Sustainable Housing in French Polynesia

Final Report

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BACKGROUND

French Polynesia

The French annexed various Polynesian island groups about one-half of the way from South America to Australia during the 19th century. These lands formally became an overseas territory of France in 1946 and encompassed a total area of 3,167 sq km (1,609 sq mi)[1] with 118 islands and atolls, but only 0.75% of this land is considered arable. The climate is tropical, but moderate with a mixture of rugged high islands and low islands with reefs. The only natural resources to speak of are timber, fish, cobalt, hydropower, sun, and wind. The total population is more than 274,000 with 47% of the population living on the main island of Tahiti Nui. Native Polynesians make up 78% of the population with the rest being Chinese and French. Literacy rates are above 98%.

Since 1962, when France stationed military personnel in the region, French Polynesia has changed from a subsistence agricultural economy to one in which a high proportion of the work force is either employed by the military or supports the tourist industry. In September 1995, France stirred up widespread protests by resuming nuclear testing on the Mururoa atoll after a three-year moratorium. There was heavy rioting for three days in the capital of Pape`ete. The international airport was nearly destroyed by rioters, and 40 people were injured in the general chaos. With the suspension of tests January 1996, the military contribution to the economy fell sharply. Tourism accounts for about one-fourth of GDP and is a primary source of hard currency earnings. Other sources of income are pearl farming and deep-sea commercial fishing. The small manufacturing sector primarily processes agricultural products. The territory benefits

[1] Slightly less than one-third the size of Connecticut.

substantially from development agreements with France aimed principally at creating new businesses and strengthening social services (CIA 2006). Separatist leader Oscar Temaru became President of the Territorial Government of French Polynesia on March 3, 2005 by popular vote for a five-year term after a long drawn out political tussle with his long-time foe, pro-French Gaston Flosse who had previously ruled French Polynesia for close to 20 years. Calls for energy and material independence from France have encouraged research into everything sustainable.

Fare MTR Bioclimatic [2]

The archipelagoes which make up the Territory of French Polynesia were hit by a strong tropical storm and five tropical cyclones which caused extensive material damage and fifteen fatalities between December 1982 and April 1983. Not since 1906 has Tahiti been struck by any major cyclones, which makes this series of storm remarkable. A regional and, as some climate scientists believe, possibly global imbalance in the Earth's heat distribution is the leading suspect (NOAA-UNDRO 1983).

The magnitude of damage done during the '82-'83 cyclone season was partly due to the rapid succession of intense storms, but the effects were also profoundly modified by a lack of cyclone experience, poor building codes, and poverty. Before 1982 political and public awareness of cyclones was low as is common in a low-frequency hazard in a region like French Polynesia where each of the widely scattered tiny islands has only the slightest chance of experiencing a direct hit. This lack of preparedness is illustrated by widespread non-observance of basic safety rules in the building trade, vague regulations which are either ill-adapted to the actual hazard or simply disregarded, the absence of collective shelters on islands or sites recognized to be highly vulnerable. For example, concrete buildings were frequently destroyed both on Tahiti and the outlying atolls. Even if there was motivation to prepare for cyclones, however, the peculiar nature of the local economy retarded both the government and the public's ability to do so. The Territory, thanks to the financial resources generated by the French military and to the advantages associated with its present territory status, boasts average income of $17,500US,[3]

[2] Fare is a Tahitian word for building. MTR is a French acronym for the Territorial Houses of Reconstruction. Bioclimatique is a French word for sustainable.

[3] Camptoirs Francais du Pacifique francs (XPF) per US dollar = 100 and is pegged at the rate of 119.25 XPF to the euro. Thus $17,500US = 1,750,000XPF

which is far higher than that of most of the other island states or territories in the South Pacific (Dupon, 1984). Yet the average price of a single family home is $600,000US, which is due mostly due to high land costs on Tahiti and is far out of reach for the average family. A government program grants land to natives for which there is a long waiting list. Even though some families do get land from the government they will often only be able to put together a house from scrap metal and wood with little structural integrity.

As a direct result of these cyclones and the devastation to residential housing that followed, French Engineers designed the Fare MTR Bioclimatic (MTR) as an emergency solution. The main features of the MTR were is sturdy modular design that could be erected cheaply and quickly and was cyclone resistant. It was conceived that only 300 units were needed, but in reality 600 were constructed. Ten years later cyclone William destroyed almost every non-MTR residence in 1992. This caused the government to re-start the emergency housing program with the MTR II design. As a result of the design's popularity the MTRs started to be sold commercially as cheap housing in 1995. Ten years later a new MTR III design was released in 2005. The government continues to subsidize 350 MTRs per year by paying for construction costs. 150 additional MTRs per year are typically sold in addition to government subsidized ones. FEI is a private company that builds houses similar in design to the MTR on the outer islands. Altogether more than 500 MTRs are constructed every year.

The current design and materials cost about $60,000US. The new design features a steeper roof, presumably to save on construction costs. The next cyclone will test how well this less-than-optimal roof angle performs. Other changes include the replacement of the triangular ridge vent at both ends of the roof in favor of smaller vents that go all the way around the house underneath the eves. All of the interior plywood materials have been replaced with pre-fabricated 9 mm fibro-cement panels, which are a composite of cement and wood-chips that are imported. The interior wall meets the ceiling at about 8 feet. All of the exterior panels are thicker 12 mm fibro-cement panels. The roof is corrugated metal with aluminum foil style insulation between the metal and the wooden rafters without any backing. All of the wooden members are Douglas fir that is imported from Oregon. The new design has removed the widows in the end of the house so there are now only 3 windows on each wall of the long side of the building. The new screened windows slide open rather than lift for safety reasons. This means that only half of the window can open, but there are fixed louvers that allow some air flow even when the window is closed. All the windows are pre-fabricated and manufactured in French Polynesia.

PROJECT GOALS

Overall Project Goals

In December of 2005 the Ministries of the equipment, earthly and maritime Transportations, harbors and airports within the French Polynesian government proposed an architectural and environmental study aiming to begin a sustainability analysis for the MTR program and conceive a new prototype based on the findings. The main objectives of this study are:

- The acquisition of data on climatic performance of the existing MTR construction
- Usage of these data for the research of the modifications to improve the existing MTR with focus on consumer savings of energy and water.
- The improvement of the dwelling comfort, by the incorporation of sustainable techniques.
- Identification of the ways that imported construction materials can be replaced by local resources.
- To oversee the construction of the proposed prototype.
- The evaluation by comparative analyses of both the existing MTR design and the new prototype.
- Estimation of the economical and ecological impact of the modifications.
- Realization of a synthesis document of the entire study that could widen the general awareness of, sensitize the public to, and demonstrate sustainable building practices as an example of the eventual possible implementation throughout the territory.

The data for this project are acquired primarily in two ways. Qualitative data are being sought through the use of a questionnaire and a simple poll. Interaction and the consultation of users constitutes and integral part of this study. Quantitative data on energy and environmental conditions are obtained by simulations and sensors. The parameters measured will include both classical energy including electricity, water, and gas as well as comfort parameters including temperature, humidity, luminosity, and the presence of suspended particles. The project is being carried out in two phases.

Tropical Architecture has taken on the management of the project and Madelaine Fava will be the lead architect. The University of California's Gump Research Station on Moorea is providing the land for a side-by-side comparison of the current MTR design and the new prototype with station manager Neil Davis acting as the project's financial officer. The Association Te Pu Atitia[4] is conducting the surveys and polls in a sensitive manner, with Hinano Murphy as the primary author. The French Polynesian Ministry of Equipment is providing technical assistance. The University of California at Berkeley is providing graduate student assistance with the computer modeling, data collection, and prototype design. The members of this team include Carrie Brown and Timothy Moore in the Building Science Group (Architecture Department), Bret Harper in the Energy and Resources Group, and Erika Parra in the Mechanical Engineering Department.

Team Goals

Our team has a dual goal in order to accomplish things on two different time scales during this project. First we were asked by the Tahitian equipment ministry to help them make the MTR more appropriate for the tropical climate. Because we are using government money to support this study it is important to produce cost-effective, short-term, and tangible results. As part of our classes focus, however, we also wanted to make the design more sustainable. Sustainable housing creates energy efficient and healthy homes, while respecting and helping the environment, which are also long-term goals of the current government as it seek more energy and material independence. Since there was plenty of overlap between our goals we have been able to work together toward a commercially viable and immediate solution while also gaining valuable insight on how to design a more sustainable and lasting solution.

[4] The Association is a native Tahitian group that is interested in utilizing traditional Tahitian knowledge.

During the spring semester we identified three specific goals:

1. Model the existing MTR in Energy-10 and Virtual Environment including
    a. A baseline model with input geometry and materials properties
    b. An analysis of thermal comfort based on climate, materials, and two representative infiltration values both with operable windows open and fixed vents only.
    c. A ventilation CFD model with operable windows open, simplified surface temperatures, and people for the two possible conditions of a light wind and no wind.
2. Experiment with the above models to inform proposed design changes including
    a. The addition of roof insulation
    b. The addition of a ridge vent and or cupola option
    c. The use of a modified materials set as noted below
3. Propose an integrated and locally sourced and/or manufactured materials solution set including, at very least
    a. A replacement for the treated wood structure
    b. A replacement for the wall infill panels
    c. An option for achieving a more insulative roof.

MATERIALS RESEARCH

The goal of our materials research was to find resources that make the house cooler and could be manufactured affordably and locally. From the beginning we suspected the poorly ventilated metal roof was the source of most of the excessive heat in the house and focused our efforts in this area. The problem is that the simple metal roof is extremely cheap to produce and install. Our prototype cannot exceed 15% of the cost of the existing design or $69,000. If we were going to either replace the roof material or make the design more complex by adding ventilation we have to save money on other aspects of the design. The most expensive element in the house is the Douglas fir wooden frame, which arrives from Oregon. Our strategy is to replace this wooden frame with locally sourced material in order to save the majority of this cost and use this leeway to design a better roof. There are many renewable options available that could replace the current wooden frame including coconut, Caribbean pine, bamboo. We are also considering composite materials such as recycled plastic.

Coconut is our prime choice because it is currently the most abundant of all our options. Small coconut tree plantations have been a part of French Polynesia for a long time and a stock of mature and readily obtainable coconut trees already exist. The local agriculture ministry has already confirmed that there is enough wood available to supply the MTR project.[5] The reason coconut wood is not currently used as a commercial building material is because it is more dense and therefore harder to cut than soft woods. Coconut, however, is the traditional building material Fiji, the Philippines, as well as Tahiti. In order to use coconut we would have to bring in people who know how to work the wood and set up a small sustainable business to supply the wood to OPH.[6] The local government sponsors a contest for new small sustainable businesses because creating jobs is on of the foundations of sustainability.

Perhaps an easier thing to do would be for us to simply replace the Douglas fir with local available soft wood such as Caribbean pine. The reason OPH does not currently use Caribbean pine is that they say quality is lower and the supply is less reliable than their dealer in Oregon. Thus improvements to the local lumber industry must be identified and implemented in order to pursue this option.

A bamboo frame is another biomass option we are considering. Bamboo is the preferred building material in the tropics because it lighter and stronger than soft woods and more importantly grows quickly in all tropical regions. There is substantial evidence that bamboo can be made resistant to mold, rot and termites, but this will have to be field tested to compare it's resistance directly with an existing MTR. At that point we would also have to establish a bamboo plantation capable to growing the required amounts necessary for the MTR project because it is not currently an abundant plant, but we estimate this could be done within 2 – 5 years.

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[5] We need 16 cubic meters of wood per house x 500 houses per year = 8,000 cubic meters of wood per year.

[6] Office Polynesien de l'Habitat is the ministry in charge of building low cost housing.

In some applications these organic materials may not be durable enough in our challenging tropical climate. Thus we are also considering composite materials such as recycled plastic, which is more resistant to mold, rot, and termites. No recycling facilities currently exist in French Polynesia, but recyclable plastic waste is separated and exported to New Zealand. No long term contract exists though so new terms are negotiated every time the French Polynesian plastic arrives in New Zealand. So far the relationship has been reasonable, but the government fears that they are vulnerable to the whims of the New Zealand recycling company. Establishing a plastic recycling business locally would create a local market for the waste material and allow for local quality control of building materials. We have not yet been able to determine the economies of scale involved in recycling plastic.

Once we are confident that we can cut costs by replacing the frame of the MTR we can focus on designing a better roof. To begin we considered traditional Tahitian architecture, which has evolved in a same climate using locally available building materials. The “fare taupee”, or houses with two arched roofs, had a wooden floor and a kind of verandah at the end. The “fare hau pape” was the simplest dwelling, rectangular in shape with the same floor and a two-sided roof. Two poles mounted at each end of the house held up the main roof beam. The roof was made from rafters attached to the beam and notched to another beam at regular interval. The extended roof formed a small overhang (Polynesian Architecture).

Figure 1: A simple rectangular "fare hau pape" built on the ground or over water (left) and a “taupee fare” (right). Drawings by J. L. Saquet

The roof was thatched using Pandanus leaves, which is an ideal material for roofing because it does not trap heat the way a metal roof does. The problem is that a pandanus is expensive and must be replaced every 5 – 7 years. Because only a limited number of people still know how to weave it correctly, a market for panduanus roofs is only accessed by resorts and wealthy residents who can afford to maintain the tropical looking roof. Locals buy MTRs because they want materials that are low maintenance and will last a long time. MTRs are the cheapest option residents have for durable and permanent housing. Those who cannot afford MTR must characteristically pull together scrap cinder blocks, corrugated metal, and plywood to construct makeshift homes. Thus, even though the current MTR design can be uncomfortable to live in when it is hot it has value as a permanent dwelling and status symbol amongst the poor.

Metal roofs are hard to beat from a lowest-cost perspective so we are focusing our efforts on improving the design of the existing metal roof. But if we are able to save enough money by substituting alternative building materials we are also considering an ironwood shingle roof. Ironwood roofs are very durable with conventional lifetimes exceeding a meal roof. Like coconut, ironwood trees are also prevalent throughout French Polynesia but they are a hard wood that is hard to cut. A company in Hawaii has had success with manufacturing and marketing modular ironwood shingle roofs.

CULTURAL RESEARCH

Security issues are also quite different than in an American residential area especially for beachfront homes. Along the coast there are a lot more people passing by who do not necessarily live in that community, while in the valleys the neighborhoods are more isolated and outsiders are much more visible. In both areas people will "borrow" things from the house freely, as is the traditional way, but the difference is that along the coast these people will often be strangers. A change of paradigm has occurred both as more foreigners move to French Polynesia and as locals accumulate more possessions they consider to be theirs. Now homeowners like the ability to lock up their possessions, particularly when they are not home.

A typical rural Tahitian family's day is very different from an American day. They normally rise around 4 am to cook a large breakfast of coffee and fish. This is the main meal of the day. Everyone leaves the house by 6 am when the father usually goes to work while the mother take the children to school, which starts at 7:15 am, before going to work. After school gets out at 2:30 pm the children return home either with the parents or shortly before them. Cooking, housework, and showers all take place before a simple dinner, which is eaten around 5 pm. Traditionally they will go to bed as soon as it gets dark between 6:30 – 7 pm. As more families acquire television, however, some families will stay up an hour or two longer, but everyone on average everyone is in bed by 9 pm.

ENERGY AND WATER DEMAND

The cost of electricity is about $0.375US per kilowatt -hour. The average French Polynesian household consumes about 9 kilowatt hours per day or 270 kWh per month, however, this figure includes households both with and without air conditioners, which substantially add to electricity demand when they are on. Residents have confirmed that indeed their electric bills are a little more than $100US per month.[7] Aside from air conditioners, which are not common among lower class families, the only major electrical load is refrigerators, though more people are also getting freezers as well. Other common intermittent electrical loads include fans, irons, lights, TVs, and washing machines. Irons are characteristically used for all clothes regardless of material or purpose. A nightlight is ordinarily left on all night. TVs are normally only used between 7 and 9 pm. Radios are frequently used throughout the day, but present an insignificant electric load. Few people own dryers because clothes lines are a ubiquitous feature in Tahitian residences. All cooking is either done with charcoal, gas, or wood rather than electricity with the majority being used in the early morning. All hot water heaters use gas which is used mostly in the afternoon. Residents typically are only active in the house between 4 am and 6 am, and again between 2:30 pm, and 9 pm. The major exception are residences with elderly and very young who are often home during the day, but these occupants are generally outside and do not consume a significant amount of electricity. Initial polls suggest that MTR occupants would be receptive to the idea of using and maintaining a renewable energy system

[7] Many people do not pay their electric bill because they claim the electric company owes them money. We have been unable to determine whether this is true or why they believe this.

The typical Tahitian household uses around 200 - 300 Liters of water per day, primarily because most occupants take at least 3 showers per day. They also have a habit of rinsing everything both before and after they use it. Water will often be left running even when no one is using it. The exception to this is on the atolls where residents are conscious of water use because there is less fresh wash water available. American style toilets are widespread and use about 1 gallon (3.8 L) of water per flush.

SIMULATION OVERVIEW

Scope and Background

The scope of dynamic simulations for this project comprised learning about the thermal and natural-ventilation behavior of the current MTR design and testing changes to that design. The current design of this prefabricated kit house—now provided as subsidized housing for thousands of low-income families throughout French Polynesia—appears, in many respects, more appropriate to a mild European climate than to the tropics. Our intent was to test this hypothesis, determine the magnitude and principal sources of undesirable thermal conditions within the house, improve our understanding or heat transfer pathways within the house, and begin to test modifications to the design that might alleviate undesirable capture, transfer, and retention of thermal energy.

Summary of findings

Through simulation, the performance of the existing design has been studied, and both effective and ineffective aspects of the design have been uncovered. Simulation results support the hypotheses that the design is poorly suited to tropical climates and that there is significant opportunity for improvement.

What we have learned thus far will directly support the two primary goals of the larger project through specific design recommendations:

1. revisions to the current production kit house design for improved thermal comfort
2. design of a new prototype house to eventually replace the exiting design

METHODS

Dynamic simulations were used to explore the thermal and natural-ventilation behavior of the current MTR design and to test changes to that design.

Weather and Climate Data

Source and Limitations

Accurate, location-specific weather data is prerequisite to simulating the behavior of a building. Data for Tahiti was supplied by the provider of the simulation software used for this project. While the specific source was not given, the data is assumed to have been recoded at the Tahiti airport. The average-year weather data file was prepared using Meteonorm, a European industry standard weather data file development tool that allows numerous years of weather data to be combined into a single representative average year. Typically, the input for this would be 20 to 30 years of data, however no information was made available regarding the duration of the original data set. More information on the source, duration, and preparation of the data would be desirable. However, given the nature of both the regional climate and the design analysis at hand, this should not have a significant impact on results, conclusions, or design strategies. That said, it is worth noting that the average-year data file tends to eliminate anomalistic days from the original weather data, so it is possible that results and conclusions might not account for a small percentage of outlying climate conditions. With regard to microclimates, the team has no data yet but will be recording actual conditions at the Gump Field Station test site on Moorea.

Trends and Characteristic Conditions

French Polynesia is located 15S 140W, more or less due south of Hawaii and about half way between South America and Australia. The climate can be described as tropical with the summer months occurring December through March and the winter in May through September. The summer tends to be humid, rainy, and somewhat hotter, while the winter is relatively dryer, sunnier, and slightly cooler.

Wind

Although wind direction varies significantly for local microclimates (there are numerous bays, ridges, hills, valleys, and ravines ringing the edges of these volcanic islands) and, in some cases from one island to another, available data indicates prevailing winds from the east and northeast as shown in the figure below.

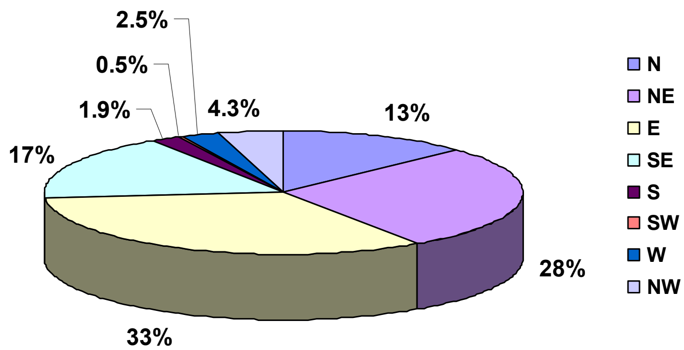

Figure 2: Distribution of wind direction over a typical Tahitian year (from weather data file)

Wind direction (hours in range)	Prevailing wind direction (hours in range)	Wind direction (hours in range)
270–45 degrees E of N	45–135 degrees E of N	135–270 degrees E of N
2,149	5,484	1,127

Table 1: Distribution of wind direction over a typical Tahitian year (from weather data file)

Wind speeds tend to be moderate. Mean wind speed in a typical year is approximately 5 mph. For the hours of 11:00 AM and 3:00 PM, when wind is most critical for natural ventilation of midday heat, in a typical year:

- 42% of these hours have wind speeds below 5 mph.
- 45% of these hours have wind speeds between 5 and 10 mph.
- 13% of these hours have wind speeds over 10mph.

While wind speed variations across French Polynesia can be significant on any given day, actual weather data and trends appear to be aligned with the data presented here.

Cloud Cover

Available data suggests that cloud cover is prevalent. Our weather file indicates that, in an average year, the sky is fully overcast more than 40% of the time while skies are clear on the order of just 23% of the time. Typical cloud cover is presented in Table 2 below. Coverage is measured in oktas (eighths of the sky covered in cloud). For example, cloud cover of 8 oktas means that the sky is fully overcast and 0 oktas means the sky is cloudless.

	Cloud Cover	Day	Night
		6am-6pm	6pm-6am
Clear	< 2 oktas	23%	20%
Overcast	> 7 oktas	41%	41%

Table 2: Cloud cover data from weather file.

Even with the tendency towards substantial cloud cover, global solar radiation remains relatively high the majority of the midday hours in a typical year. The area experiences a flux greater than 200 BTU/hr-ft^2 (630 W/m^2) for 51% of the time between the hours of 11:00 AM and 3:00 PM during the year. Midday hours above 300 BTU/ht-ft^2 (950 W/m^2) are not uncommon.

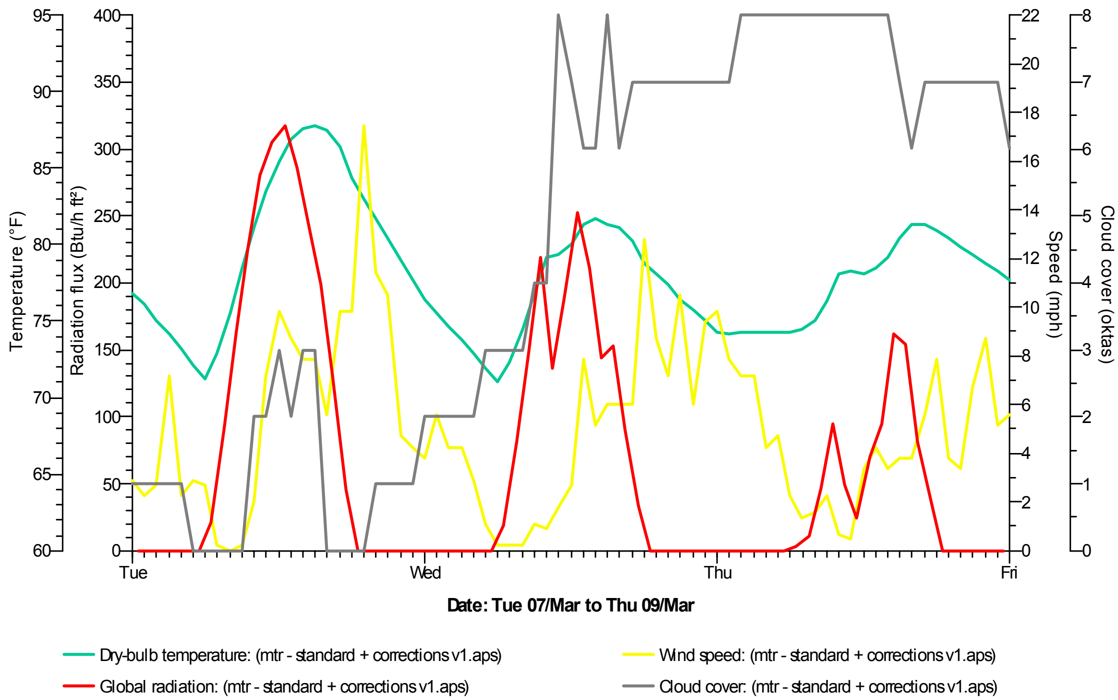

Figure 3: Plotted weather conditions for a series of three typical summer days shows a rise in both ambient temperature and wind speeds following the midday peak solar radiation. The magnitude of both effects is reduced by the presence of cloud cover.

Site

An MTR type 4 house of the existing design will be built on the Berkeley Gump station site in Moorea. The chosen site has the front of the house (the side with the porch) facing northeast. The orientation of the house with respect to wind and sun within the simulations was set to match that of the actual site. The construction site, described elsewhere in this report, is relatively open, with a number of tall palms and a hill rising at the behind the location for the house. As described in the Next Steps section, the actual house will be used, as fitted with sensors and data loggers, to calibrate the simulation model. The completed structure may also be sued to test the proposed modifications to the existing kits. Weather data influenced by the site microclimate will be obtained to support accurate calibration of the computer model.

House

A model of the MTR type 4 is modeled within the Integrated Environmental Solutions (IES) Virtual Environment software, which will be described later. The house and floor plan are shown below. The design is a 3rd generation MTR with three bedrooms plus a main living room (thus the "Type 4" designation). Other floor plans with one and two bedrooms exist. This generation does not have an outeau or Dutch-gable-like vented space at the roof ridge as the previous generation had. It does, however, include large slatted vents under the eves at the top of the exterior walls (just above the top plate and between rafters). For the purposes of constructing the roof in the simulations, this has thus far been modeled as a large and continuous soffit vent running the full perimeter of the roof.

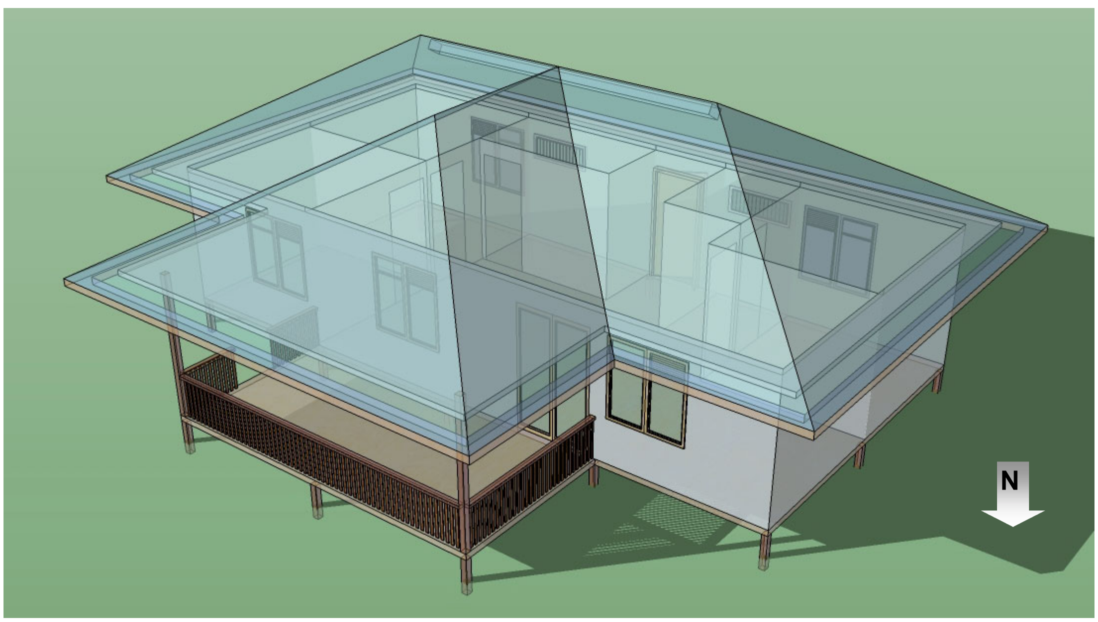

Figure 4: Illustration of the existing MTR design as modeled in Virtual Environment, including continuous soffit vent around the roof perimeter

Figure 5: MTR floor plan, as modeled in Virtual Environment with all interior doors fully open

Energy10 Modeling

While our main analysis has been and will continue to be done in IES Virtual Environment (described below), we decided to also model the house in Energy10. Energy10 is a program that we were already quite familiar with and could get results relatively quickly. It has a limited number of zones and various thermal simplifications, but has been demonstrated to give relatively accurate results for smaller structures and passive solar design, in particular.

We had to accommodate for several challenges. First, we were unable to find a weather file in either Energy10 format or TMY2, a format easily converted to Energy10 format using the Energy10 WeatherMaker utility. So, we extracted the weather data from the Virtual Environment file, converted the units and format and created our own file. Therefore, both models used the same weather data.

Second, we were using Energy10 v. 1.7. In this version, a heating, ventilation, and air-conditioning system of some type must be assumed and there is no input specifically intended for natural ventilation. So, we modeled with an HVAC system, but with settings such that it would never turn on. To approximate natural ventilation, we altered the air changes per hour (ACH).

For the loads, we had originally assumed 4 adults, plus the appropriate cooking and hot water loads. However, after Bret's trip, we realized that most cooking and showering was done outside, which would affect the internal gains. Therefore, we decreased the internal gains in our model to reflect those of a typical Tahitian family.

Finally, a number of the materials that we needed to model were not in the library. So, using ASHRAE Handbooks and Mechanical and Electrical Equipment in Buildings, we created new materials and construction cross-sections and added these to the library.

IES Virtual Environment Modeling and Simulation Tool

The IES Virtual Environment (VE) tool is actually a suite of modules including capability for: 3D modeling and construction materials assignments; lighting, electrical, and mechanical systems design; solar, daylighting, airflow, thermal, and energy systems simulations; life-cycle cost analysis, and computational fluid dynamics. The development of Virtual Environment is being lead by Don McLean, one of the two fathers of ESPr, a widely used European simulation tool broadly similar to DOE-2 in North America. Applicable standard validation tests have been competed and several large consulting engineering firms in Europe, Canada, and the United States have recently adopted VE as their preferred tool. That said, the standard validations cover very predictable and well understood test cases, which do not necessarily translate to accurate results for all possible applications of the tool's numerous capabilities.

Given its capability for integrated multi-zone thermal and bulk airflow simulations, as well as CFD analysis, IES-VE appears ideally suited to the requirements of this project. While there are other tools with these various capabilities, they tend to either be separate from one another or lack 3D modeling, appropriate integration of thermal and airflow analysis, or practicality.

Virtual Environment Modules

Virtual Environment is a self-contained multi-functional tool comprising several integrated functional modules. A Windows based interface supports navigation through the various modules and functions. The modules used for this analysis are listed in the table below. Other modules not used include lighting design, cost analysis, evacuation simulation, and modeling of mechanical and electrical systems. Within the 3D modeler and CFD tools, there is also a component modeler that we will eventually use (but have not yet used) to simulate individual occupants, lights, and the refrigerator as heat sources at specific locations within the space, rather than as evenly distributed internal loads (as we have modeled them thus far).

Module	Description
3D Model Builder	Building geometry, materials, opening sizes, and glazing are defined
Thermal	Construction materials and internal loads are assigned. Design day load calculations and dynamic simulations are performed. The results view allows inspection of all significant parameters for each hour simulated, including details such as surface temperatures.
Multi-zone bulk airflow	Nested within the thermal module, this module assigns opening types and schedules for ventilation of and flows between spaces.
Solar	Calculates shading for building and roof geometry and sun position. It also determines which surfaces will receive direct solar radiation.
CFD	Calculates and visualizes flow velocity, pressure, and temperature through space

Table 3: Virtual Environment modules used

The thermal and solar modules are closely linked to accurately determine solar gain and heat transfer through the building envelope and between zones. Materials properties, internal loads, and profiles or schedules for those loads were also assigned here.

Given the emphasis on natural ventilation, the multi-zone bulk airflow simulation module was essential. It uses a zoned airflow model to calculate bulk air movement in and through the building, driven by wind and buoyancy induced pressures and constrained by the airflow characteristics of openings (windows, doors, holes, and scheduled variations thereof).

The Computational Fluid Dynamics (CFD) module numerical provides simulation of fluid flow, heat transfer, and mass transfer processes. The objective is to gain greater understanding of the likely air flow and heat transfer processes occurring within and around building spaces, given specified boundary conditions, including the effects of climate and internal loads.

Simulation Approach

3D Modeling of Key Design Elements

The covered porch of the existing MTR design was included to accurately model shading. The large slatted vents under the eves at the top of the exterior walls (just above the top plate and between rafters) in the existing MTR design were modeled as a large, continuous soffit vent running the full perimeter of the roof as shown below. The windows in the living space and bedrooms are single-pane glazed sliders with a section of permanently open louvers, as shown below. These are modeled to have a maximum 40% opening area. The bathroom windows are horizontal openings high on the wall with operable jalousie glass louvers modeled as a 90% opening area. The two-part sliding glass front door is assumed to be 50% open at all times. The solid back door is assumed to be 100% open at all times. For the simulations, all interior doors were removed to maximize airflow. Lastly, the 0.5-m height crawlspace underneath the house was included to decouple the house from the ground and to allow airflow, as would be the case for the actual building.

Material properties for all major components in the simulation were defined to closely match those of the actual design. These included earth coupling at the bottom of the open crawlspace, OSB, plywood, and fiber-cement board used in the floor, walls, and ceiling, single-glazed windows, and the metal roof with appropriate solar reflectivity and emissivity for the roof surface and the radiant barrier material just beneath it. The table below summarizes these components and their properties. As specification for the current version of the design appear to have changed from plywood to cement board for some floor, wall, and ceiling elements since the plans that we received, we plan to update these when actual materials are confirmed.

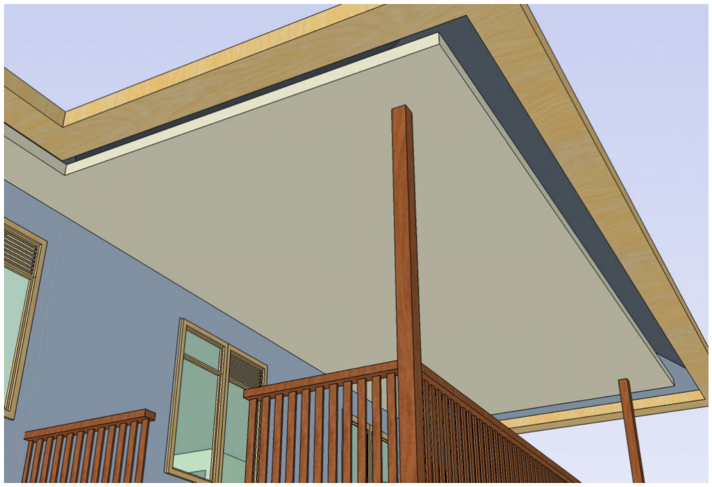

Figure 6: Continuous soffit vents as modeled on the entire perimeter of the roof.

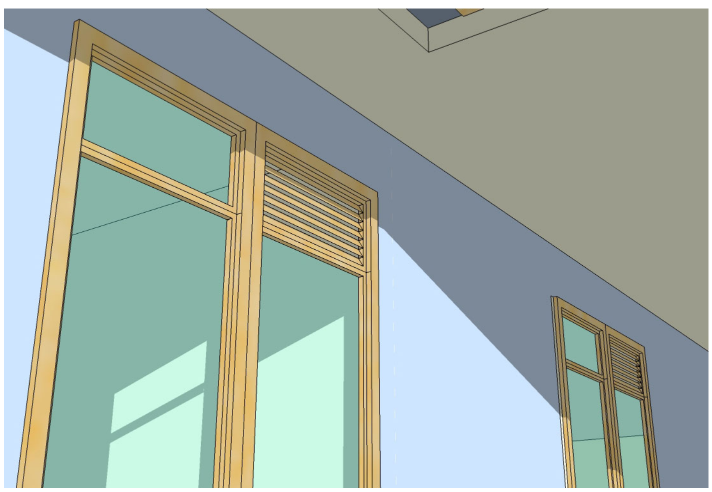

Figure 7: Primary windows consist of single-pane glazed sliders and permanently open louvers.

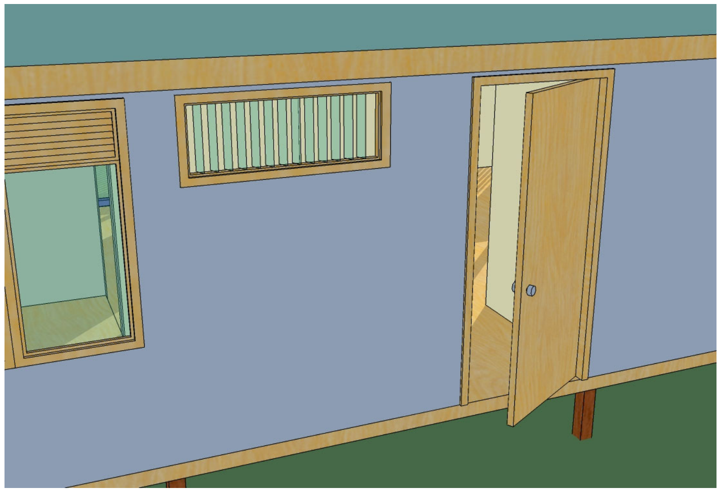

Figure 8: Fully open back door and bathroom jalousie vent window

Item	Materials
Roof	Uninsulated metal roof + aluminum radiant barrier (2.5 mm air gap between)
Ceilings	¼" plywood painted white (relatively low mass with high-emissivity surface)
Floors	¾" high-density OSB floors (density equivalent to fiber cement board)
Internal partitions	5/8" plywood interior wall (moderate density, could also be lightweight Fibro)
External wall	5/8" fiber-cement board (exterior cladding) + 2x4 studs + 5/8" plywood wall
External glazing	Single clear float glazing

Table 4: Materials used for the simulations.

Internal Loads

As Polynesian families tend to be large relative to house size, but spend a relatively large amount of time outdoors, we assumed the three-bedroom house to be inhabited by four adult occupants, 24 hours a day on all days. The thermal loads for each occupant were assumed to be 250 Btu/h (~73 W) sensible plus 200 Btu/hr (~59 W) latent in keeping with a moderate level of activity. This is intended not to represent actual occupancy over time, but appropriate thermal loads for midday conditions when we would seek to have the house support a reasonable average level of occupancy. Because we were most concerned with midday conditions, thermal loads associated with occupants were all placed in the living room space (which includes the kitchen), distributed evenly within that space, and assumed to be constant throughout the day. Other internal loads include a small 350-W refrigerator with a radiant fraction of 0.1. Incandescent lighting at 235 W total with a radiant fraction of 0.85 was included for the evening hours, beginning at 6:00 PM (more or less from sunset until midnight). Both the refrigerator and lighting loads were modeled as being distributed within just the contiguous living room + kitchen space.

Solar Analysis

Solar, or shading, analysis was included in the simulation. The house orientation is as will be the case on the actual construction site for testing. Based on the shading analysis, this orientation appears to be more or less optimal for maximum shading in all but the late afternoon hours. The late afternoon direct solar gain shows up in the results as an elevated late-afternoon temperature in the back bedrooms.

Weather Design Days

To analyze the behavior of the house, two relatively extreme weather conditions were studied. These conditions are within the range of representative days for 30-year average weather based on available data. Particular days were chosen from the weather file to isolate the effects of radiation and wind as described below.

Case 1 – December 3rd – Low cloud cover and low wind

The first case consists of a day with low cloud coverage and little to no wind. Under these conditions, the house would be expected to achieve the highest temperatures. Global solar radiation is high due to the lack of cloud coverage in the midday hours. Wind speeds stay below 2 mph during this period of high radiation.

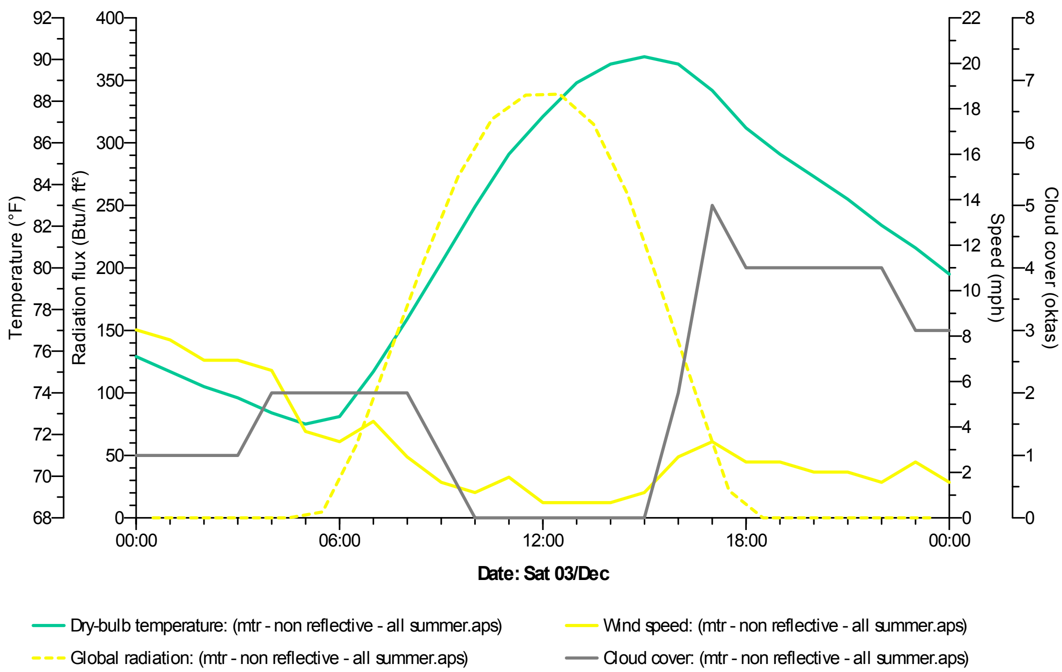

Figure 9: Case 1 – Weather design day with low cloud cover and low wind

Case 2 – January 27th – Low cloud cover and high wind

Because the effects of wind speed and flow through the house also needed to be analyzed, a day where high radiation was accompanied by relatively high wind speeds was also simulated. The intent was to look at temperatures associated with airflow driven mainly be buoyancy and forced convection. While wind speeds are greater, global radiation of this day matches that of Case 1.

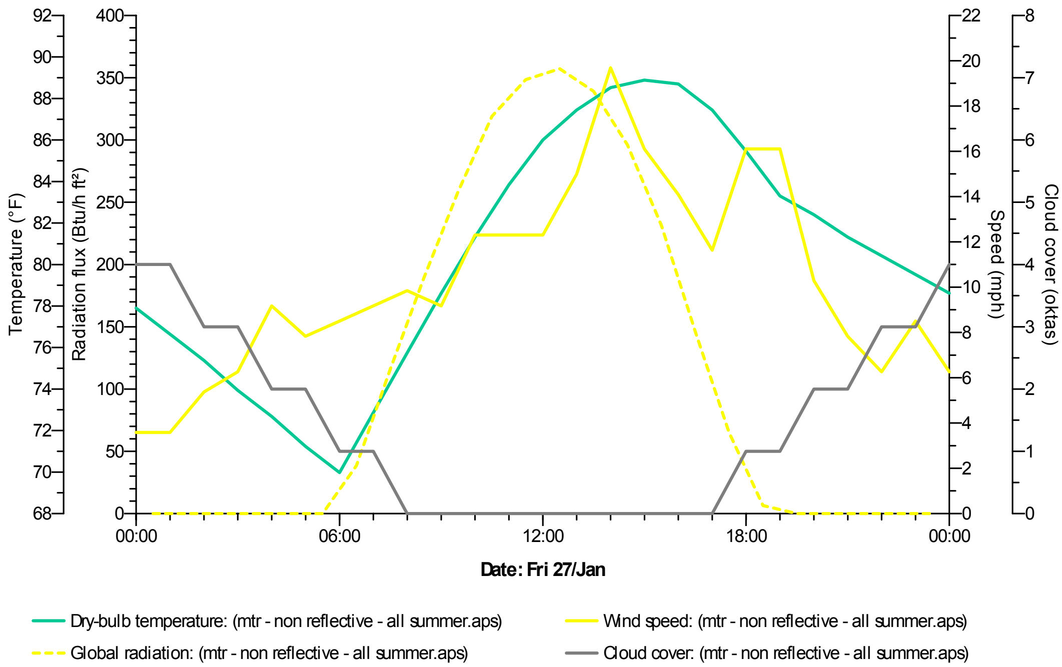

Figure 10: Weather design day with low cloud cover but high wind – Case 2

Dynamic Simulations

Simulations of the house behavior including detailed information on construction materials, window openings, shading, and average hourly weather were performed on the model. Results obtained on the design days listed above were extracted and analyzed. This was repeated for a range of cases both to test the effects of weather on day s other than those finally selected, and to test various changes to the house design, materials, and apertures. Simulations were run for many more cases than could practically be presented here. Most of these runs served as a learning process to define inputs for those documented.

Modifications simulated, in addition to the existing design, included the addition of a roof ridge vent of approximately 1 m^2 total area the top of the roof as pictured below. For all runs including this feature the vent was assumed to be 100% open.

A relatively high-albedo mid-tone roof coating was also tested. Roof coating properties in this case were an emissivity of 0.7 (vs. 0.3 in the standard design) and solar reflectivity of 0.6 (vs. 0.8 for the standard design). Because a mid-tone color (not exceptionally light or dark) was assumed in keeping with actually roof colors observed on Moorea, most of the increased reflectivity is the result of improved solar reflectivity in the non-visible near infrared portion of the spectrum.

Changing the operable window area from 40% to 95% while keeping the window size constant was also explored. This might be made possible, for example, by the use of casement windows. However, we acknowledge that casement type windows would present challenges on the often-cramped sites these houses tend to occupy.

Finally, various combinations of the above changes were simulated. This report includes results for a run that combines all of the changes noted above.

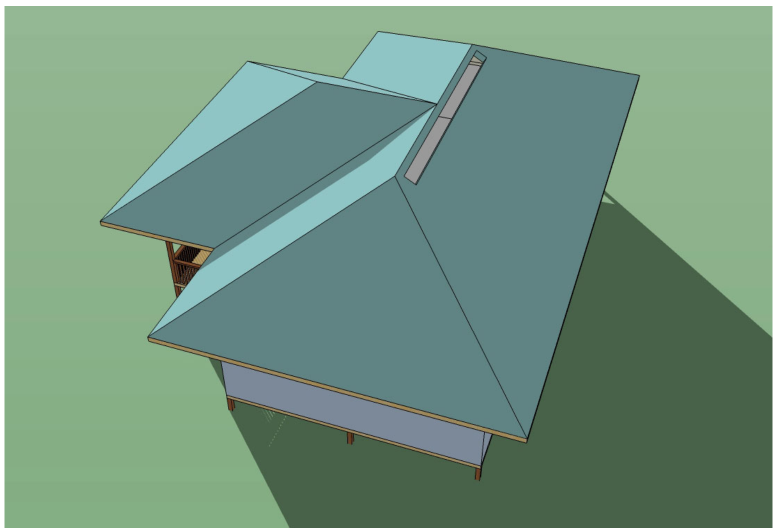

Figure 11: Simulated roof vent location and size

CFD Visualization

Boundary conditions from the dynamic simulation were used to model the air flows through the house. The boundary conditions are taken from the dynamic thermal and bulk airflow simulation, and include results from variables such as wall temperatures, volumetric flow rate, internal loads, solar gains, and inter-zonal heat transfer. This tool helps determine areas of stagnant air where airflow could be enhanced.

RESULTS

Energy10 Results

As noted within the Methods and Next Steps sections, the Energy10 modeling is a supplement to the Virtual Environment modeling that will eventually support simulation of a building-integrated solar domestic hot water system, including an approximation of its affect on thermal conditions in the naturally ventilated occupied space. It is thus of value at this stage in the process to work towards achieving approximately matched results for the tow different simulation tools. As seen in Figures 12 and 13, at 3 air changes per hour (ACH) per hour, which represents a significant airflow for the existing design, the temperature in the house is often 10°F or more higher than that of the outdoor temperature. This is in keeping with results for the Virtual Environment simulations. We suspect that the thermal comfort in the current MTR is due largely to the level in ventilation or lack thereof (in addition to solar gain to the roof zone that is transmitted through the ceiling). Therefore, we also modeled the house in Energy10 at 43 ACH, which is a back-of-the envelope calculation for a value for representing a high rate of natural ventilation. According to results thus far, achieving this level of natural ventilation under even relatively good typical climate conditions in French Polynesia would require significant redesign of the house. As shown in Figure 14. At this level, the inside temperature nearly follows the outdoor temperature, differing only a few degrees at the peak hours of hot months.

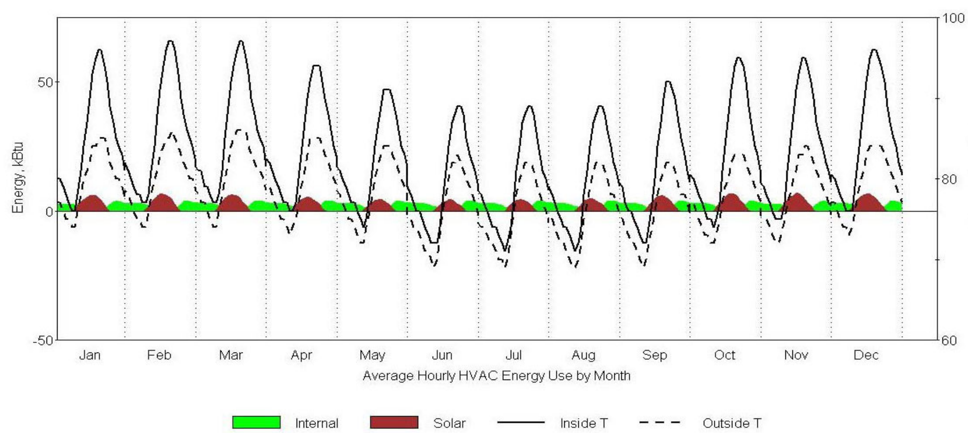

Figure 12: Annual results in Energy10 with ventilation 3 ACH

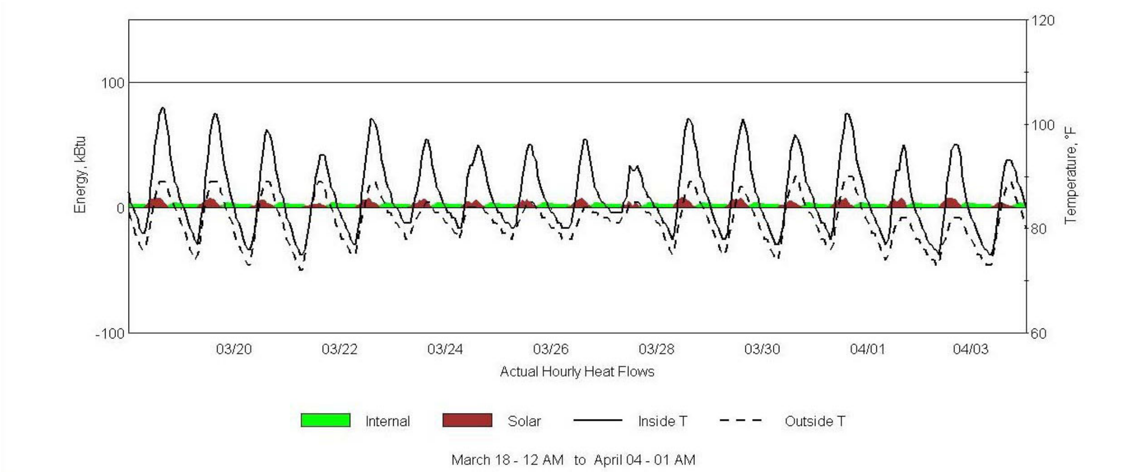

Figure 13: March 18 – April 4th results in Energy10 with ventilation 3 ACH

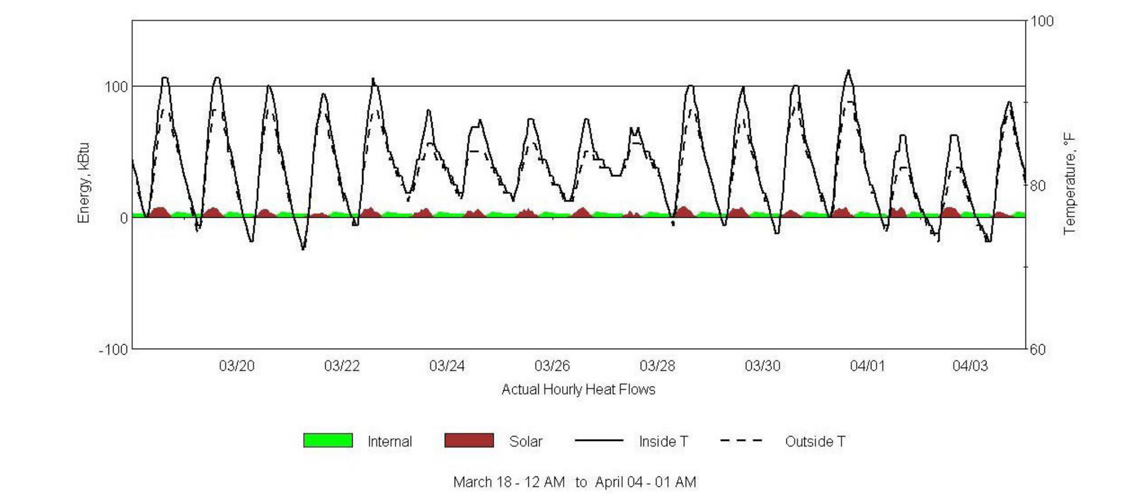

Figure 14: March 18 – April 4^{th} results in Energy10 with ventilation 43 ACH

Virtual Environment Results

The results of the simulations will be illustrated in this section and discussed later in the report. Resulting temperatures of the living room, roof, and bedroom in the North West elevation will be presented for each of the design days. Additionally, air flow through the rooms will be compared for the low wind and high wind conditions.

Modifications Temperature Results

Case 1 – No wind & no cloud cover

Figures 15, 16, and 17. The effect of the design modifications (each represented by a different curve) on temperature in the living room, roof space, and bedroom respectively, are shown on three separate graphs below.

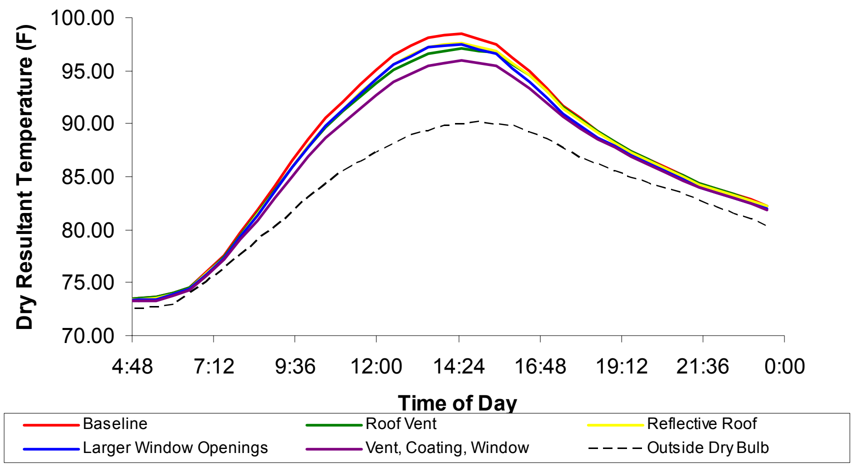

Figure 15: Dry resultant temperatures in Living Room space

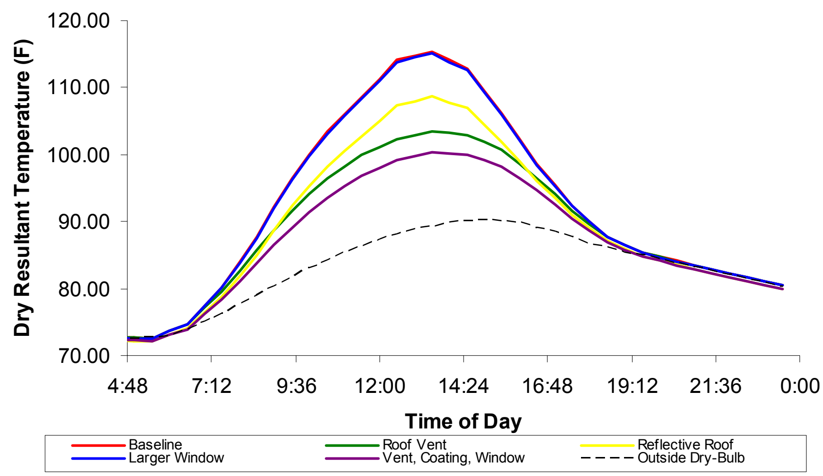

Figure 16: Dry resultant temperatures in Roof space

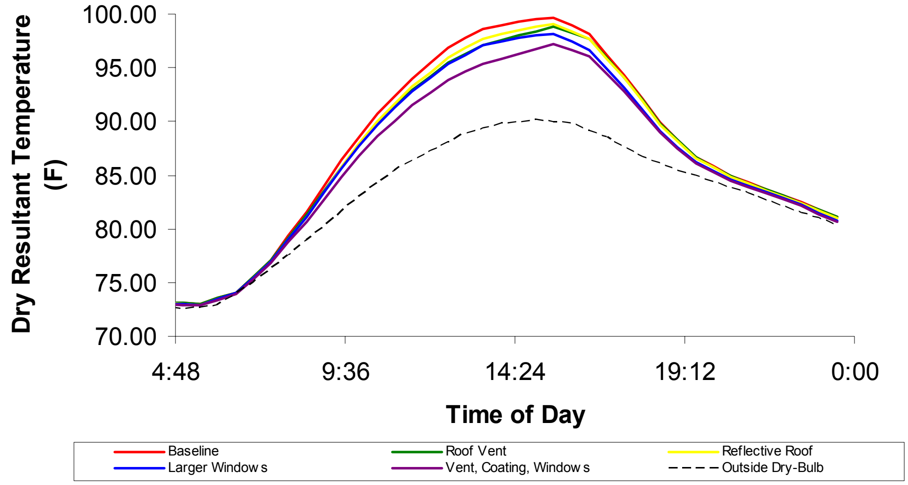

Figure 17: Dry resultant temperatures in Southwest Bedroom space

Case 2 – No cloud cover but high wind

Figures 18, 19, and 20. The effect of the design modifications (each represented by a different curve) on temperature in the living room, roof space, and bedroom respectively, are shown on three separate graphs below.

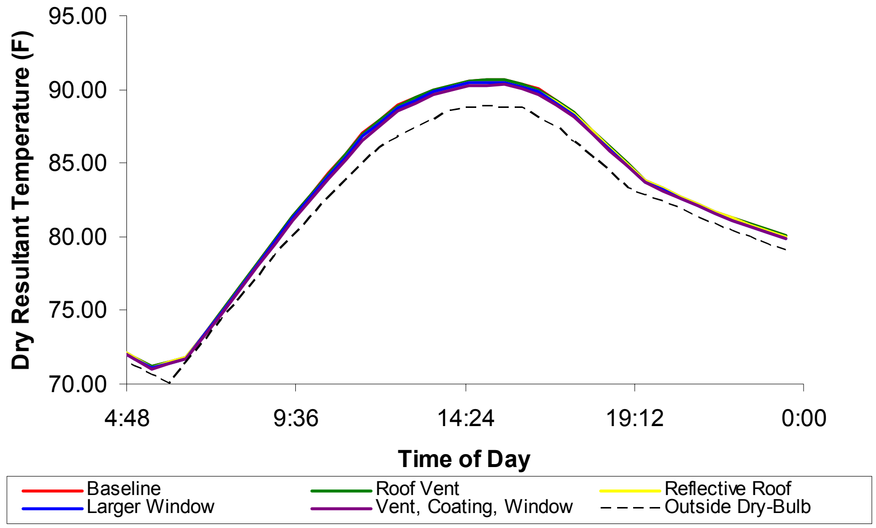

Figure18: Dry resultant temperatures in Living Room space

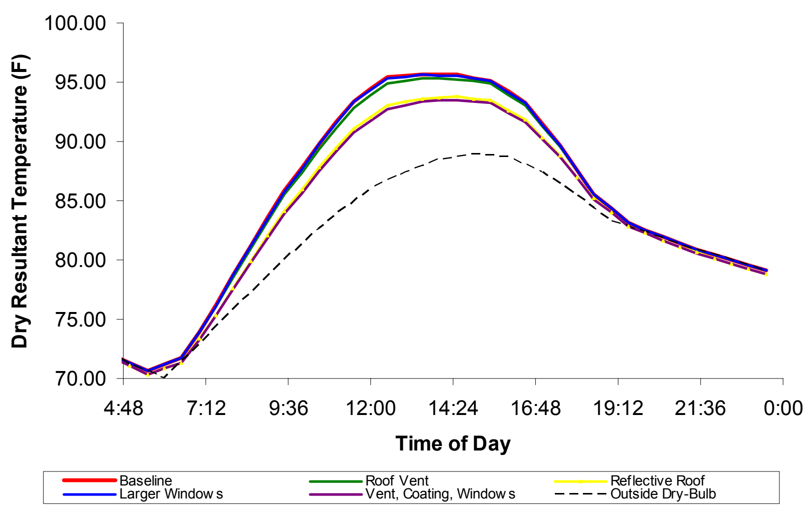

Figure 19: Dry resultant temperatures in the Roof space

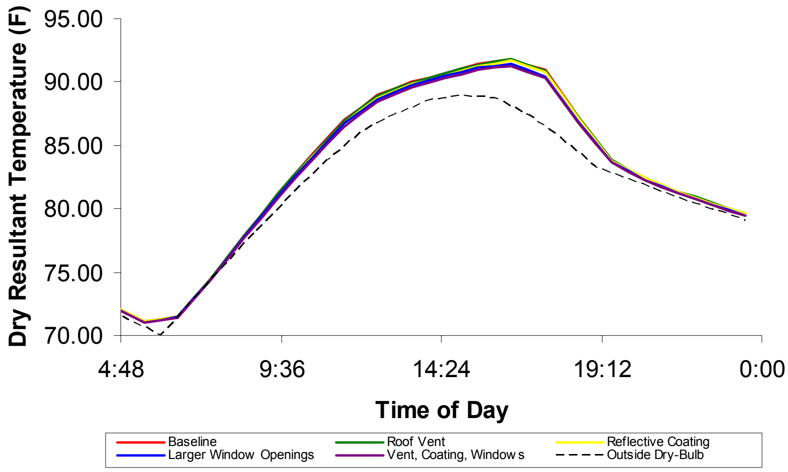

Figure 20: Dry resultant temperatures in Southwest Bedroom space

Flow Results for Modifications

Larger Window Openings

Doubling the size of window openings had some effect, but it is not sufficient to have significant impact. Flow does increase but remains too low, especially in bedroom in northwest elevation where wind does not flow through directly.

	Low Wind (1.1 mph)		High Wind (16.1 mph)	
	Baseline	Larger Windows	Baseline	Larger Window
Living Room (ACH)	0.66	0.79	3.64	5.285
Bedroom (ACH)	0.055	0.13	not modeled	not modeled

Table 5: Modification results in Air Changes per Hour terms.

Figure 21 below shows the flow in ACH in the bedroom discussed for the length of the summer using the weather data. At most, there is a flow of about 0.8 ACH in the current MTR design. Figure 22 shows that increasing the window opening will increase the flow but not significantly.

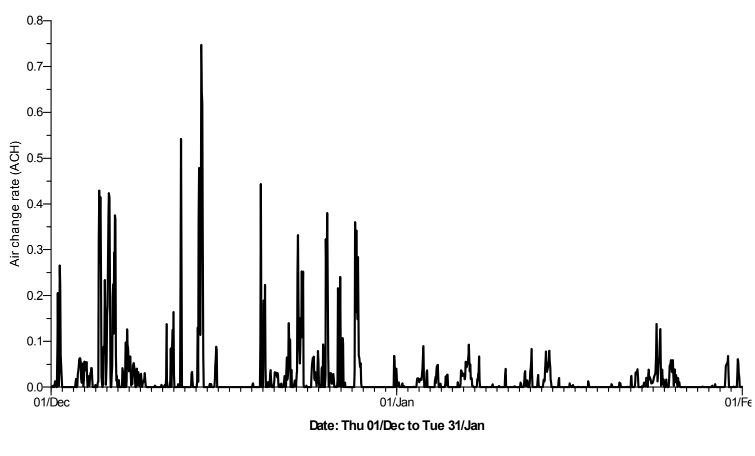

Figure 21: Current MTR flow through bedroom in southwest elevation.

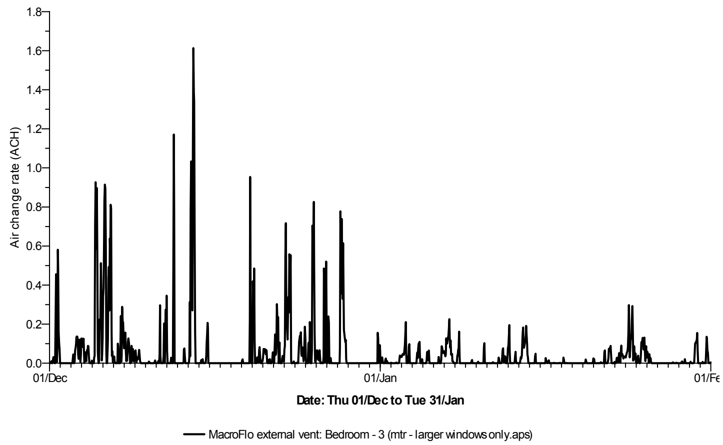

Figure 22: Flow through bedroom in southwest elevation using larger window openings.

Roof Vent

Adding a roof ridge vent showed a more significant absolute increase in the flow through the roof zone (attic space) under low wind conditions. We attribute this to the thermal buoyancy driven stack effect being more effective under relatively still air conditions when there is a build up of heat under the roof. The table below summarizes the results.

	Low Wind (1.1 mph)		High Wind (16.1 mph)	
	Baseline	Roof Vent	Baseline	Roof Vent
Roof space (ACH)	0.185	0.66	2.15	2.37

Table 6. Changes in roof space (attic) ventilation rate with a ridge vent

CFD Model

The figure below depicts the flow through the house under the low cloud cover but high wind conditions at a height of 5' above the floor surface and with the larger window openings modification. The flow varies from completely stagnant to up to 4.5 ft/s near the windows where the wind is flowing through. Most spaces outside the living room have significant regions of stagnant air.

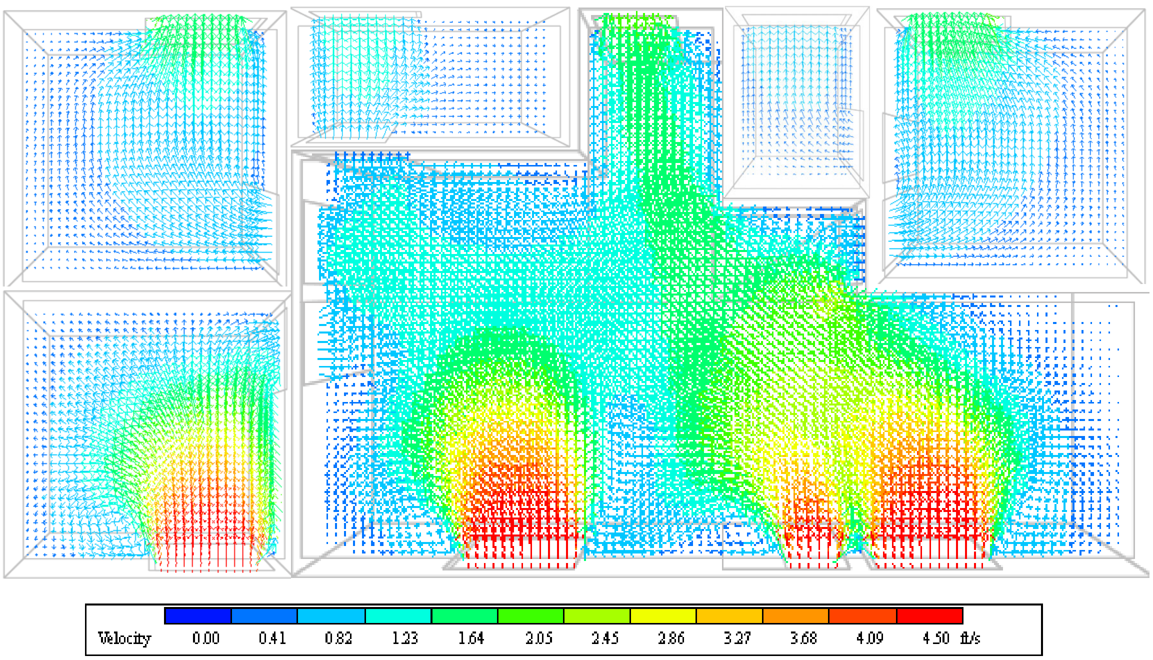

Figure 23

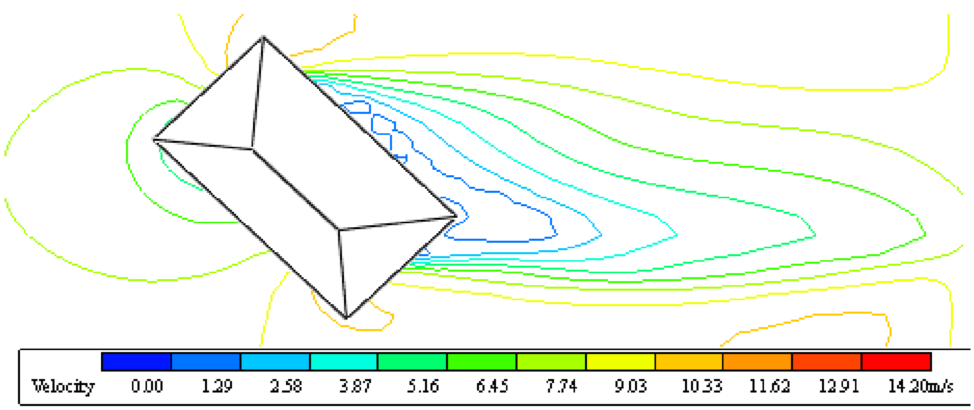

Figure 24

DISCUSSION

	No Clouds, No Wind (%)			No Clouds, High Wind (%)		
	Living Room	Roof Space	Bedroom	Living Room	Roof Space	Bedroom
Roof Vent	14.0	39.4	11.8	1.4	4.9	1.4
Roof Coating	9.3	25.9	7.8	9.7	27.2	7.6
Larger Windows	12.3	1.0	16.3	9.1	0.6	12.0
All the above	27.0	48.4	25.6	17.6	30.5	16.8

Table 7: Reduction in temperature for design changes as a percentage of inside-to-outside temperature difference.

Potential for Design Changes

Adding roof vent would provide greatest benefit on low-wind days if only one change were to be made. Comparison of the roof vent and high-albedo roof coating options indicates that on a day with no wind, the roof vent remains a larger effect as a result of benefits from harnessing thermal buoyancy (stack-effect ventilation). For the high-wind case, the stack effect in the roof space provides lesser effect, as some ventilation of the roof is clearly driven by winds. Counter-intuitively, the larger windows appear to actually have a smaller net benefit on the high wind day. Reasons for this may include better utilization of the baseline, smaller, window openings on the high-wind day, thus there is less to gain on by increasing the opening under such conditions.

Current Modeling Limitations

While its fairly straightforward to change limited aspects of the design within the model, it is somewhat more cumbersome to significantly change the overall design of the house, as this tends to introduce some modeling errors. We currently have a lack of control over weather data files with regard to creating design days to test specific kinds of design changes—*i.e.* to compare a change in design for two different design environmental conditions with only one variable adjusted.

NEXT STEPS

- The following next steps will be carried out overt the summer of 2006:
- Place sensors as described under Monitoring existing house below.
- Calibrate the model of the existing MTR.
- Refine simulations of changes to the existing MTR using calibrated model
- Test design strategies for the new prototype design
- Complete Energy10 modeling of options for integrated solar hot water

Testing will include:

- The installation of sensors and data loggers for temperatures, airflow, and humidity as described below under Monitoring the Existing House. Data collected will, in turn, be used to calibrate the model and to directly inform design.
- Virtual (simulated) and actual changes to existing MTR
- Strategies for new design

Follow-on CFD modeling will be used to:

- Uncover opportunities
- Assess proposed designs
- Inform possible options for modularity
- Inform kit instructions for best sites and orientation per microclimate

Prototype design strategy development (as differentiated from modification of the existing MTR design for ongoing production runs) will include:

- Re-design for better natural ventilation
- Vent waste heat from refrigerator
- Closer look at high-albedo & “double-skin” roof options
- Evaluate nighttime pre-cooling with thermal mass

Some of the possible design strategies and questions regarding airflow to be explored for the design of the new prototype are shown and described in Figure 25 below.

Energy10 Next Steps

For our continuing work with Energy10, we will use a new version that has newly introduced tools for simulating both natural ventilation and solar hot water heaters. We will update the current MTR Energy10 model to this version and create an Energy10 model the proposed design as well, using both natural ventilation and solar hot water. This will be most important for evaluating the potential for solar domestic hot water heating as requested by the architect. Depending on the design, there may also be potential for partially integrating the solar hot water with the building envelope to take advantage of existing roof area—*e.g.,* using currently available very thin, nearly flat, all-metal solar hot water panels with a special high-absorption/low-emissivity coating that can double as roofing—thus also using a hydronic circuit to remove some of the solar load from the roof. In this case, the Energy10 integration of the solar hot water modeling with the complete naturally ventilated building will be of particular value.

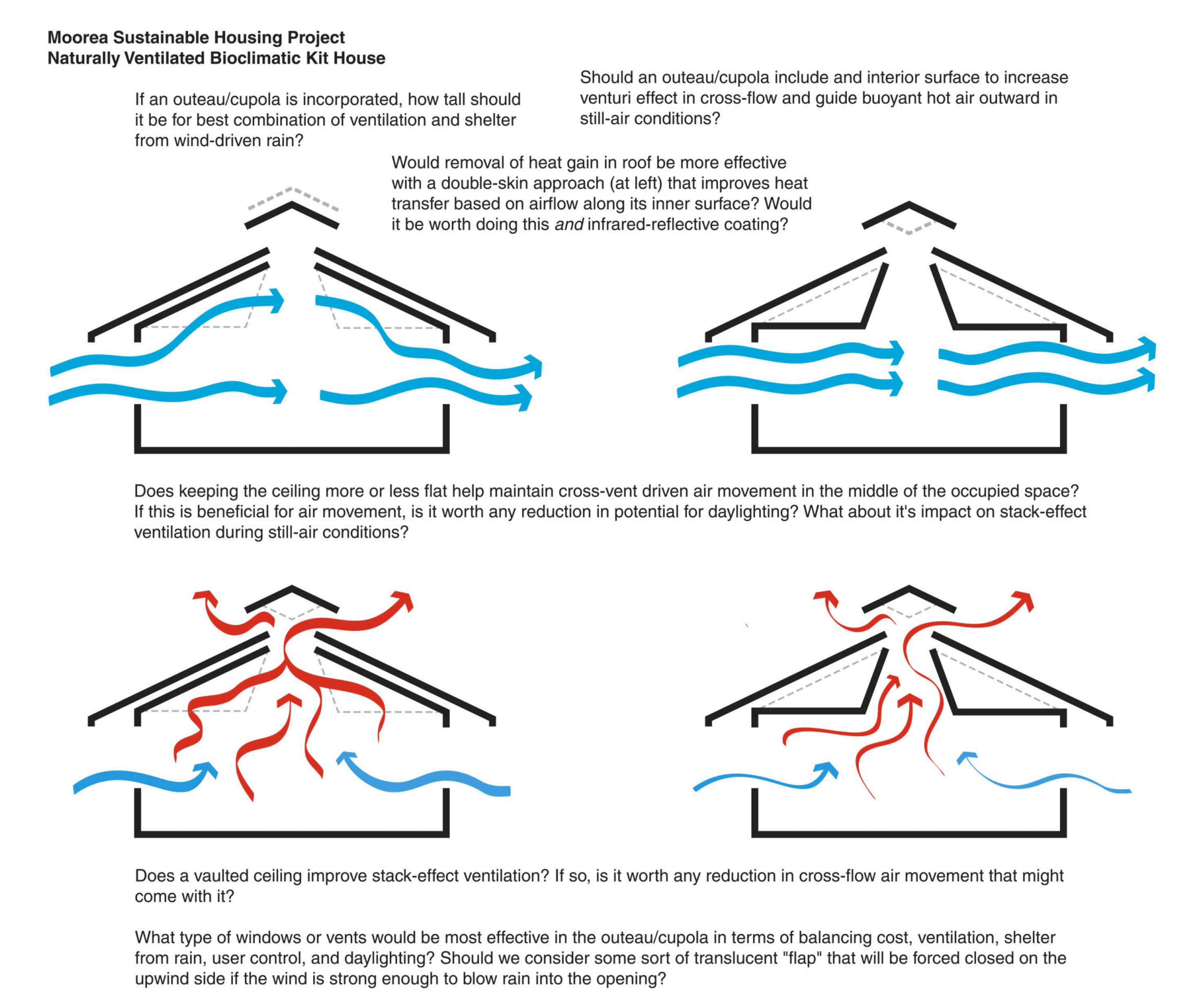

Figure 25. Possible design strategies and questions regarding airflow to be explored for the design of the new prototype

MONITORING EXISTING HOUSE

Overview

We will be monitoring both the existing MTR and the new prototype using a number of sensors placed as described in Figure 26 below. There are already two HOBO Weather stations at the Gump Station that we will be able to use. These will provide us with detailed weather information that will be specific to this year's season as opposed the weather files that we have been using for our model. With the HOBO weather stations, we will be recording:

- Temperature
- Relative Humidity
- Wind Speed / Direction
- PAR (Photosynthetically Active Radiation)
- Solar Radiation
- Soil Moisture
- Barometric Pressure
- Rainfall

In addition, we will be using a number of HOBO data loggers and ICMs (Indoor Comfort Monitor) inside the house, as diagramed in Figure XXX. The ICMs were developed for a previous study at UC Berkeley and measure dry bulb and globe temperature in addition to air speed. The HOBO data loggers will be spread around the house. All HOBO data loggers will record dry bulb temperature, but we will use one with a relative humidity sensor as well so that we can calculate mean radiant temperature for comfort assessment later.

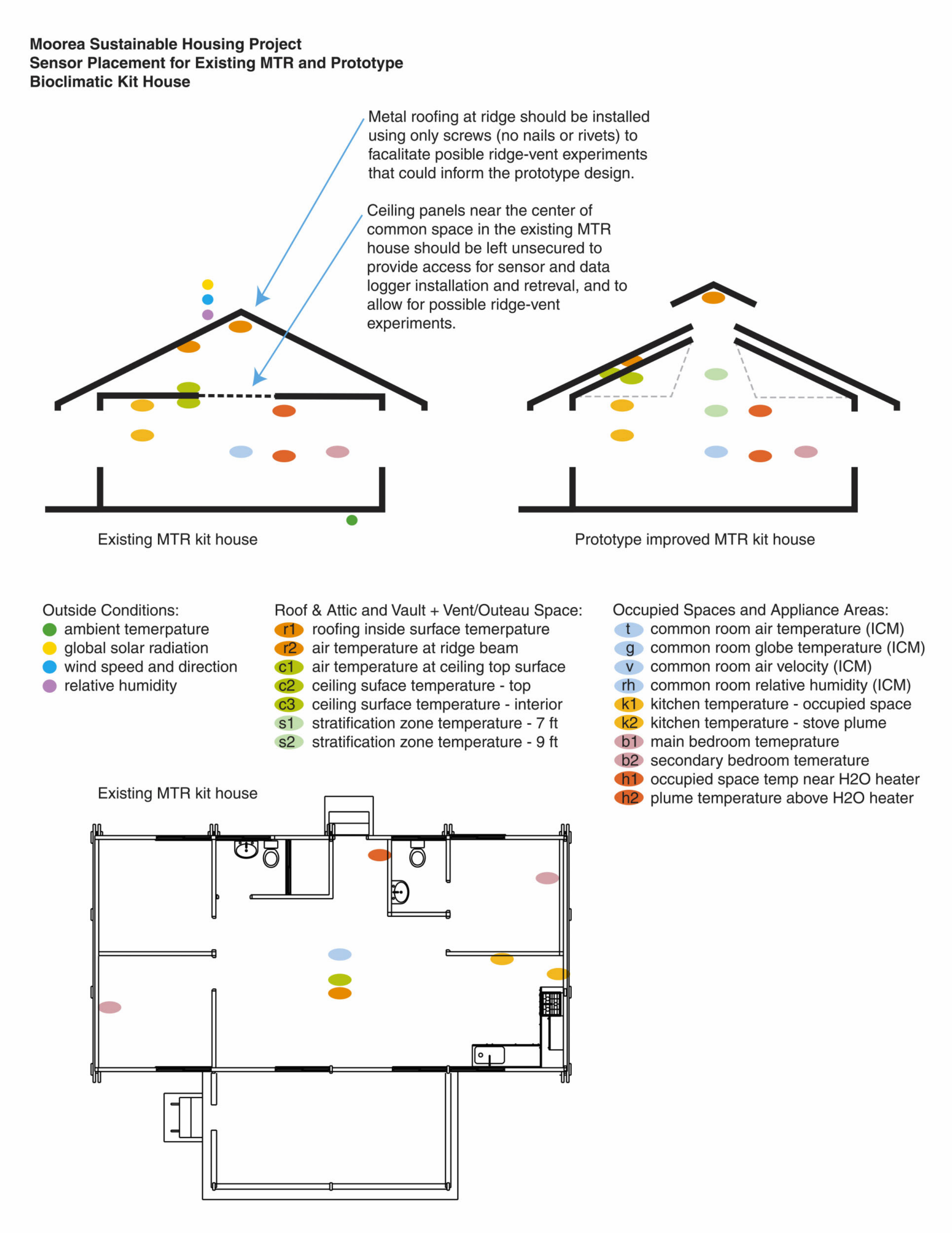

Figure 26. Placement of Sensors in Houses

FUTURE WORK:

We successfully met our semester goals for the project, but we are only a portion of the way through our goals for the entire project. We have all committed to working on this project through next Fall.

We plan to stagger site visits over the next few months so that we have someone in Tahiti as much as possible. However, we will continue to stay in contact through email and teleconferences. This summer, the current MTR will be constructed at the Gump Station site. We will install the sensors and compare this data to our simulations to calibrate our models, while continuing to fine tune them as described in the above sections. In parallel, we will also work with Madeline to prepare a design for the new prototype, while preparing simulations for this house as well. When the prototype design is finalized, it will be built next to the current MTR house for a side-by-side comparison. This will likely occur next Fall and we hope to be able to have someone on site to install to sensors there to ensure that the tests are comparable. Both houses will be monitored through a wet and dry season. The data will be collected and analyzed in order to provide our final recommendations for a new design.

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APPENDIX A: FIELD NOTES

3/28/06

Hey team –

Lots to report, this was defiantly a trip worth taking. I'm going to stick to the project information for this email, but as you may suspect I'm have a great time. Fill you in on the fun later.

I sent along a question sheet yesterday detailing who I am going to try to talk to and what questions I will be asking them. If you have any additions to that sheet before the end of the week email me ASAP. I'm planning to go to Pappete tomorrow to talk to the Forestry ministry about building material supplies. I'm told that bamboo does grow here, but haven't seen any yet so it can't be that common. In any case it is certainly not grown locally. Madeline is especially interested in using coconut and plastic as building materials. There are a lot of old coconut trees that people don't know what to do with because there is no market for coconut other than decorative wood. So there is plenty of supply and creating a small market for coconut wood would be seen as beneficial to the ecology of the island. Madeline wants to use plastic because it will not rot. It is ridiculously hot and humid here. Any building material will have to be very well protected from mold and rotting if it is organic. She sees recycled plastic as an excellent option. She is weary of the idea of using red clay because it may be hard to obtain. Some parts of the island are made of red clay, but it may not be feasible to get it. She thinks using plastic as epoxy would serve as a better binder. She also like the idea of making a grid structured house that can be flexible and rearranged to fit the site. She is big on educating people about winds and how to best take advantage of these winds to keep the house cool. We've been discussing a possible feedback mechanism to reinforce when people are taking the appropriate action to cool the house. The idea of the grid hose is to have sections that can fit doors, walls, and windows interchangeably, which the owners will decide on after thinking the sun and wind on their site.

As for our site I have lots of pictures from different times of the day and during different weather conditions. There are 2 HOBO weather stations near our site and I am trying to get this data for our models. Just from spending time on the sight I've found that the sun hits it about 7 am and site is fully shaded by a ridge/cliff that protects the site from the West by 5 pm. The site for our prototype is generally more shaded that the site of the MTR especially in the early morning. There are half a dozen coconut trees which provide intermittent shade throughout the day, but also drop really big coconuts from a height of 50 feet or more, which we will have to keep in mind. The wind is very light and comes from the bay (East) throughout the day.

If I get a chance I will also try to talk to the ministries of agriculture, recycling, industry, sustainable development, equipment, statistics, fire, and urbanism. I'm told that our prototype will not only be used to design a new kit house, but also will be used as a case study by the government for making other buildings more sustainable and giving the sustainable development ministry some direction to take the nation in as a whole. So that means our project has a lot more people interested in it then I originally thought. The Tahitian government (which is really still French controlled, but governed locally) was taken over by separatists last year who want to separate from France. If the current leadership stays in power they will probably separate from France, but this would severely impact the economy. That is part of the reason they are so interested in becoming self-sufficient. It is unclear whether the current government will be able to maintain its control in the upcoming election. Members of the Tahitian royal family are still alive and are seen as the faction that wants sovereignty immediately and possible return to some sort of monarchy system, but do not have widespread support. The 2 major parties are the blue and the orange. Be careful not to wear these colors during election years or risk harassment.

I'm also trying to talk to OPH who sells the current kit houses. The current MTR we are working with is "second generation" as there was a previous model. Apparently they have also come out with a new "third generation" model that is inferior to the current one we are working with. I don't know much about this new model, but I hear they have done some inexplicable things like remove the roof ventilation and change the roof angle so that it is less optimal for balancing hurricane wind speeds. Why they have done this I don't yet know. Also, some people apparently get land along with a subsidized house from the government. I suspect this is probably a program for natives, but I will try to get the details from OPH who should have data on who is buying these houses. My impression so far is that the youth (20s) are the ones buying houses and they don't want thatch roofs because it is a big deal to replace them every five years. The older generation don't seem to mind thatch roofs as they are still relatively common amongst homes, maybe 50% of houses I see have thatched roofs. There is a fake plastic thatch that is available. I don't know if this is worth following up on or if it's just silly.

"The Association" is the elders group I was suppose to meet with on Thursday. Unfortunately, this meeting has just been cancelled because Hinano Murphy (our cultural consultant and wife of Frank Murphy who is the station manager in charge of physical stuff) is on leave with a back problem. She lives near the station so it may still be possible to ask her some questions, but I shall see how that turns out. This also means I may not be able to go inside of any MTRs here on Moorea, but hopefully I'm meeting with someone tomorrow morning in Tahiti who has promised to show me some MTRs on that island. Hinano is our key to cultural sensitivity and we should go through her before asking any possibly prying questions of the locals here who have a reputation for being very shy. Also, there is a French documentary maker who wants to document this process of redesigning the house using traditional wisdom from beginning to end for French TV. This person is currently in France so as far as documenting the beginning of the project I think they are already behind.

Security and voyeurism might be 2 areas that we haven't previously considered to be important. Apparently locals will help themselves to stuff in beach side houses because they don't see it as stealing so much as "what's yours is mine, too". There is not a strong sense of boundaries amongst houses and as a result people tend to let themselves in and help themselves to beer or take a nap on the couch. This sounds kind of nice, but has become more of an issue as people own more stuff that they consider theirs and as this stuff becomes more valuable. I don't know which way locals want to go with this, e.g. build fences in the American style of good neighboorship or encourage traditional communal system. Voyeurism is also a tradition here as people will peak in the windows all the time, especially if there is a woman home. It can also go further than this to the point where men will sneak in the house at night and lightly run a woman's arm to find out if she is interested. The woman can say no easily enough, but this can still be unnerving I'm told. There are also rumors that the men will cover themselves in oil in order to make a slippery escape in the event the husband wakes up. I know this all sounds kind of crazy, but that's why you sent me here right, to find this type of stuff out?

Neil is the station manager in change of (research) personnel. He is friendly, lives at the station, and very English. He is very interested in this project and with renewable energy. He talks about someday running the entire station on solar power, which will cost about $5 million and take up a lot of space. This is economic because Moorea has some of the most expensive electricity in the world, about 18-20 cents/kilowatt-hour if I understood him right. Madeline is still trying to get us an electric bill. She doesn't pay for electricity because it is included in her rent. The people she felt comfortable asking don't pay for electricity because the electric company (EDT) owes them money, but I still don't know why. Some of the drafters in her office actually live in MRTs but are very shy and she has to be careful about asking them to see their house because she is kind of their boss. Hopefully this will all be cleared up though if I can just talk to the electric company. Neil is the person we need to give all receipts for reimbursement to. The convention, however, will not be signed for another month because they had to change something. So no money for at least another month. I will try to find out if they will be able to build the MTR as they said next month, but it may be delayed until at least May.

The ferry is the cheapest way to get to and from Moorea. It makes about 4 trips a day which take about an hour one way and cost around $9 or 900CFP. The exchange rate is $1:100CFP, so conversion is easy. I get around using the communal car or land rover. I've had them pretty much to myself since there aren't that many people here, but a bunch of people came today so I may have to share now :(the supermarket is about a mile away and they take Visa and Mastercard, but they are not open after 8 am on Sunday. Also, they usually close for 2-3 hours during lunch. There are other local markets and cash machines about 2 miles away in a small town. I've noticed a traditional way of getting around seems to be running along the side of the highway. I haven't tried this yet though - too hot.

We need to reassess when we are going to make future visits. Madeline says it would be better to come in May rather than August. It would also be better to have someone here in late September to install the probes when the prototype is up. Madeline is planning to come to Berkeley in January to prepare our findings for the Tahitian government and we should plan to spend a significant amount of time on that report while she is visiting. This makes more (economic) sense then shipping all of us to Tahiti in January.

Random facts I've absorbed: There are about 250,000 people in FP and greater than 2,500 people in Pappete (probably more like 10,000). Hydroelectric and oil are the main sources of electricity in Tahiti. Oil is used almost entirely on Moorea, which has it's own power plant. The steep interior valleys are used for industry while the waterfront area is used for commercial and residential purposes. The highland ridges and mountain tops in the center of the island are undeveloped and protected to preserve the watershed. The resorts (about 2 dozen) are mostly owned locally, but operated by Americans. The tourists are mostly from the United States, France, Japan, and Australia. China is building 2 new resorts for their own tourists because their citizens can only travel to certain places pre-approved by the Chinese government. FP is a French territory, not a colony. People burn leaves and yard waste in their yards after it rains to reduce the fire risk. Fire is not a big problem here because everything is so wet, but I haven't seen any fire station yet. There is talk of moving the industrial portion of Pappete port further East where it will not be visible from cruise ships that visit the port. Black sand beaches are on the east side of Tahiti where there is more erosion of the basalt rocks. White sand beaches are on the west side where the sand is made up of crushed coral and shells.

Apparently the locals are crazy for "jeeps", which are actually big new pickup trucks. They cannot afford these cars so they get 15-20 year loans from the banks to pay for them and put up their land as collateral. As you can imagine most people end up defaulting and losing their land to the bank. I'm still trying to find out why this ridiculous scheme is allowed and what happens to the land the bank acquires.

3/29/06

So I visited the ministry of equipment (civil engineering/infrastructure in English) this morning. The equipment ministry is our sponsoring ministry for this project. Madeline originally approached the ministry of durable development (sustainable development in English), which would seem like the natural choice, but they demanded that we set hard electricity savings targets that would be hard to hit since the people living in our house are already using a minimal amount of electricity. They also think our project is just too expensive. So we are working with the equipment ministry instead. What I gathered from our meeting today though was that they are skeptical of our plans to use "exotic materials" such as bamboo (yes, I have found bamboo in very isolated patches), coconut, and plastic when there are no facilities that are currently making these products. They would rather see us simply improve the design to make the house more comfortable using the existing materials so that the new version can be available quickly. Madeline would like to do both. She sees new small businesses springing up that could locally produce the materials necessary to build our prototype version of the house with "exotic materials". I agree because this would be in line with the idea of long term sustainability. So this is what I proposed. We could model our new design with existing materials using our modeling software to get a good idea of how much the new design will help make the MTR more comfortable. This can then be implemented immediately if necessary. We will continue to build the prototype out of new materials even if these are not yet locally available (but could be someday) because it is more important to figure out how these materials will perform in this climate. If they work well, we (or someone) can work toward figuring out how produce them locally in the future. So our project has 2 focuses now, one as a short term solution for increased comfort and one as a long term solution for sustainability.

Speaking of materials, we need to figure out a way to determine the R values and/or thermal qualities of all the materials we propose to use. How can we do this if we come up with some new composite that has *never been used before? The equipment ministry has serious concerns about using bamboo as a building material because they think it's more prone to termites than Douglas fir. There are certainly chemicals that can used to treat both materials, but they are often not properly applied here and the result is a serious termite problem. I'm planning to ask Hinano to ask the Association if there are any traditional ways of combating termites and other pests in line with our sustainable mandate. Of course any suggestions they have will have to be thoroughly tested to make sure it will work in our application. In any case we need to keep termites in mind when we design the prototype. Using pandanus leaves or other thatch seems like an idea we should drop. Aesthetics, cultural preference, and insulating values aside, pandanus is very expensive and needs to be replaced every 5-7 years, which is not feasible for the people buying these houses. Madeline has confirmed that thermal inertia (thermal mass in English) should not be used inside the house because it does not get cold at night. I can testify to the fact that it stays above 80 deg F all night! I have proposed either using the earth as a heat pump in reverse or using rainwater catchments to collect water for a combined cooling (think radiator) and gray water system. What do you think? There is some question as to whether it is legal to collect rainwater here (for health reasons, not supply), but people commonly do it in any case. Perhaps this can be used in a crude heat exchanger to heat water. The only reason a house need hot water here is for showers and even that is not essential since it doesn't get that cold here. A typical Tahitian house uses 200 – 300 L of water a day.*

The equipment ministry was helpful in giving me some composite wind maps that correspond to what I've been seeing on our site. They also promised to send an electronic copy. The prevailing wind in FP is from the ESE, but once you get away from the coast it follows an upslope pattern during the day and a down slope pattern during the night. Our site is right on the coast, but is also in Cook's bay which is protected from the East wind. As a result the winds (which are very light) come from the NE (mouth of the bay) during the day and from the SW (from the mountains) by the time the sun sets. I haven't heard back from the researcher who collects met data on the site, but hopefully he will have a more complete picture of when the winds actually change direction.

I also found out that average residential electricity usage is between 270-300 kWh/month, which costs about $100. This figure includes all houses with and without air conditioners. If I get a chance to talk to the electric company hopefully they will be able to give me a better idea of how many people use air conditioners. French Polynesia landfills all of the municipal waste, but they are trying to build an incinerator for the medical waste in the future. The only gaseous fuels available are Butane and GPL, which I think is LPG in English, otherwise known as Liquid Petroleum Gas. No propane. These gases have to be imported, along with gasoline and diesel, as refined products because there is no refinery here. The gaseous fuels are stored in 2 spherical tanks (one of which appears to be covered in grass – some kind of experiment to keep it cool I think) within the middle of the harbor, which is not the safest place in the event of an accident or worse. There are plans to move the fuel storage to the airport, but it's not clear how this is any safer. Additionally there is no methane terminal and there is no plans to build one any time soon. The 2 power plants in Tahiti burn either heavy fuel oil or residual fuel oil and together produce 70% of Tahiti's electricity. There are no pipelines in Tahiti so all fuels are moved by truck including the power plants fuel. The rest of the electricity is supplied by a large hydroelectric dam. On Moorea all the power is supplied by a single oil burning power plant. There are no recycling facilities in FP. All recyclables are bailed together and shipped to New Zealand to be processed and resold. Once the recyclables get to New Zealand, FP officials they have to pray that NZ takes the recyclables for free because there is no contract and sometimes NZ asks to be paid for taking this material. This is yet another reason to create an alternative market for recyclables (either raw or reprocessed) as building material.

William, from the transportation ministry, said he would show me some MTRs on Tahiti this afternoon, but I wasn't able to get in touch with him so that didn't happen. This is turning out to be a common problem here. I think I have spotted some MTRs, however, here on Moorea, which I'm going to try to check out with Madeline tomorrow. There is a concrete block version of the MTR in addition to the wooden version we are working on. The concrete version is apparently "mo betta" and therefore more expensive, or vice versa. In any case I will try to see one of these concrete versions tomorrow if I can.

I think I mentioned this before but we all need to sit down and figure what our schedules are for the next 9 months. I told Madeline that we need to have the questionnaire answers by mid-April in order to incorporate them into our analysis. She thinks this is possible, but may need a short list of questions that will directly affect the inputs to our computer model. The rest of the questions can be answered later. I will work on making a short list at some point. Let me know if you come up with essential questions that need to be answered in order to make the model more realistic. E.g. – what do people cook? When do they cook it? How many showers do they take? When do they shower? Do they take hot of cold showers? I have observed that in general Tahitian people go to bed early and get up early so a typical American residential load schedule would not be appropriate in amplitude or timing here. Indeed, I have been going to bed between 8 and 10 pm (except for tonight) and getting up between 5:30 and 7 am easily enough.

I told Madeline we would deliver a complete analysis of the existing house by May 7th. It is important that this appear to be a quantitative analysis complete with pretty graphics and graphs for the equipment ministry who are all engineers. Madeline really wanted Carrie (because she is an architect) to come out to Tahiti in May, but I seem to remember this being a bad time for Carrie. An alternative would be for Madeline and Bruno, from the equipment ministry, to come out to Berkeley in May. The question is when in May would be best for us. They could either come out to help us synthesize our final report the last week of April, observe our final presentation the first week of May, or work with us after our finals are done. The convention has been delayed until next month so construction of the MTR will not take place until at least late May. Depending on when Timothy gets out here (were you planning on May or June?) you may get to see it built. I'm told it will take approximately 2 weeks to build. The prototype is still scheduled to be built in September, but it absolutely has to be built by October in order to capture some of the dry season or we lose 6 months. We still need someone to come out and install the probes after the prototype is build. Madeline still wants to come to Berkeley in January to synthesize our report for the Tahitian government.

Erika – Madeline suggested you check out the Djibouti (?) Cultural Center in Noumea, New Caledonia (another French territory) that was designed by Renzo Piano. Apparently the mechanical engineers spend a lot of time trying to come up with an effective way to capture the wind for natural ventilation. It would be interesting to see what they came up with, how well it worked, and whether we can apply any of the lessons learned to our project, which has a similar climate.

Timothy - I told Madeline that you may be able to help draft the drawings for the prototype while you are out here. Do you know AutoCAD? There is money set aside for a draftsman and Madeline would rather have someone who knows the project than hand it off to another draftsman blindly. Another option would be to hire an American because apparently that would be faster than having someone in her office do it.

Random observations: Madeline adores my yellow Berkeley notebook. We should get her a couple from the bookstore, preferably one with grid paper or small lines (smaller than college ruled). Apparently they are hard to come by out here. Madeline also thinks we should design everything in meters. This 20x40 feet stuff really screws her up. She is also big on using the golden rectangle (1:1.618 . . .) if you know what that is. The tropical fruit here is very small and sweet, but the other fruit and vegetables are large but lack flavor. Madeline thinks it's because plants need to struggle to taste good. She says there's too much sunlight and water here so the plants have it easy and just fill up with water. She sites the facts that good wine comes from vines grown in rocky and sandy soil or otherwise harsh conditions. On this point I would have to agree. I find that I am eating a lot less because it is so hot and drinking a lot more. Soup is really good at night because it help you re-hydrate and replaces your salts, which is important because you pretty much sweat continuously all day here. They also sell 1 L bottles of mineral water with magnesium and other salts in it, which seems to be marketed towards infants, and people who don't want to get cramps, very smart. My impression is that the tap water is fine to drink because I see other researchers at the station drink it, but I haven't tried it yet. A lot of people will stop drinking from the tap after heavy rains. I'm not sure why. I can tell I'm beginning to ramble so I'll sign off now and write more tomorrow.

- Bret Harper –

- In wine there is wisdom. In beer there is strength. In water there is bacteria. - German Proverb

3/30/06

Hey team, what a day –

I think these emails are as much for me to organize my notes as for you to stay up to date on what's happening. I'm behind by about a day and a half and won't be able to cover everything tonight but here's the most interesting thing I learned.

A correction about the wind maps: I actually have 3 very similar wind maps that correspond to the different seasons here although the maps do not specify which season is which. In any case I have determined that the wind on our site generally comes from the NE during the day and from the opposite direction at night. This daytime wind is combination of the dominant East wind across the islands and the upslope with that comes from the North in Cook's bay. The down slope wind dominates during the night. Keep in mind that these winds are often very light at our site. In order to take advantage of maximum cooling possible with current design we will be orienting the MTR with the deck facing NE. This way we will be comparing the ideal MTR orientation to the ideal prototype orientation. Even though people do not always use the ideal orientation when constructing their house, to use a less than ideal orientation would may look like we are giving our prototype an unfair advantage in comparison. It would also be unusually cruel to Timothy who will be living the MTR for good amount of time this summer. Make no mistake, you will be hot regardless of what we do with this MTR, but Madeline assures me that it is at least less humid in Jun, Jul, and Aug. Conveniently the ideal cooling orientation is also the side with the best view

NE is the optimal orientation for 5 reasons.

1) the wind is able to travel though the house parallel to the interior walls without being blocked

2) the shaded deck will pre-cool some of the incoming air

3) since the large rooms are in front and the smaller rooms in back the air should accelerate as it exits the house though smaller areas

4) the bathroom and kitchen are located on the downwind side of the house allowing the heat to immediately leave the house

5) the deck will protect some of the north glazing from direct sunlight especially during the morning. The afternoon is when the house will perform the worst because of the exposed NW glazing and accumulated heat.

We need to test which of these 5 effects are significant and which effect has the largest cooling effect using the CFD model.

3/31/06

First some notes about the last orientation email I sent. If the wind ever comes from the North we will have a wind shadow problem because there is not enough room to properly space the 2 houses to ensure laminar flow in one direction. I still haven't heard form Sean to find out how often this may be the case. Also, the prototype site is generally more shaded than the MTR site. The easiest thing to would just be to cut down the offending trees, but this does not seem very sustainable and would make it considerably hotter and less comfortable in both houses. Let me tell you shade makes all the difference here. Other options include planting similar size trees in the same position for each site or simply re-planting the offending trees somewhere else. It may be more important, however, to gather data from houses that are not artificially cooled by shading since we cannot count on shade for all sites. Sorry Timothy.

I visited the inside of MTRs today and met with Sweatgo (?) the director of OPH! Got lots of pictures to show you when I get back. All of these pictures are for the new (version 3) MTR that was developed late last year. This is the same version we have been working on as far as I can tell. Madeline gave me the construction drawings and details for the version 2 house but this will have limited usage now. Madelaine was working with the previous version 2, so there was some confusion up until today. We have both decided to use version 3 as "the MTR" since this is the only design being built now and analyzing the version 2 would only add unnecessary complexity though it may generate some interesting results. All of our questionnaire answers will be from families living the version 2, however, since the version 3 is brand new. This means we can and only use their answers to determine Tahitian living habits (e.g. when do the cook) rather than a qualitative evaluation of the comfort level (e.g. is the house comfortable during the day). We will determine the comfort level of the house quantitatively using our sensor array. Anyway, one of the houses I saw was only had the wooden frame and we're befriended the owner who wanted a picture of himself in front of this new house. This means we will have someone to talk to during our next visit who can tell us about the differences between his old house and the new version 3 house.

So here's the correct history as opposed to the one we presented in class that was confused: in 1983 cyclone Veena destroyed a lot of housing and the French government started the MTR program as emergency hurricane resistant housing. It was conceived that only 300 units were needed, but in reality 600 were constructed. In 1992 the program was re-started with version 2 because of typhoon William, which destroyed a lot of housing, but the MTRs performed very well during this storm, which contributed to its popularity. In 1995 the MTRs were sold commercially as cheap housing rather than emergency housing. In 2005 memory of the cyclones has been lost and the version 3 was designed with a less than optimal roof angle that is steeper than the previous versions purely for aesthetic reasons. The version 2 roof was shallow and symmetric in order to balance pressure during a cyclone. They also replaced the triangular roof vent, which opened at each end, with an under-eve vent, which run all around the house, presumably because it is a simpler roof to build. They have also replaced the interior plywood with 9 mm fibro-cement panels that are composite cement and wood-chip pre-fabricated panels that are imported. The exterior panels are 12 mm fibro-cement. The roof has aluminum foil style insulation under the metal roof with no other backing, such as plywood. Also, they have removed the glazing from the ends of the MTR, probably to save cost. All windows are manufactured locally and slide open sideways because the old style where they swing up was a safety concern. This strikes me as similar to the local campaign to not drink and drive . . . because the beer bottle may roll under the pedals and prevent you from stopping.

The most expensive element of the house is the wooden frame, which comes from Oregon. That is why all the board lengths are in feet and the other measurements in meters. I think we should focus on replacing the wooden frame with something cheaper. This could be bamboo, coconut, ironwood, Caribbean or Norfolk pine. The biggest obstacles we face with replacing the wooden frame are that we have to show the new materials are more termite resistant than treated Douglas fir and that they can be manufactured locally. There is enough supply of wood here (we need 16 cubic meters of wood per house x 500 houses/year =

8,000 cubic meters of wood per year), but the Tahitians don't know how produce lumber in a reliable manner. That is the main reason OPH imports wood from Oregon, because they say the reliable supply makes it half the cost of obtaining wood locally. There is a program that is supposed to bring in Fijians in to train the locals in proper wood handling techniques in the future. If our houses could sustain a small and sustainable lumber business we could apply for a government sponsored contests for new small and sustainable businesses. Madelaine is very excited about this. We could apply for additional money if these businesses encourage renewable energy or employed the handicap or women. FP men have a drinking problem similar to the one Sainath writes about in India except here the men drink Hinano instead of arrack, but the domestic abuse problem is the same.

Anyway the main purpose of saving money on the wood frame would be to build a better (and more expensive) roof because that would make all the difference in terms of cooling. It would also allow us in make the roof look Polynesian, which is very practical design for this climate, without romanticizing the materials. The version 2 design incorporated cheap and decorative trim in the colonial style. This makes the house very cute and contributed to its popularity. We have to keep these lessons in mind because if people prefer the look of the MTR to our design based solely on the cute factor that would be a disaster for our initial dissemination. The current roof is very simple and the local contractors are very experienced in building it, so that reduces cost. Any changes we make to the plans will involve additional building costs because 1) the contracts are used to always building the same design and 2) will involve moving the French inertia to try new and/or unproven designs, which is just as significant if not more so in all seriousness. By this reasoning we figure we might as well make a lot of changes rather than just a few because economies of scale, if you will. The possibility of not building a rectangle house is attractive, but we need to balance this with size and stay within 15% over the MTR cost with our prototype, which comes out to only $69,000. I think an L shape may serve this purpose by using the covered deck to maintain the rectangular footprint. Designing a cheap, flexible, mass producible, and sustainable house is the real challenge of this project in contrast to most architecture projects that have clients with a larger budget and are site specific. This is something we should emphasize in our papers and presentations. Keeping cost low is really key for our project.

Tahitians are not a minority in FP. I don't have the ethnic break down in front of me but 95% of MTR owners are Polynesian. The government subsidizes 350 MTRs/year by paying for the construction. The owner has to come up with the $60,000 for materials themselves (the average house price in FP is

$600,000). 150 MTRs/year are sold in addition to the subsidized ones. FEI is a private company that builds houses similar in design to MTRs on the outer islands. This means that more than 500 MTRs are constructed every year. There is also a government program that gives land to natives on a waiting list. Many of the natives use this land to build an MTR, which is a big step up from the shanty houses they piece together from spare building materials in a haphazard fashion. Previous attempts at building low income housing failed because they tried to put the Polynesians in apartment buildings, which does not fit the lifestyle of families because of the lack of outdoor access. As in most tropical climates the people spend most of their time outdoors and only come inside to sleep at night. A lack of land and security issues, both related to population growth, have made this more difficult in modern times and increased the use of the home during the day. The cheap single family home seems to be the only compromise that works for FP.

What we need to produce before the end of the semester for the government is this: determine the optimum MTR orientation under the full range of sun and wind direction combinations to demonstrate which factors matter most and how to determine the ideal orientation given any specific site. This will involve varying the 5 factors one by one that I listed in the previous email. It will also involve varying the position of the deck, which is commonly done, but only to fit the property. Talking with the builders, I got the impression that there is no thought given to wind or sun orientation. The size and shape of the property entirely determine the orientation currently when constructing MTRs. Doing a really through study of orientation will impress the local government and be the easiest thing to change to make the house more comfortable without increasing cost. If we have time we can analysis other cheap options including adding thicker insulation under the roof, building in a partially shaded area, removing the interior ceiling, replacing the original roof vent and/or painting the roof a different light pastel color (Does brown work better than red? How about green?). I think it would also be helpful to determine whether a 1, 2, or 4 slope roof would make for a cooler design.

We also need to focus on drafting our final report. In the introduction it will be important to place Tahiti in the general context of pacific island nations that are faced with similar problems rather than focus on the connection to France that appears to be weakening. FP has a similar and somewhat retarded electricity infrastructure with respect to other island nations. I feel like I am best suited to write the introduction so I will begin that when I return. Materials research is therefore secondary, and design of the new prototype will have to wait until we get some data from the MTR. Madelaine and I have been brainstorming extensively on the design of the prototype with curved roofs, perforated walls, separating air and light openings, using shade netting, porch swings, floor vents and even hydro and/or thermal powered fans . . . but I will save that discussion for later.

More bad news about the convention: the equipment ministry refuses to commit to the date they previously told us the convention would be signed by, which was in a month.

As far as scheduling updates go, we are suppose to participate in a big PR exercise to promote what the Gump station (locally known simply as Berkeley) is doing to promote sustainable housing. This will involve fancy graphics from our models with animation if possible. The Association will be invited along with the minister of equipment (Solomon) and the president of FP. This is our chance to push the idea of real long term sustainable solutions and not just quick fixes for comfort as is the priority of the officials we are working with now.

Moorea produces 380V, 3 phase AC power that costs $0.38/kilowatt-hour! There is no power buy-back (net-metering) yet, but this is expected to change once the government gets around to it to encourage larger renewable energy systems. The Gump station is eventually planning to run entirely on Photovoltaic cells placed on new buildings and in large arrays. This part may only be of interest to me, but here it is: Americans approached the FP government recently to build an Ocean Thermal Electric Conversion (OTEC) platform that would use the favorable thermal gradient of the ocean here to produce electricity. The primary reason for its rejection was the size the Americans insisted on – 100 MW. The only other successful OTEC plant is a 1 MW facility in India and was built by a Japanese company. The technological jump of 100 fold was considered to be unproven and therefore unrealistic in the French view. This is part of the reason France is trailing all European countries in renewable energy, including the US. The proposed design utilized a 12 m intake pipe imbedded with glass beads to that it would only be 10% heavier than water. Anyway FP only consumes 50 MW of electricity during peak times so the proposed plant would also be oversized and a plan would have to be developed for the excess energy. Possibilities could include more air conditioning, desalination, and/or hydrogen production, but the French would have none of this. As it stands now 8 dams produce 15 MW of electricity or 30% of Tahiti's demand. The rest is made up by burning MDL, which is heavy fuel oil that is one step up from residual produce that is often used for asphalt. All oil imports come from Singapore and FP has a demand that is 0.0001% of Singapore's oil demand. The only gaseous fuel available in FP is butane, which everyone calls propane. There is a plan to use Sea Water Air Conditioning (SWAC) in the hospital in Tahiti. This involves using cold deep sea water to directly cool the *building rather than producing electricity. Bora Bora has an electric demand of 100 KW peak power or 0.1 MW.*

4/2/06

I talked to Hinano today, what a remarkable woman. She speaks 4 languages and so do her 4 kids with excellent clarity. She lives with Frank up in a valley near the station in a beautiful house without any real walls that they build themselves. When I arrived she had all the kids burning vegetation that they had cleared from the rainforest to grow a garden with banana, papaya, taro, and other things. The garden was irrigated by a small stream that ran though their property. It reminded me a lot of the area I grew up in, but we never really knew how to manage the land and make it productive like Hinano. We grew bananas and limes with mild success. The lemons and oranges never worked. It was clear that at our house someone had grown taro in irrigated patches behind small stone walls before, but I have no idea how recently that was as the stone walls were very overgrown and may have been over a hundred years old for all I could tell. It was so cool to see that some native people still have all the traditional knowledge and are still very savvy in the modern world of internet and the global community.

As it turns out the typical rural Tahitians have a very different routine than Americans. They rise at 4 am to cook a large breakfast of coffee and fish. This is the major meal of the day. They are all out of the house by 6 am. The father typically goes to work and the mother takes the kids to school that starts at 7:15A and goes to work after that. If there are any elders in the household they will sometimes stay home with children who are too young for school. Otherwise the house is empty until after school gets out at 2:30P. They will do household work and typically take hot showers (especially the kids) around 4 pm. Dinner is around 5 pm. They will use the stove to heat water, but otherwise the meal is simple. They will go to bed soon after it gets dark around 6:30 - 7 pm. Some families stay up and watch TV, which is common now, and end up going to bed between 8 and 9 pm.

The major electrical load is the refrigerator, though more people are also getting freezers now too in order to store fish when they make a large catch. Other common electrical appliances include lights, TVs, washing machines (no dryer), and irons. Apparently they iron everything and never fold clothes. When they need a change of clothes they will take it down from the drying line, iron it (even if they are just going to wear it around the house), and put it on. There are always clothes hanging on clotheslines. These clotheslines are on the deck, in the kitchen, and outside. They prefer outside lines, but need inside lines for when it rains.

Many families leave a light on all night because they are frightened of bad spirits. If integrated a low energy nightlight, possibly utilizing LEDs this may help them save electricity. Hinano also thought most people would be receptive to the idea of using renewable energy.

They are also crazy about using water. They typically take at least 3 showers a day, usually outside. They are also constantly rinsing everything and hanging it up to dry. They have no misgivings about letting the water run when they are not using it (expect on the atolls where there is not a lot of water). If they have to shower inside, they like to have it open to the outside so they can go hang up their towel on a line, rather than walk through the house all wet. They also cook and eat outside as much as possible. Hinano tells me that in most people will not use the indoor kitchen or dinning area at all. She says they don't like to use the indoor kitchen because they don't want the kitchen smells in the living area. They especially like to have a sink outside where they can clean fish. Traditionally, Tahitians had separate fare (buildings) for sleeping, kitchen, shower, and toilet. We should consider detaching these areas (except the toilet) from the sleeping area since that is what they do anyway as soon as they start living in their house. They have grown accustomed to using the bathroom indoors with a flushing toilet so that should not be changed. They will often extend their house with extra sheet metal to create areas for cooking and showering outdoors whenever possible. In fact they spend most of their time in this outdoor extension. Some families will even utilize the deck area for sleeping and the bedrooms for storage because they prefer to be outside. As a result most MTR are very neat and tidy because the area is not used for day to day living. Storage is an issue and is something we need to allow for as the current MTR does not have any. Any storage area does need to be well ventilated, however, because otherwise the stuff being stored will grow mold or rot very quickly.

Locals buy MTRs because they like materials that will last a long time and are low maintenance. Again I got the impression that a pandanus roof is too expensive for the average person because there is somewhat of a shortage of pandanus roofers (due to resort construction) and it needs to be replaced every 5 years. Some people will put pandanus under a metal roof, however, which extends its life to around 25 years. This is something we could look into using. Hinano thought it would be great if we could either use coconut husks or wood as a building material. She says that coconut husks are very strong and plentiful. She had one central post in her 2 story house that was a coconut tree and has been there for over 20 years without any termite damage. She says this is because it was an old coconut tree cut in July-August and soaked in saltwater for 7-15 days. Old trees have less sap and in July-August all the sap runs down and out of the tree, which allows it to soak up salt water more readily. The tree can then be dried and used, but not cut into lumbar.

Always use the whole log and it will never be eaten by termites because they don't like the salt. This can also be done with bamboo and pandanus. She showed me an example in her house where a split bamboo wall was connected to a treated 2x4 of pine. The bamboo had been there for 20 years undamaged while the pine was full of holes. The same was the case of a woven pandanus screen that had been prepared in the traditional way, completely undamaged. This is defiantly something we should put to use in our prototype. It would be very cool if our prototype was more resistant to termites than the treated lumbar in the MTR. That may turn some heads in the government.

I also think we should consider making the house as open as possible since that seems to be the Tahitian preference and makes sense for the climate. The 2 obstacles to this are rain and security. The driving rain, strong winds, and hurricane all comes from the NW from October though February (the hot/wet season), but especially in December. The West and SW also have dangerous winds. Tahitians used pandanus leaves and steep roofs to deal with cyclones. The pandanus leaves would get blown away, but the roof structure would remain and they could rebuild. They also claim that a steeper (2 sloped) roof helps because it doesn't act like an airplane wing, which has a shallow profile and a tendency to lift off. Indeed the Gump dormitory has a steep, but weakly constructed roof (it's made of 2x3) that has survived many cyclones. I'm told a house should never be exposed to this NW direction. In fact the house should always have an East or NE orientation to let in the trade winds and the early morning sun. This is just as Madelaine and I determined! The trade winds are constant and steady from May though July (the cool/dry season) and generally come from the SE during this time. There is a hupe, or downslope wind at night, but it is generally very weak and nobody pay much attention to it. Ideally the hupe will ventilate the house in the opposite direction as the normal flow. Letting in the sun is not a problem in the morning because it is still relatively cool while people are home, which is before 6 am.

Security is an issue for houses on the beach because there is more traffic there and everyone doesn't know each other. People still like to be able to lock up their house during the day to prevent people form "borrowing" stuff. I guess we still need walls, too bad because Hinano's house was so pleasant even in the mid-afternoon heat. One thing we don't need are screens on any of the house openings because locals don't worry about mosquitoes and bugs and screens actually do slow down the air movement significantly. I have experienced this first hand at the station.

Hinano and others have seen a definite change in climate during the past couple decades. She tells me that the winds come late now. Also, the rain all comes at once in long spells rather than intermittently. This suddenly changes to dry periods which are also strangely unbroken for many weeks.

Hinano is going to find out more information about traditional measurement systems from the elders, but says people used measurements based on human anatomy (like the English system) before the French introduced the metric system. The elders have very particular measurements for palm and pandanus weaving that is all based on body proportions. She also said there is no problem filming meetings with the elders in the future for documentation purposes.

In order to make the house look more Tahitian we could use the fake plastic pandanus I mentioned earlier. The community is split as to whether this looks better than a metal roof. All the same we should check out lifetime of this product as a primary roofing material.