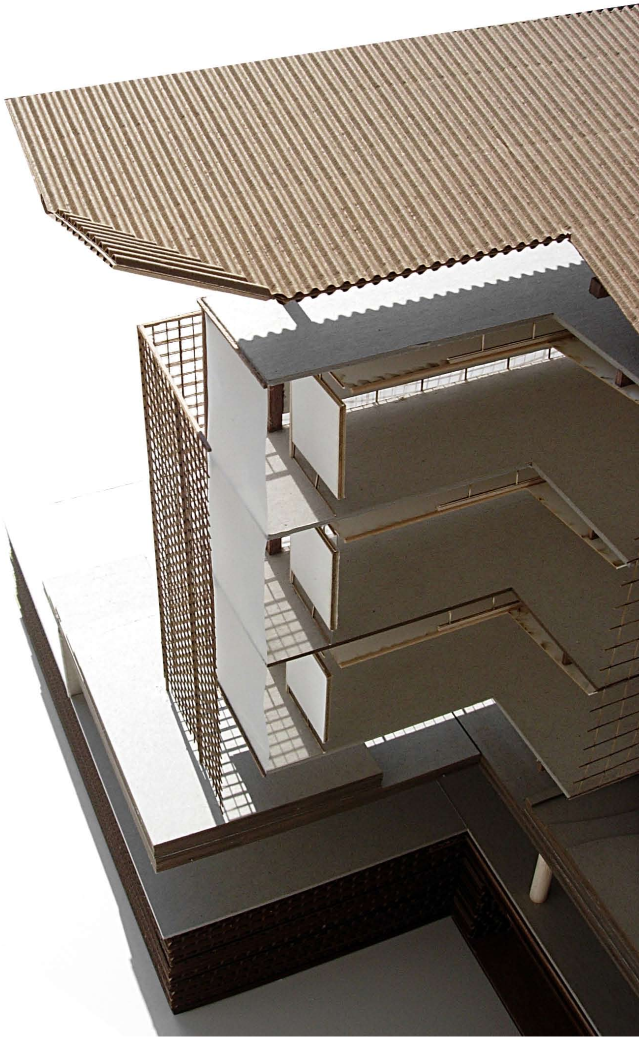


Fig. 74. Layers composed of foliage screen, insect screen and floating partition.

Fig. 75. View into the garden court from the activity space.

Conclusion

It is clear that a model is needed for subtropical architecture, one in which passive and mechanically assisted methods of cooling are the baseline, and mechanical air conditioning serves as the last resort. This need arises from issues such as climate determinism, thermal neutrality and the steady-state approach, which are the main factors of abuse and over-reliance of air conditioning. These issues were to be resolved, in this thesis, by achieving three main goals. The first goal was to maximize the annual time window of evaporative cooling of occupants throughout the spaces of school buildings located in hot, humid climates through natural and induced ventilation methods such as cross-ventilation and buoyancy. In situations where natural air movement was poor, forced ventilation methods, such as the use of fans, were to be integrated into the design. The second goal was to minimize the reliance on air conditioning systems within interior spaces of school buildings in hot, humid climates. And the third goal was to facilitate the localized control of microclimates within the school building. The conceptual basis for achieving these goals, termed the garden classroom, was to create garden spaces within and surrounding classrooms to provide positive, thermal qualities of human comfort to their occupants.

The research process began with three case studies, each representing a different outlook on cooling strategies. They ranged from sealed, air conditioned boxes without any windows, to sealed boxes that featured operable high windows which were probably never opened, to a fully open-air structure featuring a wide range of degrees of enclosure. While the case studies demonstrated a number of cooling strategies, none provided a hybrid solution to provide passive cooling most of the time, reserving the assistance of air conditioning to temper the summer extremes. When asked their opinion, most of the author's peers considered the open-air school building an interesting prospect to visit, but not to work or attend class in everyday. Consequently, the sealed, air conditioned school buildings did little to excite, due to their sequestering nature. This only further emphasized the reality of the subtropical cooling dilemma. It became obvious that a handbook of passive and mechanical cooling strategies for the subtropics needed to be compiled to understand an array of methods in a simple fashion, such that they could be integrated into the initial phase of the design process. The concepts found in the handbook became the foundation for the systems illustrated in the final design.

A major turn in this thesis was the realization of the cooling potential of the garden. The most important idea distilled from the Denham Oaks Elementary School case study was the implementation of gardens around the classroom communities at a variety of scales. At the largest scale exists an oak preserve. Stepping down in scale, students are greeted by foliage in a courtyard, along whose edges are the entrances to the classrooms where students are greeted by even smaller gardens. The exploration of this idea, in tandem with reading Lisa Heschong's *Thermal Delight in Architecture*, inspired the garden classroom concept. The garden classroom is the appropriate link between the student and thermal comfort. It provides the sensorial aspect of cooling, while also accomplishing the biological mechanics of cooling. Scented breeze, rustling leaves and dappled light, as well as, lower air temperatures, lower ground temperatures, lower building surface temperatures and evapotranspiration all contribute to the garden classroom's attractive qualities.

After completing research and analysis of the case studies, it became evident that in order to assess the contemporary cooling issues in the subtropics, one has to fully understand the climate of the subtropics, and its effect on the human body and psyche. The main factors related to cooling in the hot, humid subtropics include thermal comfort, the comfort zone, the Human Comfort Chart, air movement, meso-climate and microclimate. The significance of the Human Comfort Chart, to this thesis, is that up until this point in the research, it was difficult to quantify and compare thermal comfort qualities. An added significance to the chart is that it factors humidity as a key element of human comfort, along with the ambient air temperature, making it an ideal method for subtropical climates. Understanding human comfort in relation to the hot, humid climate amplified the importance of air movement. Whether a captured breeze, the stack effect, or fan-assisted ventilation, air movement across the human body is quite possibly the most important concept learned in this thesis. Understanding the microclimate is one way of anticipating the strength and consistency of air movement at a particular site. Analysis of the microclimate also defines most of the variables that inform early design decisions, in particular which passive cooling strategies will be employed, such as those listed under "Building Groups" in the handbook. The meso-climate, on the other hand, covers a much broader area. With the aid of the Human Comfort Chart, meso-climatic data such as ambient temperature and relative humidity readings can help the designer to understand the range of temperatures to be expected daily, monthly and annually, and how they fall in relation to the comfort zone.

The next portion of the research, site analysis, consisted of meso-climatic and microclimatic analysis of the site which was selected in downtown Tampa. Other than being located in the subtropics, there were two main reasons for selecting this site, as it related to cooling. The first was to engage the challenge of an urban microclimate in which the winds are unpredictable and extremely calm in some areas. The second was to apply the garden classroom concept to a multi-story school. The meso-climatic data collected was used to find the month requiring peak cooling, as well as the duration in a twenty-four hour period requiring peak cooling. Other important factors were the high precipitation values. The microclimatic data was collected in a series of observation studies on-site. A psychrometer was used to establish the dry bulb temperature and relative humidity at varying points across the site, and factors such as wind, sun and shade, reflectivity of surrounding surfaces and effects of thermal mass on the site were recorded. The wind, in particular was very difficult to record, since it was affected by all of the surrounding context buildings. Most of the breezes that happened on-site were eddies created by negative pressure zones on the leeward side of surrounding buildings. The eight-story condominium building to the east posed the largest windbreak, and probably had the biggest impact of any contextual feature on the school design. Due to the fact that the prevailing winds come from east-northeast, the building prevents almost all of the prevailing winds from reaching the site. Accordingly, the selected site is in a wind shadow until the afternoon when the winds typically switch directions. Furthermore, the only prevailing winds that cross the site are approximately sixty feet in the air, sailing off the top of the condo building. This factor became the starting point for the conceptual program of the school campus, in particular the classroom communities. A functional program, based on local public elementary schools, was introduced into the design process to determine the scale of the campus. The allotted mechanical spaces in the program were reduced to accommodate wall and window mounted air conditioners, since the anticipated load, in terms of duration, would be greatly reduced.

Using strategies from the handbook, a microclimate-responsive solution was reached. First, building groups were laid out based on hourly wind and shade diagrams. The wind diagrams indicated that the ideal location for the classroom communities to catch the prevailing winds coming off the top of the condo bldg would be the west side of the site. The shade diagrams indicated that the ideal location to share shade from the condo building was along the east edge of the site, but that the only shade to be offered was in the early morning. Seeing that there was no shared shade to be offered from the surrounding context during midday and afternoon heat, it became evident that in order to lower the temperature of the site, the majority of the site and the proposed buildings would need to be shaded in some way. There was also the issue of the height of the prevailing wind current. At three stories high, the classroom communities were about twenty-five feet short of catching the wind current above. By creating a raised ground plane, lifting up the classrooms, and designing the roof as a windcatcher, the prevailing breeze could be brought down into the classroom garden courts. Grasses, shrubs and trees could be planted on the raised ground plane to create a series of gardens that would provide passive cooling to the students through shade, evapotranspiration, and the sensorial connection. Furthermore, the underneath of the raised earth was designed as a parking garage that serves as a buffer against the heat of the street. Wrapped in a porous skin, the hot air moving into the garage is cooled in the well-shaded space before moving into the surrounding campus buildings.

This would seem like a perfect scenario. The wind catchment system relies on a constant, moderate wind to be brought down into the classrooms via the roof. However, Tampa's prevailing winds rarely follow that description.

Additionally, although most of the surrounding context is not higher than the roofs of the classroom buildings today, in an urban setting it is very likely that will change. The realization at this point in the design process was that the entire design depended on a constant breeze that did not exist. The solution to the problem was a solar chimney, using the same central garden court that the breeze is intended to move down through in windcatcher mode, before entering the individual classrooms. As a solar chimney system, the roof would be fabricated of corrugated metal which heats up very quickly. The roof heats the air around it, causing the air to rise. As a result, hot air from the classrooms would be drawn out through high windows into the court, while cool air is brought in through low windows along the outside of the building. On overcast days, fans along the roof would increase the velocity of the air, as it is drawn out, into the court and up past the roof.

For the solar chimney system to work the air being brought into the classrooms through the low windows would have to be cool. Because these windows were located along the outside of the classroom buildings, the temperature of the air around the outside of the building would need to be lowered. By shading the building with a series of layers, the interior spaces can benefit from an intake of cool air, much lower than the ambient air temperature outside. The layers in the final design consisted of grasses, shrubs and trees, architectural screens covered with foliage, louvers, white insect screens, operable windows and doors, and moveable interior partitions. By separating these elements to appropriate distances, shaded spaces are created within the building's layered skin, permitting the incoming air to drop significantly. The air is further cooled in these tertiary spaces by shaded ground ponds, which remove heat from the air without contributing to the humidity. Each individual element from the foliage covered screen, to the white fly screen, to the shaded ground pond, has the potential to lower the temperature from 1 to 3 degrees, and sometimes more. When the combination of shading elements in one particular area of a classroom building is added up, the sum of cooling has the potential to approach 10 degrees. Having stated that, imagine a hot summer day with an ambient temperature recording of 88 degrees, a high which Tampa rarely reaches. Presuming the air being drawn into the classrooms was 78 degrees, that would mean that the air moving across the students falls within the comfort zone. Which means that according to the Human Comfort Chart, ___ percent of the students are comfortable inside the classroom. Furthermore, the supplement of fans would only increase the sensation of cooling.

It is the author's opinion that the research was successful in achieving the goals of this thesis. The potential to place the incoming ventilation air at a temperature within, or just beyond the cusp of, the comfort zone during peak highs implies a reduction in the need for air conditioning. The integration of multiple layers, many including operable characteristics, imply localized control of the amount of cooling taking place. The specific placement of high and low windows promotes air movement and evaporative cooling of occupants.

The architecture of hybrid cooling suggests an architecture of inhabitable layers that range from natural to man-made, based around cooling the surrounding air. Whether promoting cross-ventilation or the stack effect, it offers the opportunity to blur the boundaries between nature inside and nature outside. It offers humans the opportunity to have a closer relationship with the thermal delight of the surrounding natural world that is so often shut out.

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