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THE HYGROTHERMAL PERFORMANCE OF THE NET EXTERIOR INSULATION WALLS

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Engineering Science and Technology Division

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REPORT 2: Year 1 Analysis

Date Published: April 2006

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NEED/PROBLEM DEFINITION

Moisture penetration in liquid or vapor form through a building envelope can affect not only the building's durability and indoor air quality, but also the energy efficiency of the envelope itself. For example, excessive moisture for extended periods of time may cause mechanical, chemical or biological degradation of wood-based components, corrosion of metallic components (studs and ties) efflorescence (moisture-induced salt transport and spalling). Accordingly, the service life of any building envelope component is dependent upon how well moisture penetration is controlled.

Key Issues

Systematic moisture engineering analysis is advisable for all cladding systems. Exterior insulation finish wall systems have become one of the most popular exterior building envelope systems in the residential as well as the light commercial construction market in the United States. These residential application of conventional EIFS wall systems were based on the principles of face sealing and consisted of exterior reinforced synthetic plaster base and finish coats, and EIFS insulation applied over a sheathing substrate (usually oriented strand board [OSB], plywood or gypsum based products). Another problem was the inclusion of vapor barriers in areas where, according to ASHRAE, none should be included. Typical wall configurations over which the EIFS system is applied included an insulation cavity, a vapor retarder, and finally interior gypsum board (Figure 1). EIFS cladding systems are advantageous because they are aesthetically pleasing, energy-efficient, lightweight, and low in construction costs for a wall cladding system.

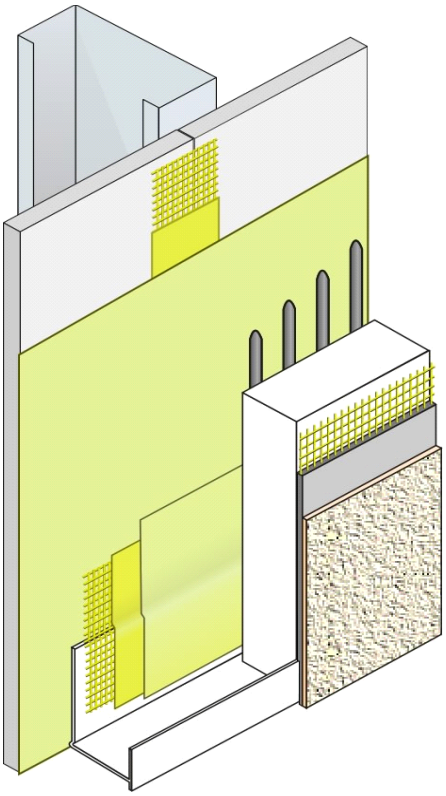

Figure 1: EIFS Wall System

Various investigations by consultants and research organizations [Crandell and Kenny, 1995], as well as by EIFS manufacturers, have shed light on the causes of reported envelope failures beginning in late 1995 in Wilmington, S.C. Such envelope failures have been attributed to the penetration of water due to substandard windows (in excess of 47% of problems) and flashing details (35% of problems) [Nelson and Waltz, 1996]. While moisture entry should be avoided for any building envelope system, it is often overlooked that walls cladding systems can deal with incidental moisture, but cannot cope with massive failure of good construction practices allowing for extensive moisture penetration.

To address these issues, a new generation of EIFS wall systems has been devised by the EIFS manufacturers. These new systems have implemented with multiple lines of defense for water management and are currently being validated for thermal and moisture performance. The purpose of this EIMA/DOE/ORNL research project is to further explore the performance of

these innovative wall systems. The intent is to determine how to maintain thermal performance while also optimizing the drying potential. Vapor barrier and "smart retarders" positioning may provide air barrier and weather barrier continuity that is superior to current technology.1 EIFS manufacturers have invested heavily in the research and development of innovative building material and system products. These companies have over 1000 years of expertise in the chemical, construction and equipment-related fields, and have developed innovative alternatives to conventional critical material systems. These systems have favorable market potential, especially in energy retrofit applications as well as in new commercial constructions (EIFS).

Scientific Merit

To date, performance data has not been available on the hygrothermal response of walls that includes all climatic effects (such as the effects of rainwater, solar radiation, night sky radiation and the influence of wind speed and site/wall orientation on both the convective and mass transfer coefficients). This results in misinterpretation of the hygrothermal processes that occur in wall cladding systems. This in turn limits the use of innovative strategies (such materials with memory capabilities or material layers with strong functional dependencies on transmission coefficients) that could enhance the durability of wall systems. The present trend is to condemn high levels of insulation in building envelopes. Modifications of conventional EIFS systems have been proposed that alleviate moisture-induced damage, but this may degrade some of the thermal performance advantages by the introduction of either a ventilated air cavity (which short-circuits the thermal insulation) or a drainage mat. Modification of the basic system may increase the drying potential of the wall, but no evidence exists that this would provide a useful solution in the case of high exterior environmental loads. A systematic moisture engineering research and design effort is required to avoid short-circuiting the energy efficiency of the wall by bringing exterior conditions next to the sheathing board and also to prevent increasing the air leakage of the wall.

There are currently no comprehensive design guidelines for moisture control with EIFS wall systems. This hinders the introduction of new and innovative materials that could further enhance the whole performance of a building. While existing guidelines enable such generalities as "minimize vapor transmission through the envelope," "eliminate water entry," and "use moisture management principles," quantitative information is lacking. In addition, there are no databases on the ranges of water vapor permeability, moisture liquid diffusivity, sorption and suction material properties should be used in various material layers of wall and climates.

[1] The Use of Housewrap in Walls: Installation, Performance and Implications, PHRC Research Series Report No. 59 University Park, 1998) p.41.

Energy Impact

As moisture accumulates within the envelope assembly, thermal conductivity may increase by a factor of up to 3 for polystyrene foam insulation, 4 for high-density fiberglass insulation, 3.1 for aerated concrete, 2.3 for concrete, and 2.0 for red brick (IEA 1996; Dechow and Esptein 1982). Moisture can also decrease energy efficiency due to the local evaporation and condensation of water. Indeed, this additional mode of heat transfer can increase the energy transfer across the building component by 5–150% of that occurring under dry conditions (Pedersen and Courville 1991; Langlais 1982; Hedlin 1983). Trapped moisture in roofs and wall systems may compromise the building envelope and augment the heat transfer by 130% in reroofing applications (Kyle and Desjarlais 1994).

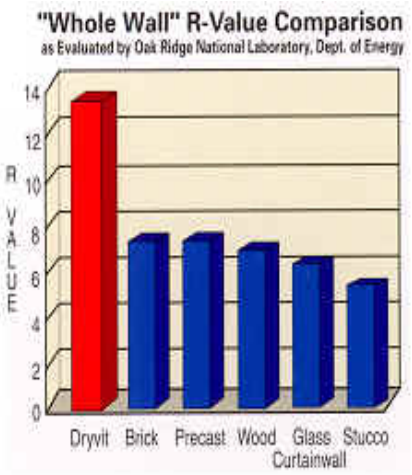

Figure 2: Whole R value of Walls

In recent wind-driven rain analysis by Karagiozis and Salonvaara (1998) and Kuenzel (1994), the presence of wind-driven moisture in wall systems can cause an increase in energy consumption of 12% compared to consumption in ideal dry conditions. Furthermore, because some construction materials display strong affinity for moisture, the air leakage through a building becomes a strong function of moisture present in the envelope.

This was confirmed from measurements conducted by Persily (1982) and Kim and Shaw (1986) that demonstrate seasonal variations of up to 33% attributable solely to the amount of moisture present. Buchanan and Sherman (1998) state that the air infiltration accounted for up to 40% of the heating and cooling costs in more than 50 residential buildings tested by Caffey (1979). Reducing this considerable waste of energy is an important incentive for innovative EIFS wall systems. Currently, in the northwestern United States, local municipalities and cities are reverting to pre-1980 energy design, negating the energy-efficiency gains achieved since 1980 by DOE. Misleading information persists that airtightness control, which may account for up to 30–50% of energy efficiency in buildings, is responsible for moisture-induced damage. Envelope systems have become more efficient by reducing the effect of thermal bridges, by making the envelope more airtight, and by adding more insulation. In energy-efficient envelope systems the presence of moisture increases energy consumption increases. The 1998 U.S. Census reported that, of approximately 94.7 million household units in the United States, 10.9 million showed severe water leakage from the inside, while 16.9 million U.S. homes had leakage from the outside. Johanning (1999) notes that over 9.7 million owner-occupied units required repairs and asks, “What does that tell us about the status and quality of the U.S. housing stock and the possibility of water intrusion and subsequent microbial growth?” Indoor air quality can also be affected by the moisture tolerance of building envelope structures. Irritative and toxic effects caused by fungi through inhalation of microbial by-products such as endotoxins, glucans and mycotoxins are just now being examined by public health researchers. (Husman, 1996, Johanning 1999). Moisture ingress is a factor for the growth of such fungi. This EIMA/DOE/ORNL research study aims at paving the future path for the design of building

envelope systems such as walls, roofs and basements in terms of whole performance. Whole performance includes issues such as energy efficiency, moisture performance, and system and sub-system durability performance. Durability is defined here in terms of providing sustained energy efficiency over the expected service life of the material or system. This integrated approach will be based on solid building science principles and adjusted by field data to develop a set of envelope sub-system objects. The performance properties of these objects will be applied to advanced hygrothermal and damage models, which will be complemented and benchmarked by laboratory and field results. These models will then be used to predict the response of the envelope system to a wide range of climatic conditions. Using modeling in an iterative manner allows development of innovative building materials and systems by providing ranges for hygrothermal properties for optimal performance for any exterior and interior environmental conditions. This research project will provide the necessary guidelines for engineers and assist in the design of exterior wall systems for application in both residential and commercial wall construction. It is envisioned that these innovative products will eliminate existing water ingress problems at joints and interfaces and provide a durable, energy-efficient wall system. This application of the next generation of weather-resistive membranes provides the necessary second line of defense to deter liquid moisture entry and control the vapor transmission of the exterior cladding. This may also be applied to a variation of the EIFS, to provide the redundancy in wall design such that, if the cladding is compromised, the wall is designed to dissipate and dry out safely. The current research identifies potential regions of risk where different performance properties and attributes in the wall systems configurations are required. As the performance characterization is understood and quantified based on the measured field and hygrothermal dynamics, this knowledge can be translated to design guidelines for exterior insulation wall envelope systems. This critical information will be made available in various forms to the building envelope designers and architect.

Description of Research Approach

The EIMA/DOE/ORNL exterior insulation research project considers building envelope wall designs as a whole, rather than isolating one material or component system.

The research approach is summarized below as:

1) development of a set of hygrothermal material property characterizations (heat, air and moisture) of critical construction materials and sub-systems;

2) complete wall laboratory testing for thermal, air leakage, and moisture performance;

3) hygrothermal characterization of field testing to expose a series of innovative wall systems to real environmental conditions.

4) hygrothermal characterization of field testing to expose a series of innovative wall systems to higher than average environmental conditions.

5) employ hygrothermal modeling to simulate field and laboratory tested walls to allow subsequent optimization of the critical elements of the EIFS wall system.

6) design methodology will be developed that will provide options for energy efficiency while controlling heat, air and moisture transport to prevent material deterioration and potential biological contamination of the indoor environment.

The technologies that have been applied in this research project are newly developed weather-resistive exterior barrier and drainage systems, that is, exterior ventilated assemblies which provide a second line of defense to the building system. Research will be conducted to quantify the ability of these advanced moisture drainage systems to protect against unintended water entry from cracks and joint movement and interface joint degradation. Depending on the wall system configuration a variety of approaches may be employed.

Three of these are as follows:

- Liquid applied membrane technology. The new family of liquid membrane material systems used as exterior weather-resistive barrier will be selectively introduced as a function of climatic loads. These liquid applied membranes are innovative in the way they handle water condensate due to vapor pressure gradient changes or ingress of liquid water from exterior environmental sources (precipitation). These materials may be further engineered to provide gravity-assisted flow by modifying the surface tension characteristics of the exterior sheathing. This allows advancement in current weather-resistive barrier characteristics: . These systems are insensitive to ambient temperature and relative humidities. These remarkable material property characteristics clearly distinguish these products from other products currently on the market as they may be readily applied to field conditions. In addition to vapor, liquid and drainage control, these membranes provide air leakage control that may significantly reduce energy losses.
- Synchronous exterior and interior wall element moisture management technology. Several elements of wall materials and sub-systems are engineered to minimize the time that moisture is collected in conventional EIFS walls. This is achieved by using materials that have high transmission and evaporation capabilities. In some instances these are an assembly of materials, or subset of an envelope, that maximize the transport and drying capabilities of the walls. The work needed to optimize these products in EIFS walls has not been performed.
- Ventilated exterior claddings. In these systems, the exterior cladding is intentionally ventilated using direct integrated systems, channeled foam systems or indirectly provided using adhesive channels. A variation of these systems will be included to assess vented, unvented and ventilated systems.
-

These three innovative approaches can be applied to nearly all generic configurations of wall systems and climate found in the United States. The hygrothermal research being conducted is developing a framework for moisture analysis to determine the maximum level of energy efficiency that may be applied without adverse moisture-induced problems. The immediate application of this wall system would favor not only cold and mild climates but also hot and humid climates. The marketing of these wall systems would be as complete systems, with an increase of durability and long-term performance. For this reason proper engineering must be conducted to eliminate problematic scenarios, seeking in general to develop moisture management by wall designs with high drying potentials.

Effective moisture control requires that the local relative humidity in all wall components be maintained below a threshold limit. If the threshold is exceeded, moisture must be dissipated to either the indoor or the outdoor environment during the annual cycle, before damage can occur.

Our research, includes a list of technology assessments required before employing innovative wall systems and must consider the following building science issues:

(a) Vapor diffusion: How tight or breathable should the retarder be? Where should it be installed?

(b) Water management: How do you manage water entry? Where should this be applied ?

(c) Thermal control: How much insulation is needed? Where should it be applied for various wall configurations? How do you eliminate moisture-induced thermal losses?

(d) Air leakage control: What tightness is needed? Where should it be applied?

(e) Control of system and sub-system effects: Where to control by proper design of interfaces and joints?

The field analysis performed in Charleston (Hollywood), SC will provide the building science answers for a hot and humid climate. Future extension to other regions of the USA will be possible, as the ORNL moisture model will be calibrated with the unique features of the exterior insulated walls. In this research project emphasis is placed at developing all the needed calibration of the ORNL hygrothermal model.

RESEARCH STEPS

A number of steps are involved in the research. Figure 2 demonstrates the scientific approach that is required to accomplish the deliverables of this project.

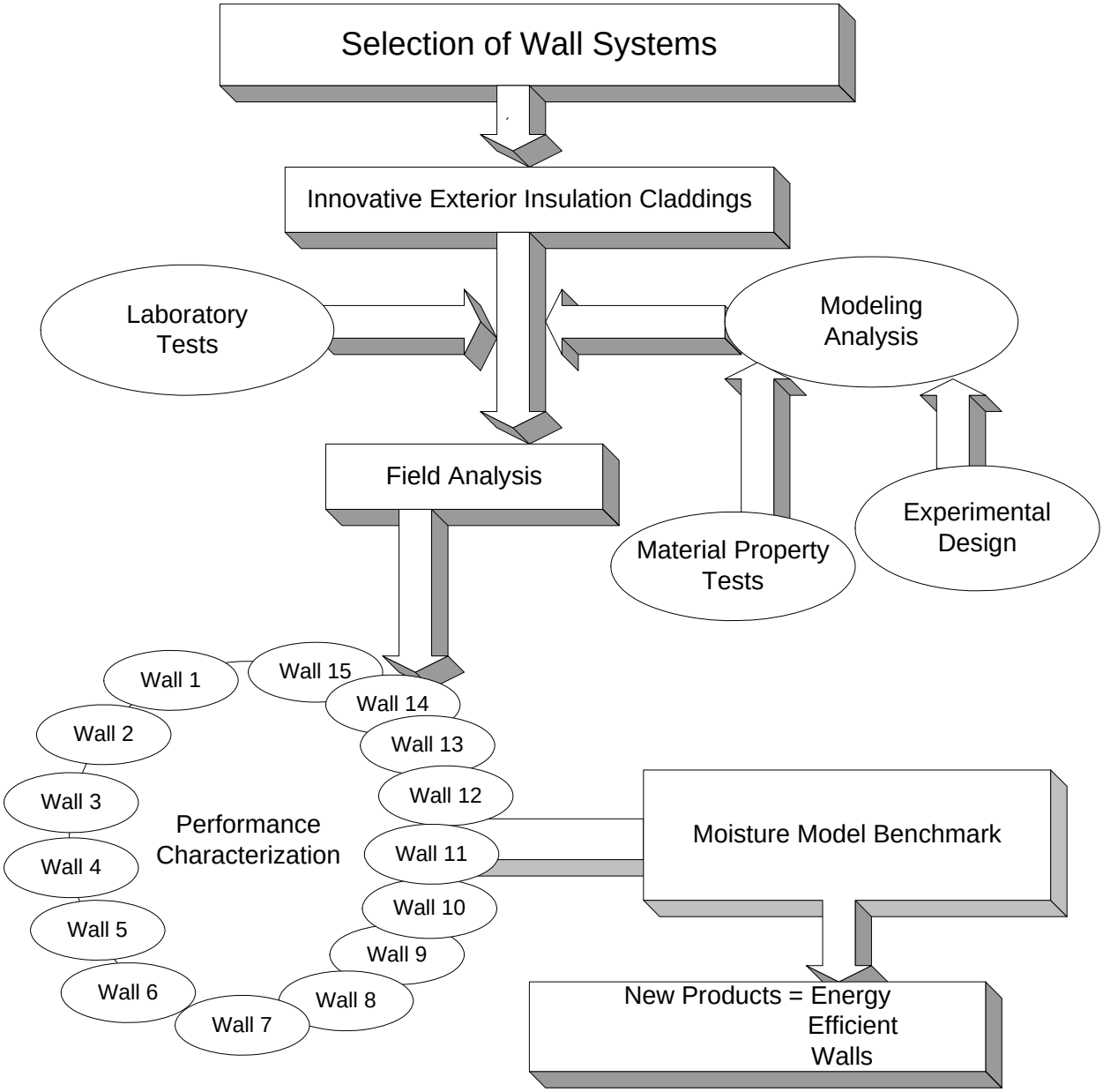

Figure 3: Research Approach for the EIMA/DOE/ORNL Project

Objective of Research

The research performed for the EIMA/DOE/ORNL project intends to provide a quantitative analysis through a series of Field, Laboratory and Modeling activities of the hygrothermal performance of a number of exterior cladding systems with emphasis on exterior applied insulation. The focus of this study is to investigate the response of a selected number of walls (15 Walls) to interior loading and exterior climate found in the south-east of USA (Charleston, SC). The impact of the three innovative system features (liquid applied membranes, smart vapor retarder systems, and exterior cladding ventilation) on the hygrothermal performance of EIFS. Two additional wall systems are also being investigated using brick and cementitious board siding. The EIMA/DOE/ORNL project is targeting the mixed-hot and humid climates zones found in the south-east.

NET WALL SELECTION

A committee set-up by EIMA members, and ORNL staff configured a set of wall systems for testing at the NET facility that was aligned to the objectives of the project. Listed in Table 1 is the complete list of wall assemblies.

Table 1: Wall Assemblies investigated in the NET Facility

System	EPS	Attachment	Drainage/ Air Space	Weather Barrier	Sheathing	Framing	Insulation	Vapor Barrier
EIFS #1	1 ½" Flat	Ribbon & Dab	NA	NA		CMU		Note #1
EIFS #2	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
EIFS #3	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	Membrain
EIFS #4	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	Yes
EIFS #5	4" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	0	None
EIFS #6	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	18 ga @16"	R-11 Unfaced	None
EIFS #7	1 ½"	Mech. Fastened	Grooved EPS	House wrap	Plywood	2 x 4@16"	R-11 Unfaced	None
EIFS #8	1 ½"	Mech. Fastened	Grooved EPS	House wrap	Plywood	2 x 4@16"	R-11 Unfaced	Yes - 6 mil poly
EIFS #9	1 ½" Flat	Mech. Fastened	Mat	House wrap	OSB	2 x 4@16"	R-11 Unfaced	None
EIFS #10 Ventilated	1 ½" Flat	Adhesive	Lath	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
EIFS #11 Commercial	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	ASTM C1177 Gyp. Board	18 ga @16"	R-11 Unfaced	None
3 Coat #12 Portland Cement Plaster	No	Mech. Fastened Note #2	3.4 Metal Lath	2-Layers Grade D 60 Minute	OSB	2 x 4@16"	R-11 Unfaced	None
1 Coat #13	1" Flat	Paint – later date Note #2	Woven Wire Plaster Base 1x20ga.	1-Layers Grade D 60 Minute (behind foam)	OSB	2 x 4@16"	R-11 Unfaced	None
Brick #14		NA	Air Cavity 1"	1-Layers Grade D 60 Minute	OSB	2 x 4@16"	R-11 Unfaced	None
Cement Board Siding (Cladding)	EPS	Mech. Fastened	NA	1-Layers Grade D 60 Minute	OSB	2 x 4@16"	R-11 Unfaced	None

Typical Interior Finishing – ½" drywall, primed and painted (1 coats acrylic paint)
Note #1 – finished with furred ½" drywall, primed and painted (1 coats acrylic paint)
Note #2 – Painted white initially. Plywood = ½". OSB = ½". Lath = G 60

WALL INSTRUMENTATION LAYOUT

In each of the walls, with exceptions to the steel stud configuration and the concrete block wall system each system include 17 thermistors, 6 relative humidity sensors and 8 moisture content sensors. For the steel studs, wood moisture content sensors were developed and installed at the same locations to provide data for local moisture conditions in the wall. In figures 4 through 7 a few of the sensors are displayed as instrumented in wall assembly.

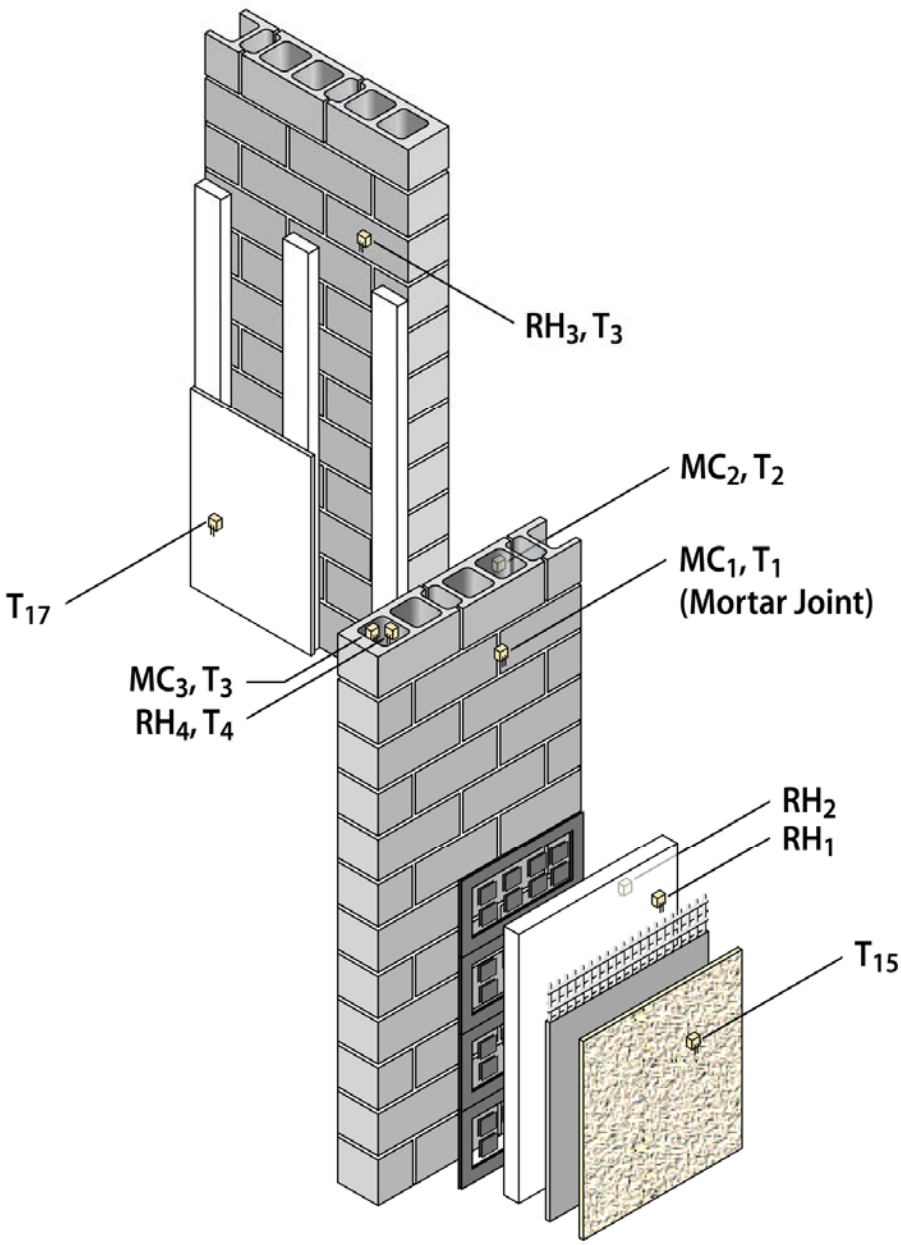

Figure 4: Instrumentation Configuration for Wall 1

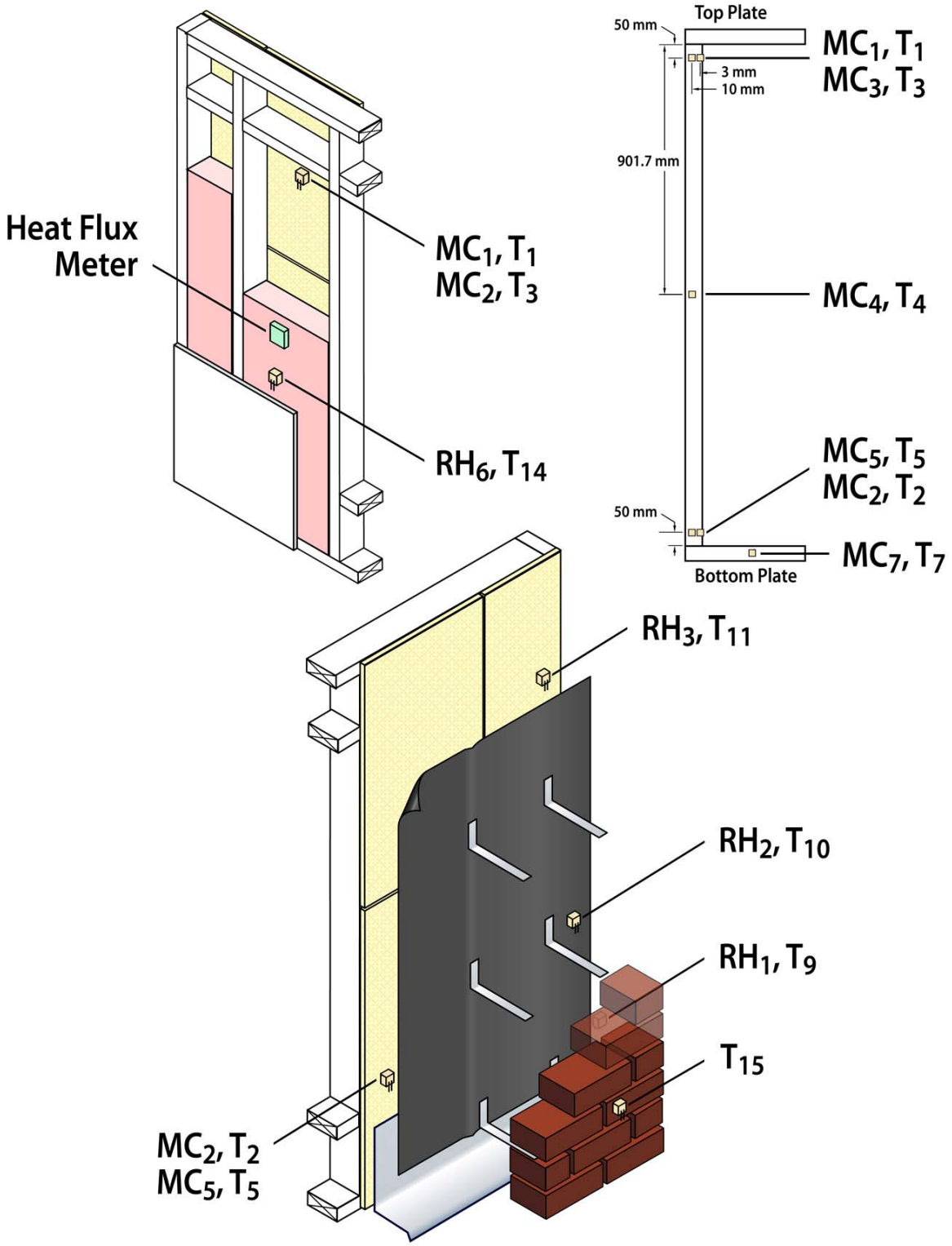

Figure 5: Instrumentation Configuration for Wall 14

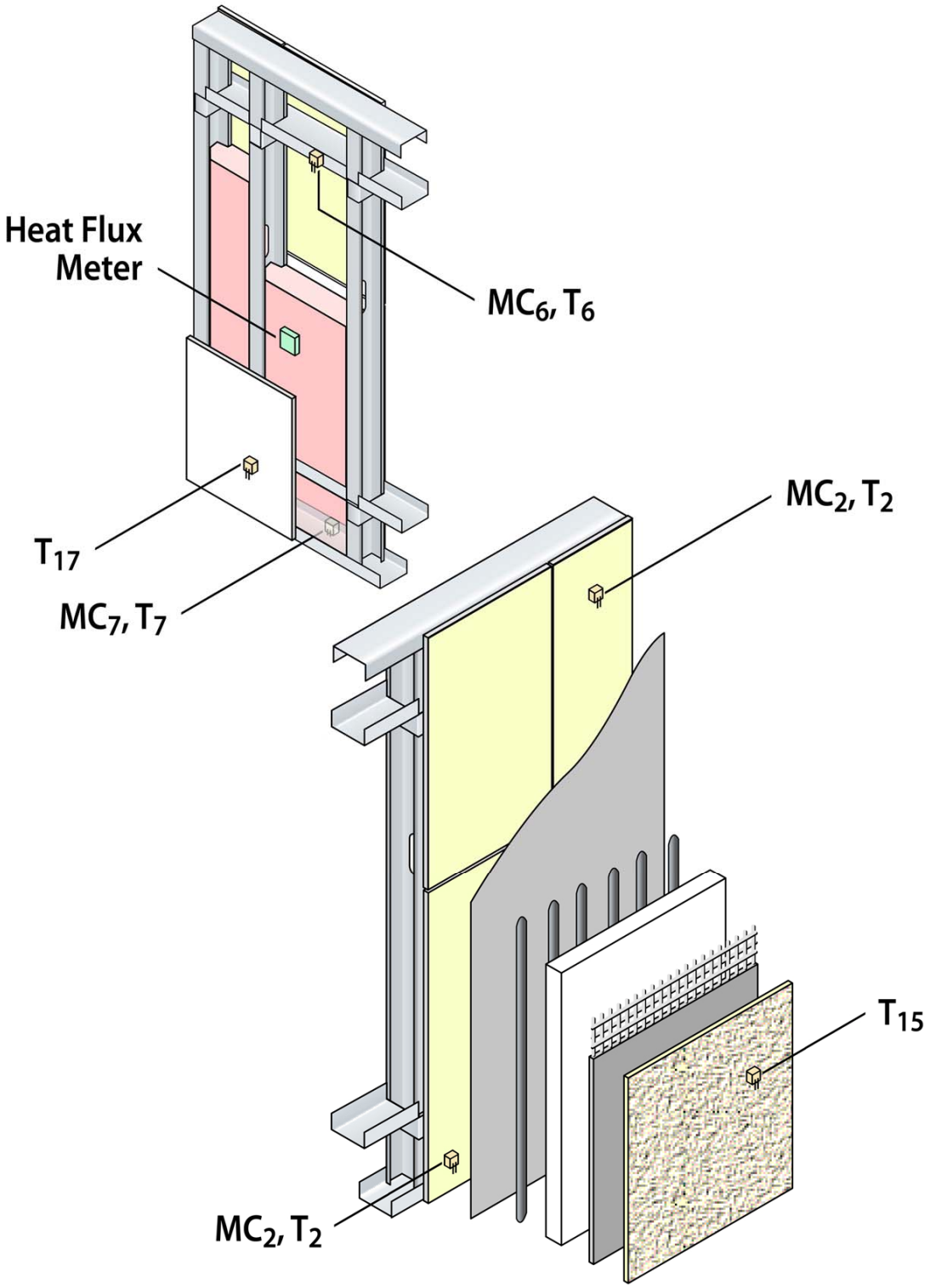

Figure 6: Instrumentation Configuration for Steel Frame Walls

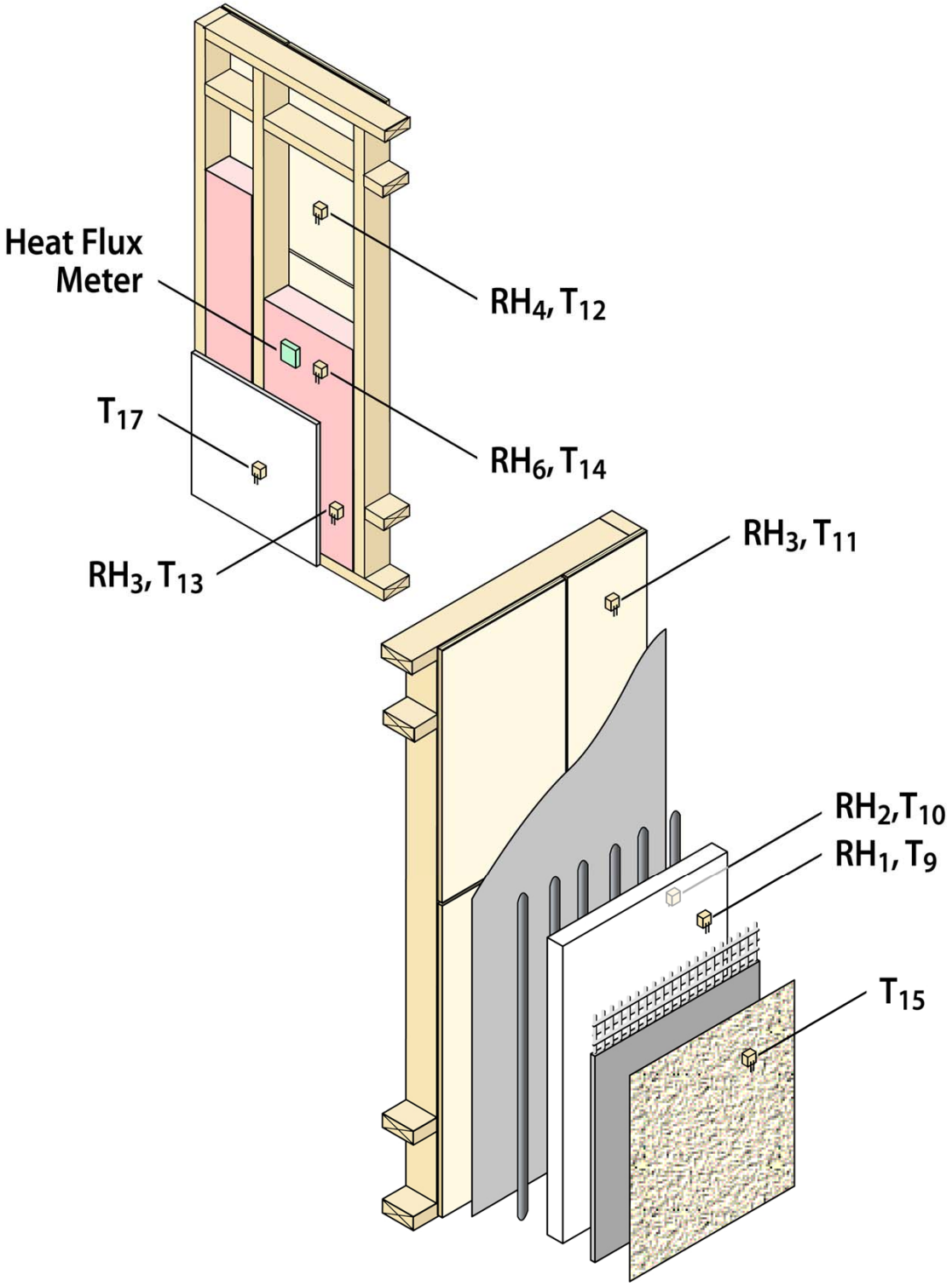

Figure 7: Instrumentation Configuration for Wood Framed Walls

As displayed in Figures 1 through 7, the moisture contents (MC1,T1), (MC3,T3) are located 50mm below the top plate while (MC2, T2) and (MC5,T5) are located 50 mm above the bottom plate. The difference between MC1, MC2 and MC3 ,MC5 is the depth of the moisture pin at either 10 mm or 3 mm respectively.

MC1 and MC2 are closer to the exterior than MC3 and MC5. MC4, is located 901 mm from the top plate into the sheathing board, while MC6 and MC7 are located in the top and bottom plate respectively. MC4, MC6 and MC7 are all located 3 mm into the wood material. MC8 is located in the studs (steel (a small piece of wood is used) or wood) at 1000 mm from the top plate.

The relative humidity sensors are placed in the following manner:

- RH1 attached to the exterior face of the foam or in contact with inner most part of the brick/cement siding, or inner most surface of stucco. (Placed in the middle of stud cavity, TOP)
- RH2 attached to inner face of the foam or weather resistive barrier for brick/cement siding/stucco (Placed in the middle of stud cavity, TOP)
- RH3 bored into the exterior sheathing board (Placed in the middle of stud cavity)
- RH4 attached to the interior sheathing board (Placed in the middle of stud cavity, Top)
- RH5 attached to the interior sheathing board (Placed in the middle of stud cavity, Bottom)
- RH6 attached to the exterior gypsum sheathing (Placed in the middle of stud cavity, Top)

The heat fluxes were measured for the following walls:

- Heat Flux Sensor 1- Wall 1
- Heat Flux Sensor 2- Wall 3
- Heat Flux Sensor 3- Wall 5
- Heat Flux Sensor 4- Wall 6
- Heat Flux Sensor 5- Wall 9
- Heat Flux Sensor 6- Wall 10
- Heat Flux Sensor 7- Wall 11
- Heat Flux Sensor 8- Wall 12
- Heat Flux Sensor 9- Wall 14
- Heat Flux Sensor 10- Wall 15

The heat fluxes sensor was placed in the middle of the stud cavity at mid height of the wall.

CHARLESTON SC EXTERIOR ENVIRONMENTAL LOADS
Long term data
Geographic Characteristics

Hygrothermal weather data was compiled for the geographic location for Charleston, SC. In Figure 8, the annual United States precipitation is displayed in terms of inches of water, and a distinct distribution of geographic precipitation isolines exist.

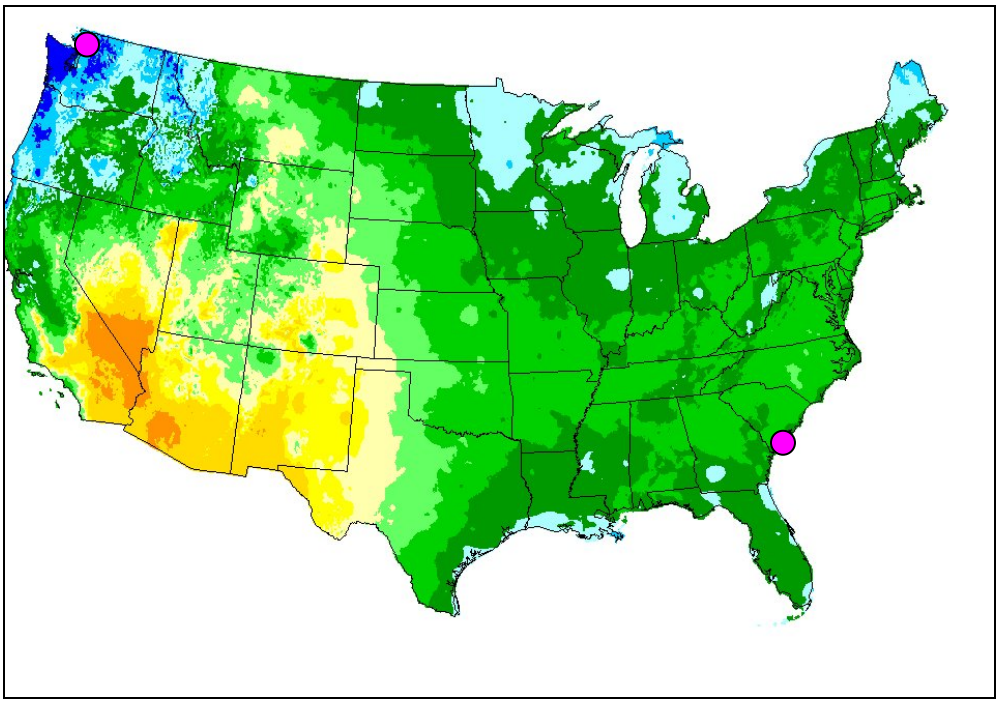

Figure 8: Geographic Location/Yearly Rainfall (Blue- High, Yellow-Low)

In Figure 9, the IECC zones are also shown. These were used by the IECC to develop a method to determine the appropriate application of vapor retarder requirements based on environmental mapping. It is obvious that in the development of Figure 8 a thorough hygrothermal climate analysis was not performed. It is primarily an energy based map with some minor modifications. As such strict adherence to this map to distinguish the hygrothermal features and performances of building envelopes.

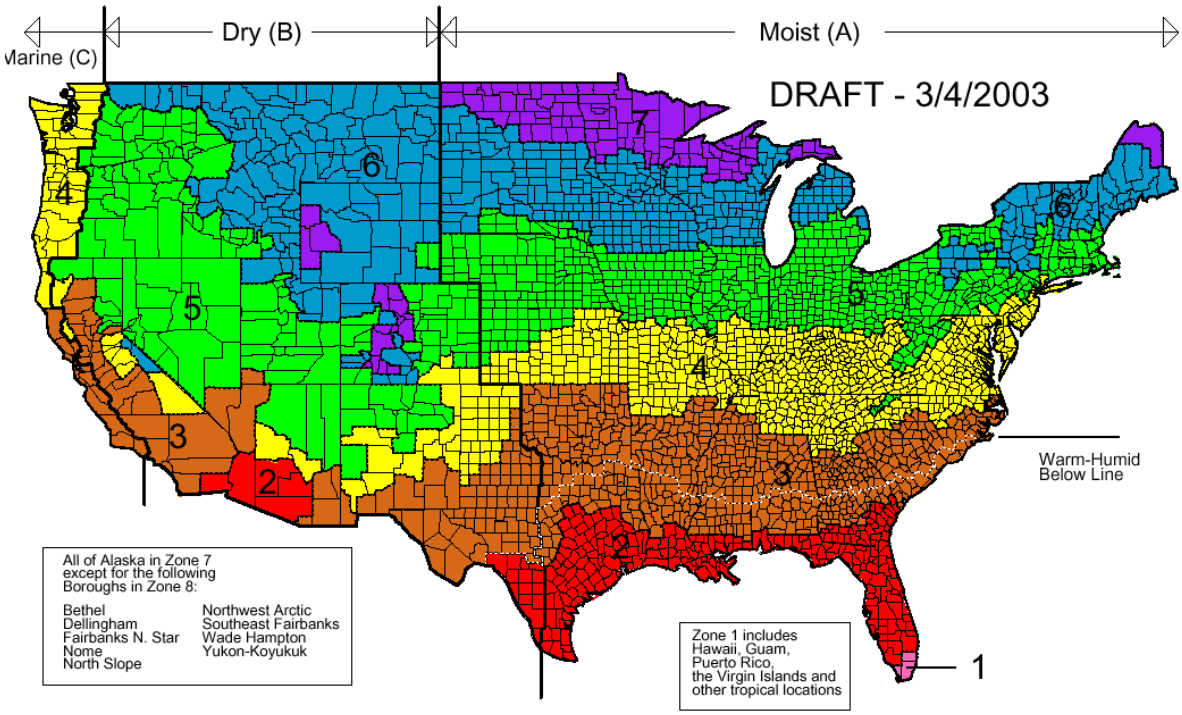

Figure 9: IECC ZONES

In Table 7 the Average Monthly Temperatures and Rainfall are depicted for Charleston, SC. From the multiyear data in Table 1, Charleston receives 48 inches of rain and the average annual 66 ºF.

Table 2: Charleston, SC Average Monthly Temperatures and Rainfall

CHARLESTON/MUN.,SC., UNITED STATES OF AMERICA WorldClimate

Weather station **CHARLESTON/MUN.,SC.** is at about 32.90°N 80.00°W. Height about 14m / 45 feet above sea level.

Average Rainfall

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
mm	75.6	79.6	89.7	63.2	87.3	132.6	169.6	165.4	131.3	85.9	60.7	79.2	1220.9
inches	3.0	3.1	3.5	2.5	3.4	5.2	6.7	6.5	5.2	3.4	2.4	3.1	48.1

Source: CHARLESTON/MUN.,SC. data derived from GHCN 1. 2314 months between 1738 and 1990

CHARLESTON/MUN.,SC., UNITED STATES OF AMERICA WorldClimate

Weather station **CHARLESTON/MUN.,SC.** is at about 32.90°N 80.00°W. Height about 14m / 45 feet above sea level.

24-hr Average Temperature

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
°C	9.7	10.8	14.1	18.1	22.5	25.8	27.2	26.8	24.6	19.4	14.4	10.5	18.7
°F	49.5	51.4	57.4	64.6	72.5	78.4	81.0	80.2	76.3	66.9	57.9	50.9	65.7

Source: CHARLESTON/MUN.,SC. data derived from GHCN 1. 2014 months between 1823 and 1990

When using the US National Climatic Data Center (NCDC) hourly climatic data with 30-year weather data (SAMSON) that include solar radiation and rainfall precipitation data for Charleston, SC.

The first activity required was to develop Moisture Design Years from the 30-year hourly data, by selecting years that represent hygric loads appropriate for moisture design purposes. In the past, hygrothermal modeling used weather data from energy calculation models. Weather years for energy calculations have serious limitations when employed in hygrothermal modeling, as the criteria for their selection is completely different. An analysis procedure developed at the International Energy Agency (IEA), *Annex 24 on Heat, Air and Moisture Transport in Highly Insulated Building Envelopes,* was used in this project to develop two weather years that coincide with the 10th percentile coldest and hottest years with corresponding hygric loads, which are significantly different from those used in energy calculations. The influence of rain load was included in the analysis to determine the hygric loads. The reason for using the 10th percentile year data (rather than the worst conditions) was that a seasonal adjusted condensation load may be allowed to occur once every 10 years. This load was expected be effectively dissipated by the envelope systems, as some moisture capacity in terms of storage and release is present in most walls. Hourly temperature and relative humidity data are plotted out in Figures 11 and 12. The hourly rain precipitation is plotted out in Figure 13.

Wind-Driven Rain

Wind-driven rain is a critical hygrothermal load. Indeed, in most instances, this load is several times greater than all other loads combined. As such, the selection of orientation for the hygrothermal simulations must be assigned based on analysis of the amount of water load each orientation receives. The maximum load must be established for each orientation before a moisture engineering analysis is preformed. This requires a better understanding of the prominent wind direction and concurrent wind driven rain occurrences. In this project, the analysis was performed for both weather files (10th percentile coldest and hottest year) used in the hygrothermal simulations. As depicted in Figure 10 for Charleston, SC the two of the highest wind-driven rain locations were oriented East and South.

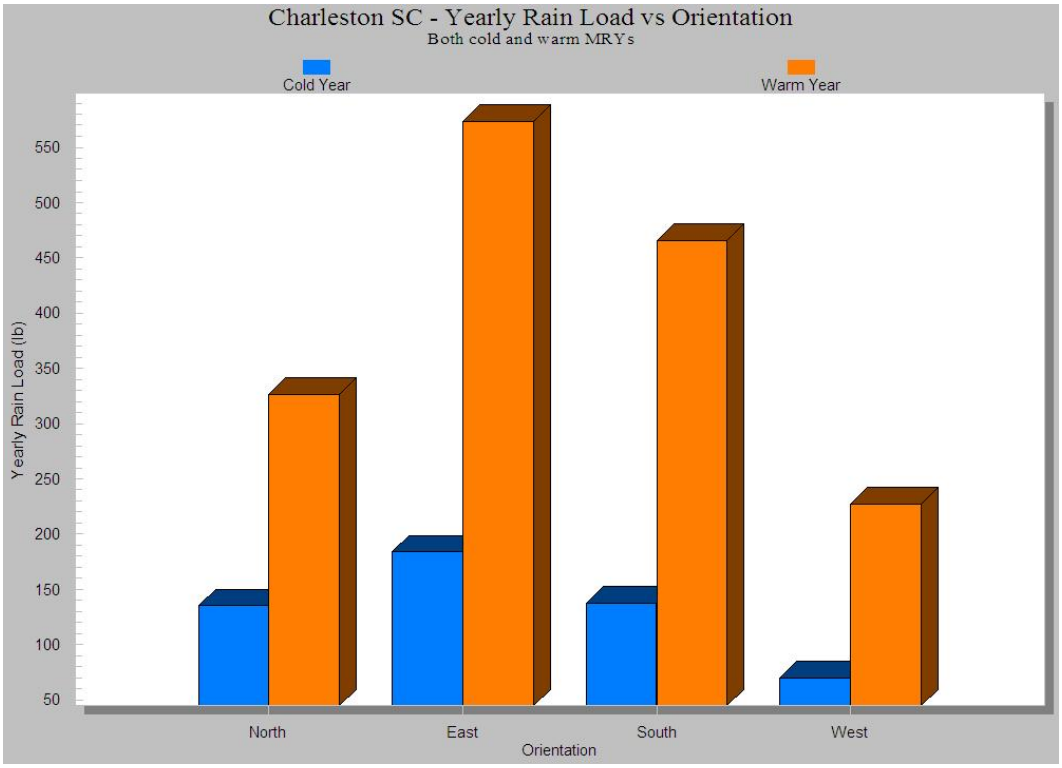

Figure 10: Wind-Driven as a function of Orientation

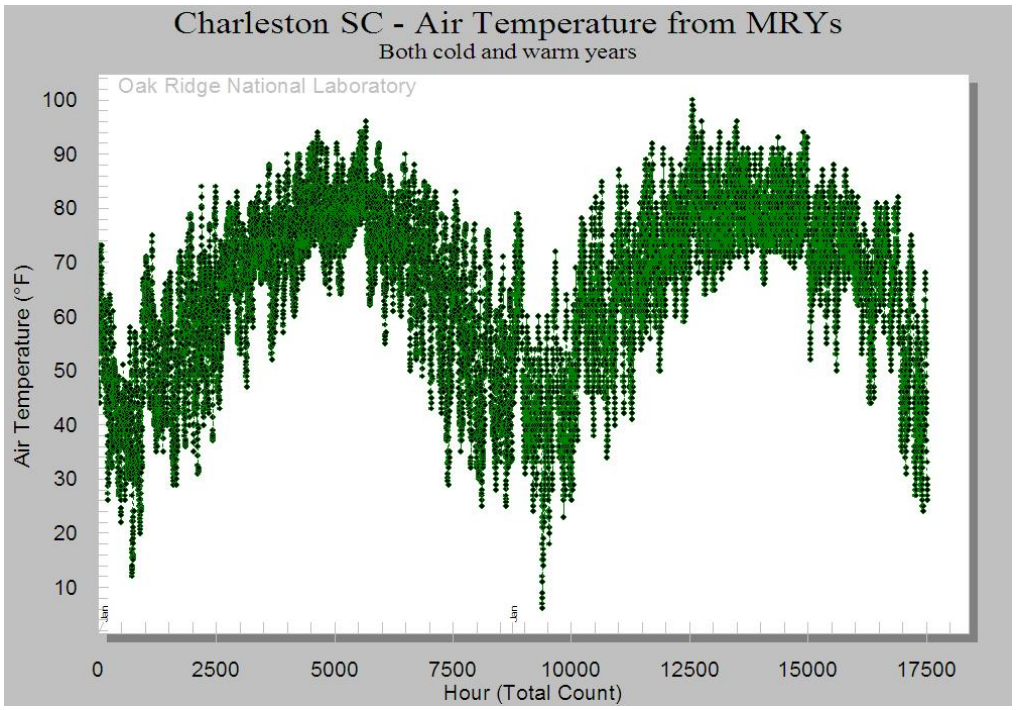

Figure 11: Hourly Air Temperatures for the 10 % cold and hot years

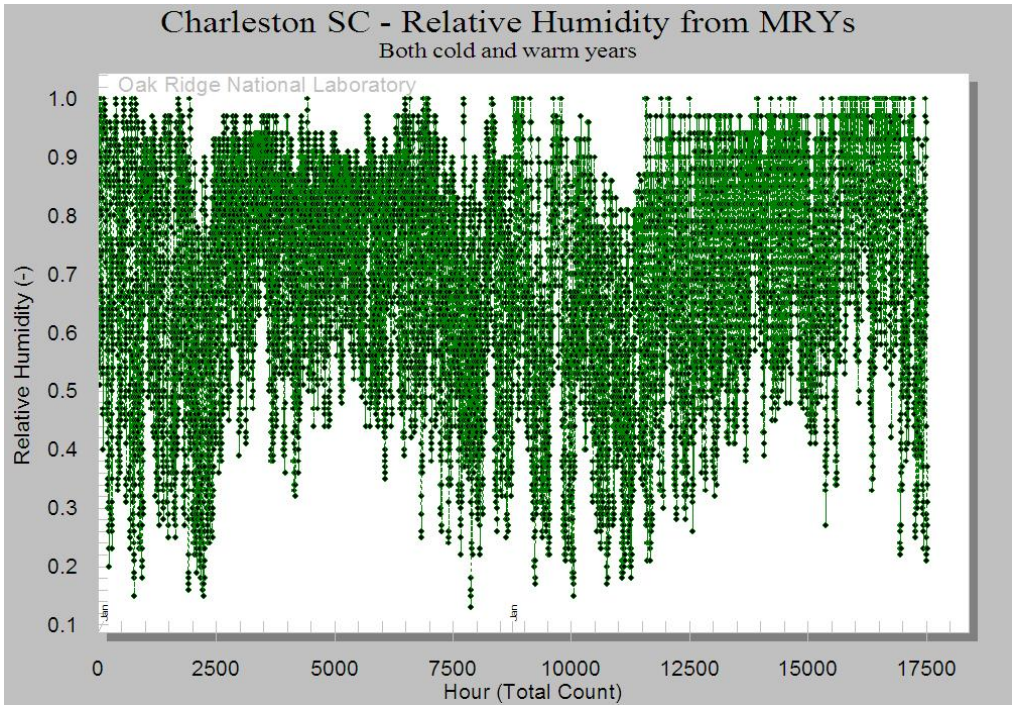

Figure 12: Hourly Relative Humidities for the 10 % cold and hot years

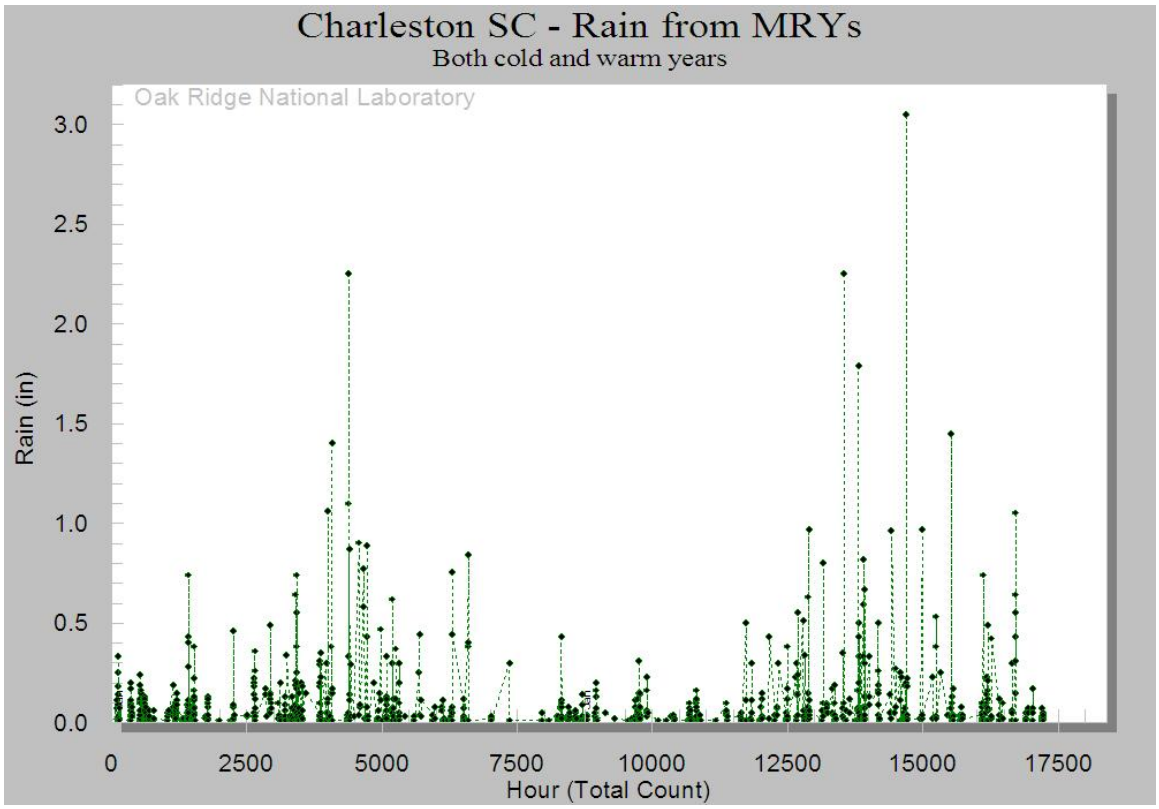

Figure 13: Hourly Rain Precipitation Air Temperatures for the 10 % cold and hot years

Measured Interior and Exterior Environmental Conditions

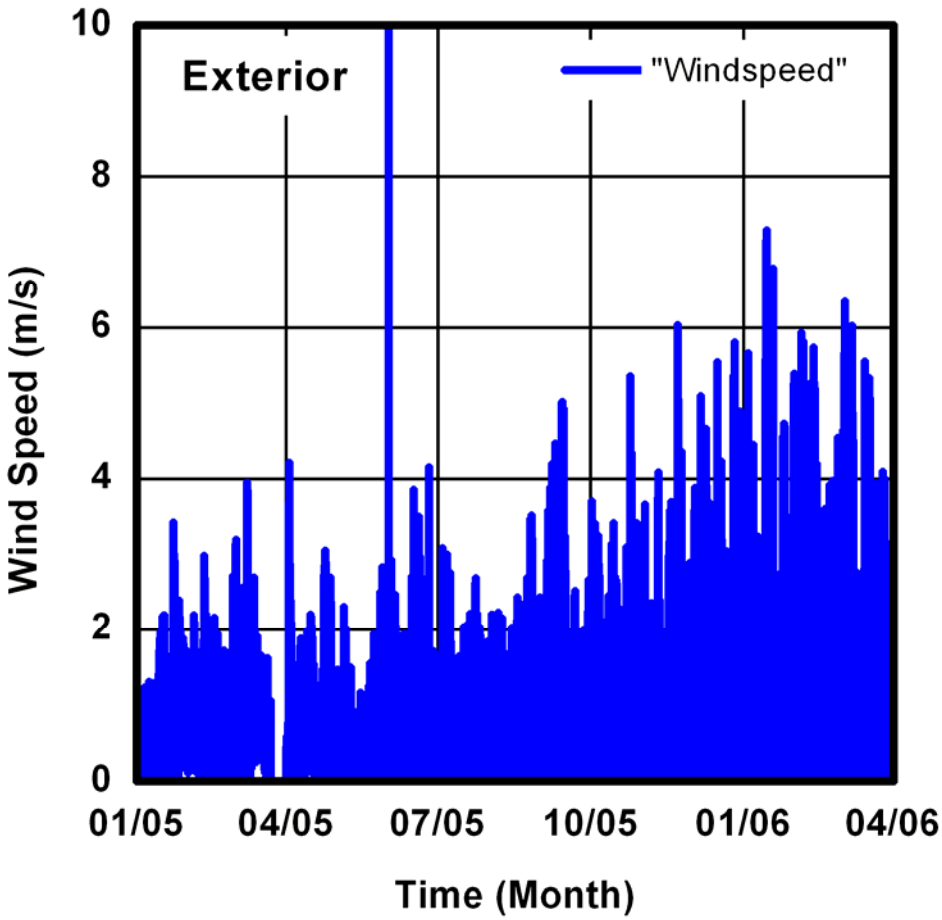

Figure 14: Wind Speed

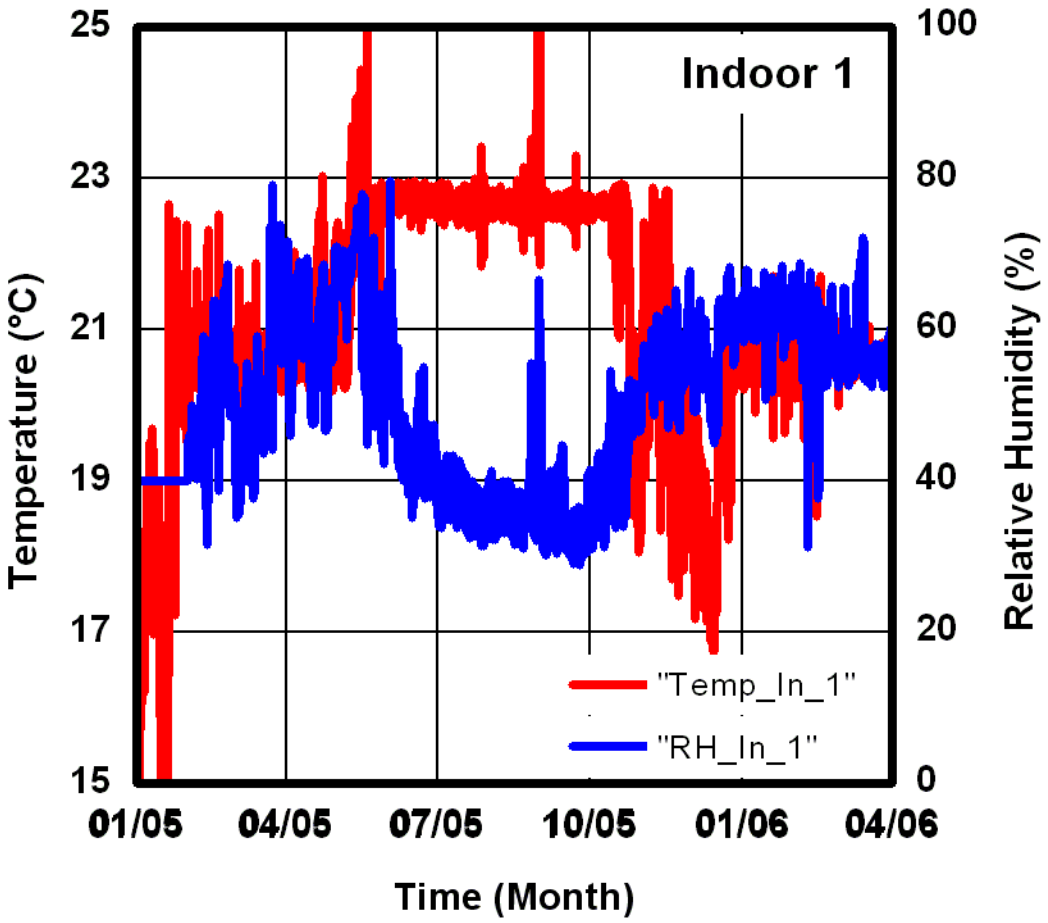

Figure 15: Temperatures and RH for Section 1

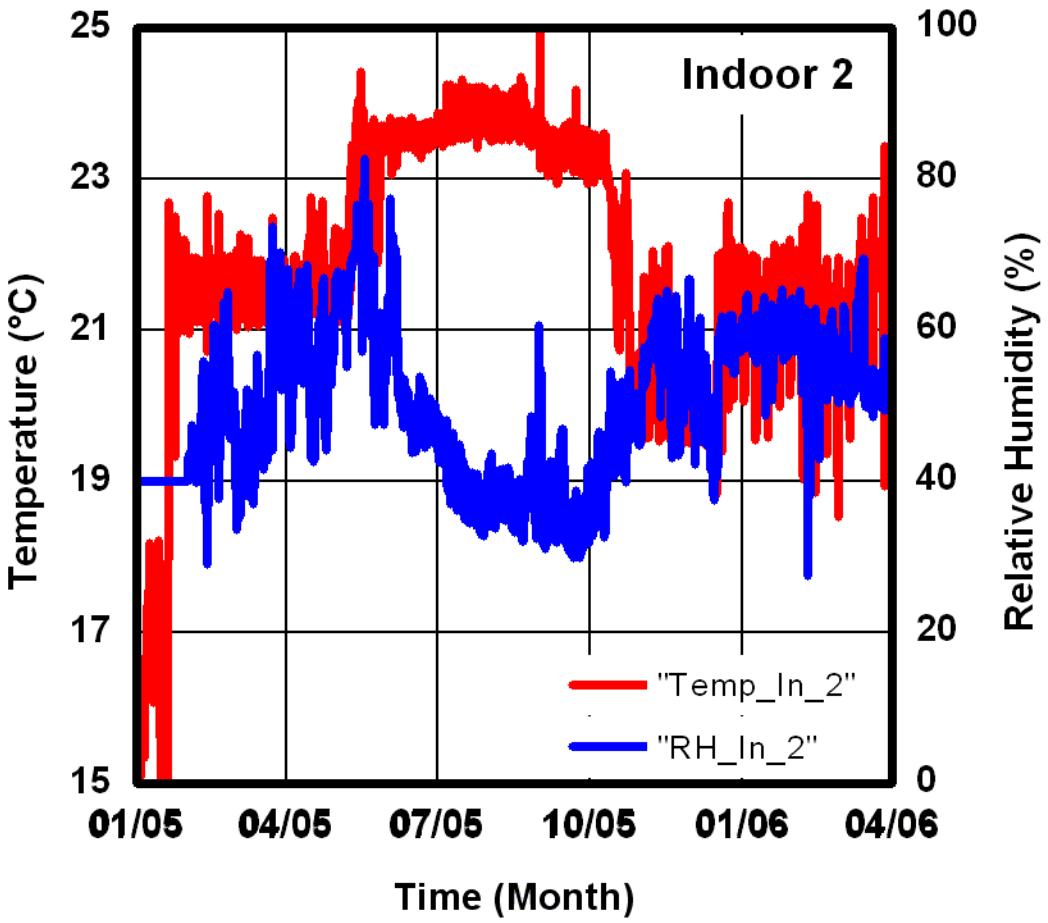

Figure 16: Temperatures and RH for Section 2

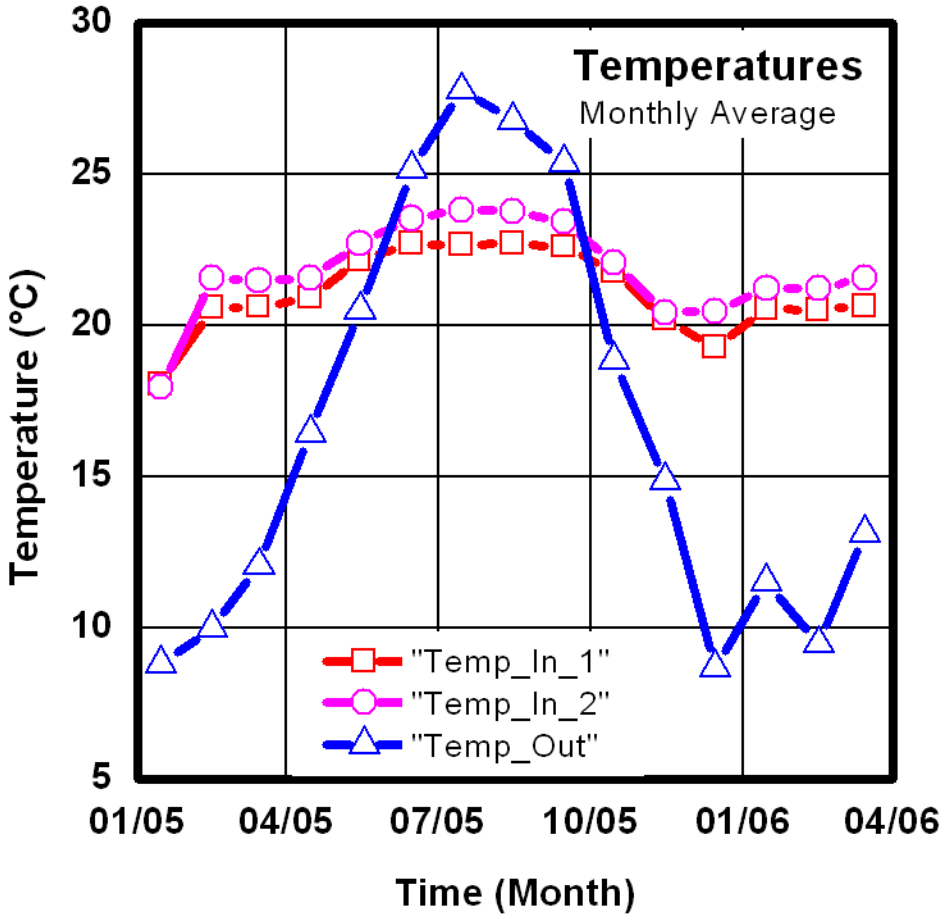

Fig. 17: Monthly Averaged Temperatures for Interior and Exterior

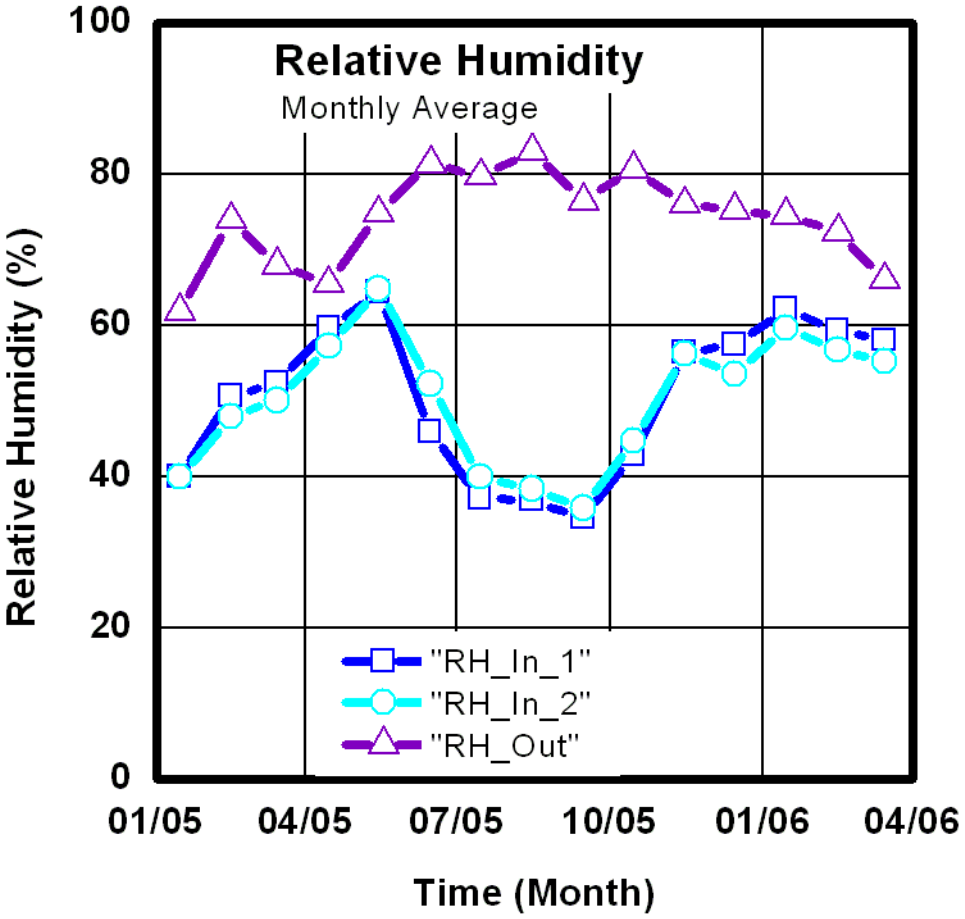

Fig. 18: Monthly Averaged Relative Humidities for Interior and Exterior

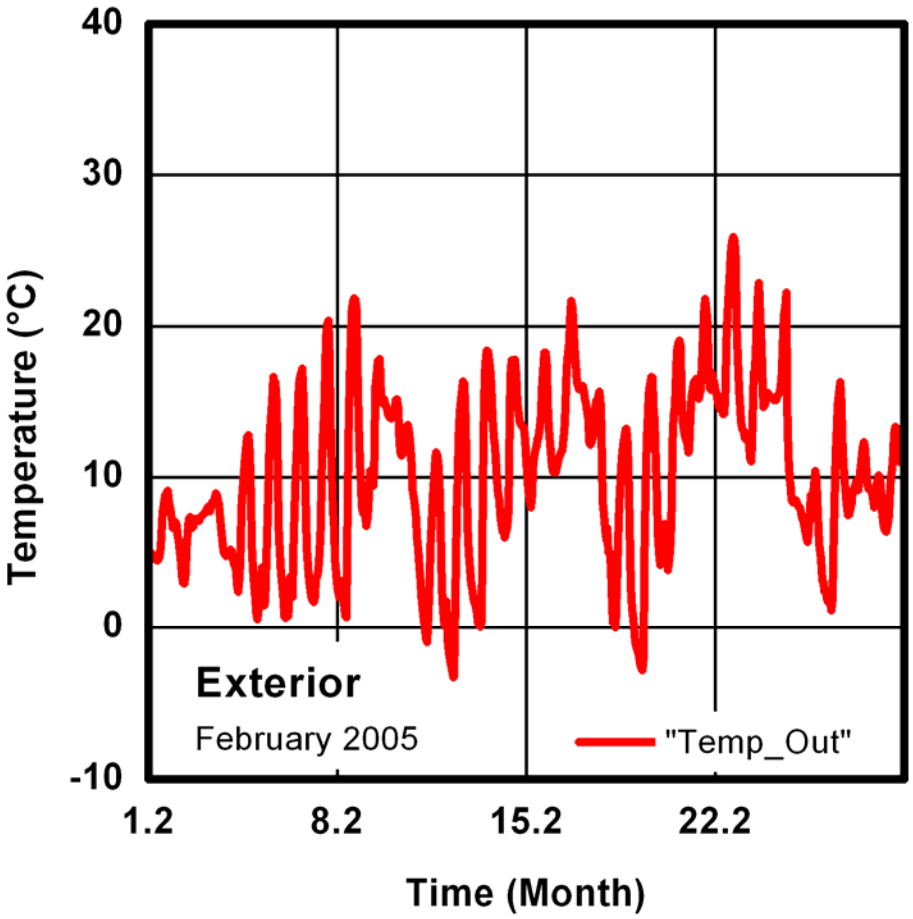

Figure 19: Exterior Temperatures (Winter)

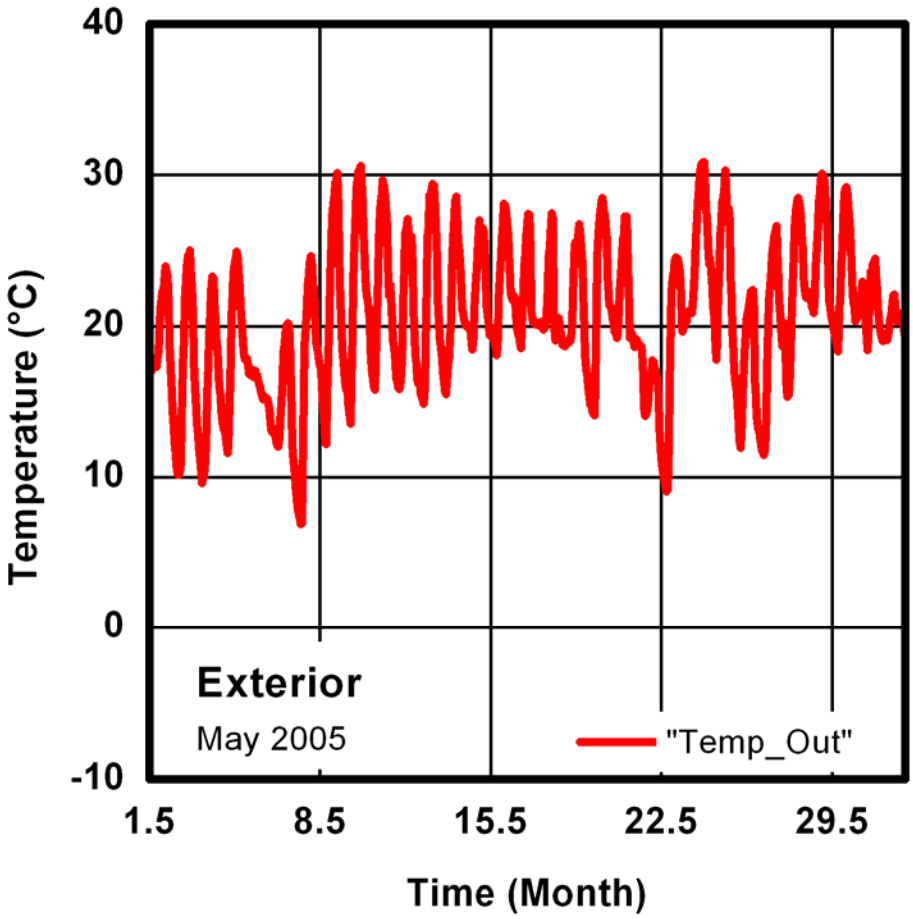

Figure 20: Exterior Temperatures (Spring)

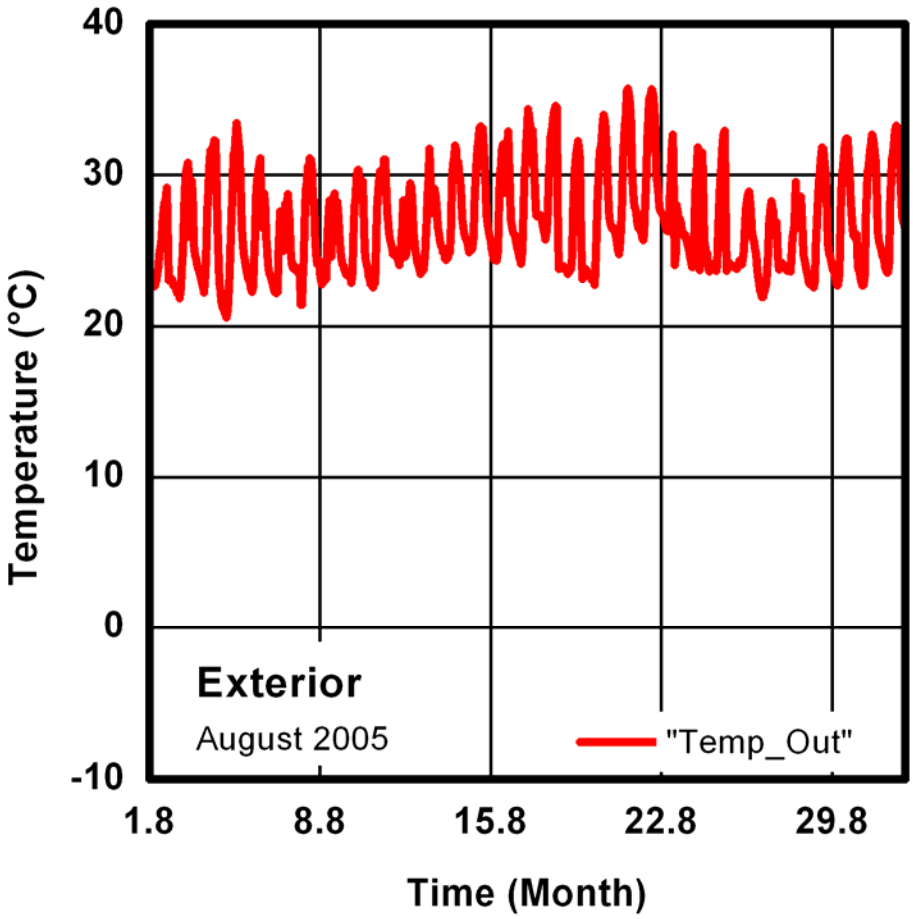

Figure 21: Exterior Temperatures (Summer)

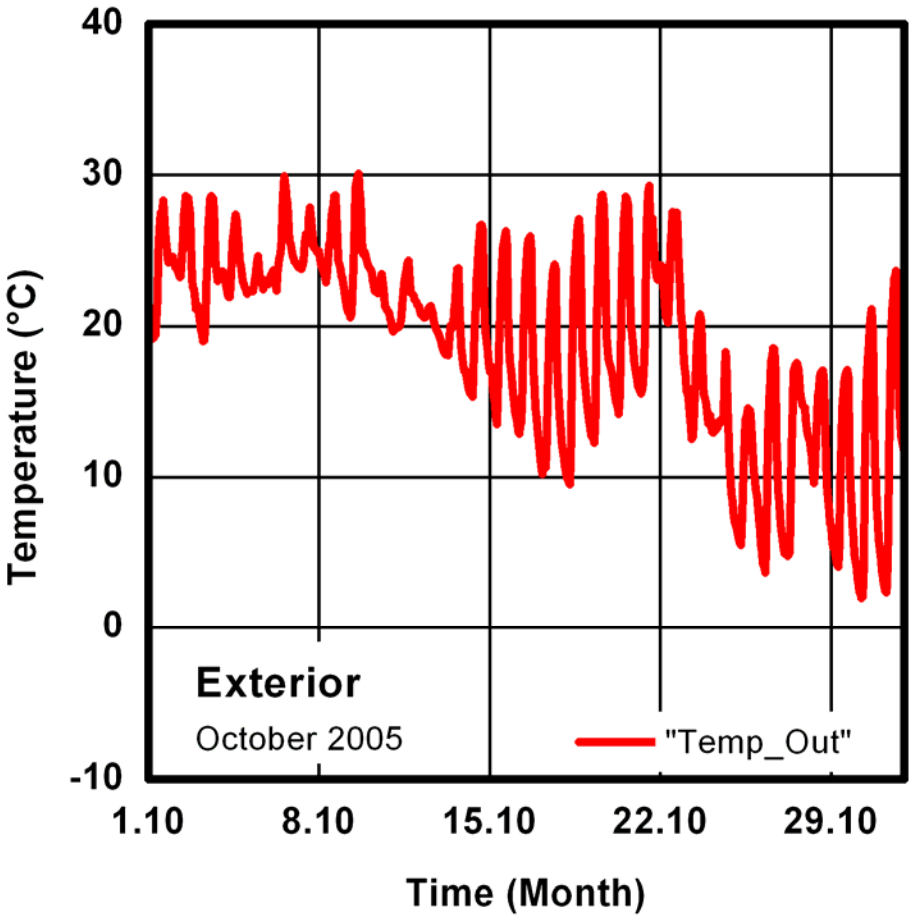

Figure 22: Exterior Temperatures (Fall)

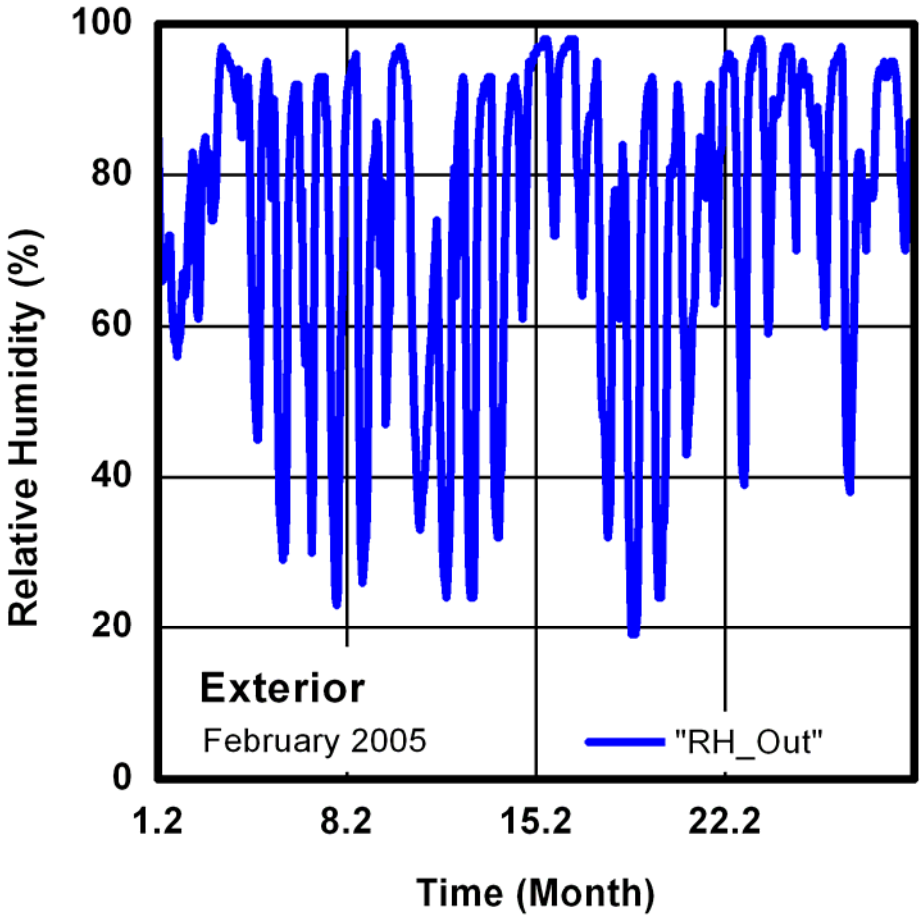

Figure 23: Exterior Relative Humidity (Winter)

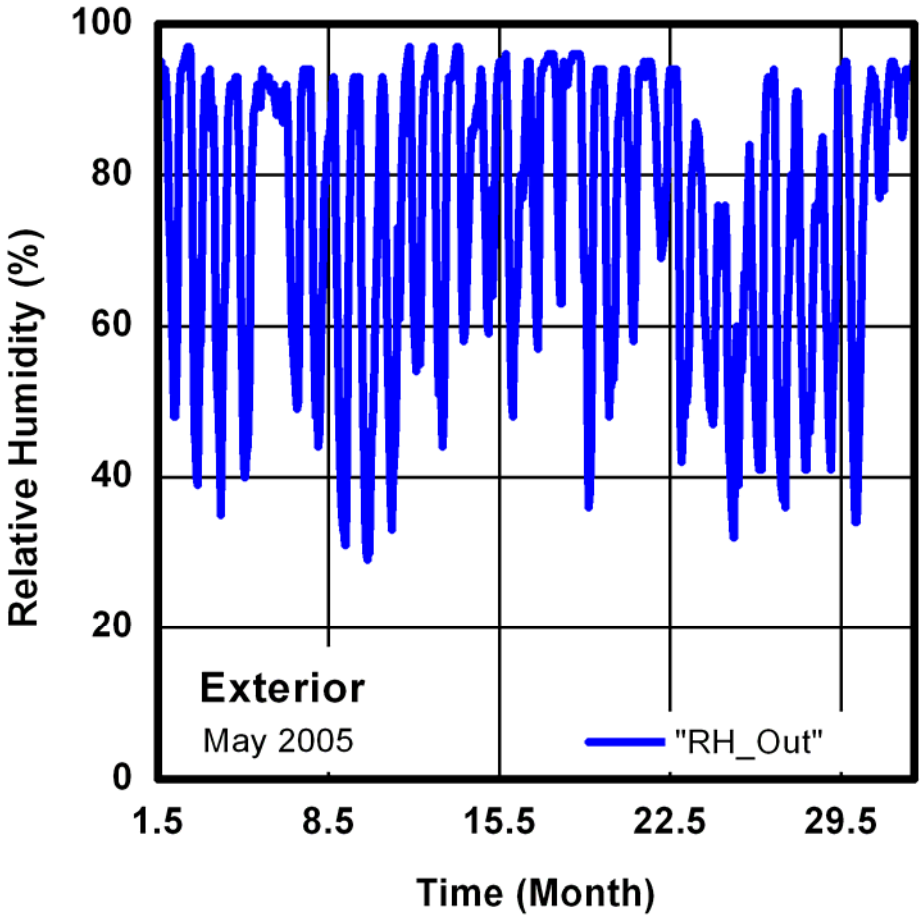

Figure 24: Exterior Relative Humidity (Spring)

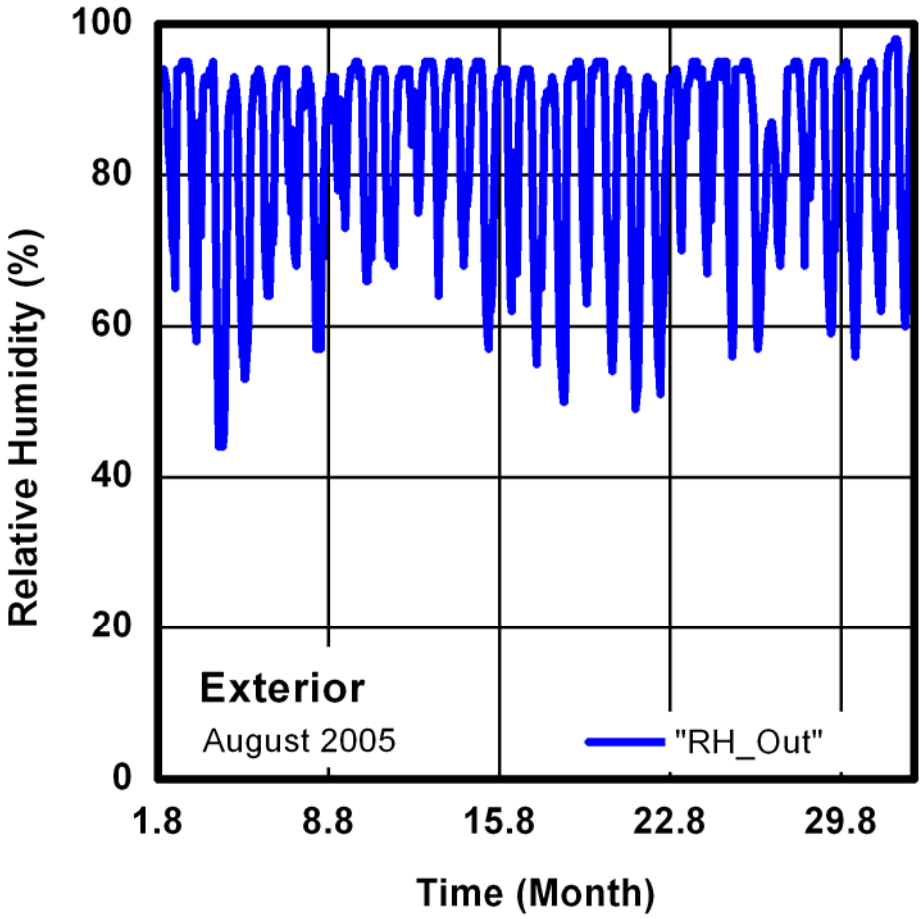

Figure 25: Exterior Relative Humidity (Summer)

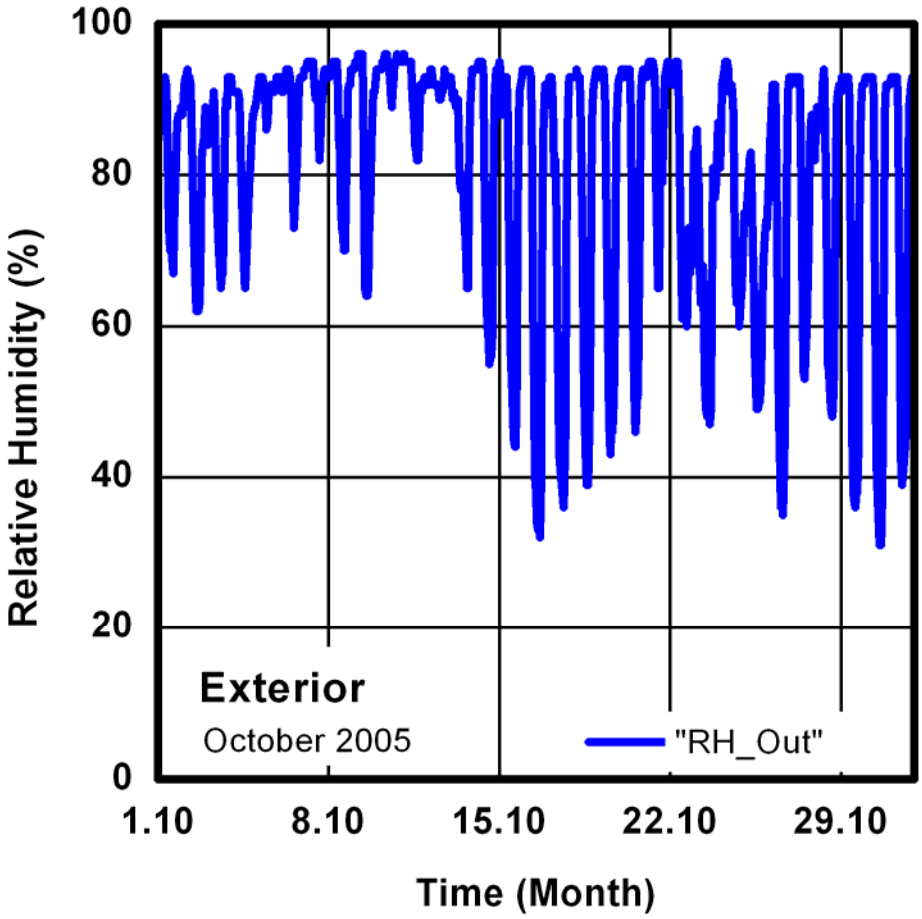

Figure 26: Exterior Relative Humidity (Fall)

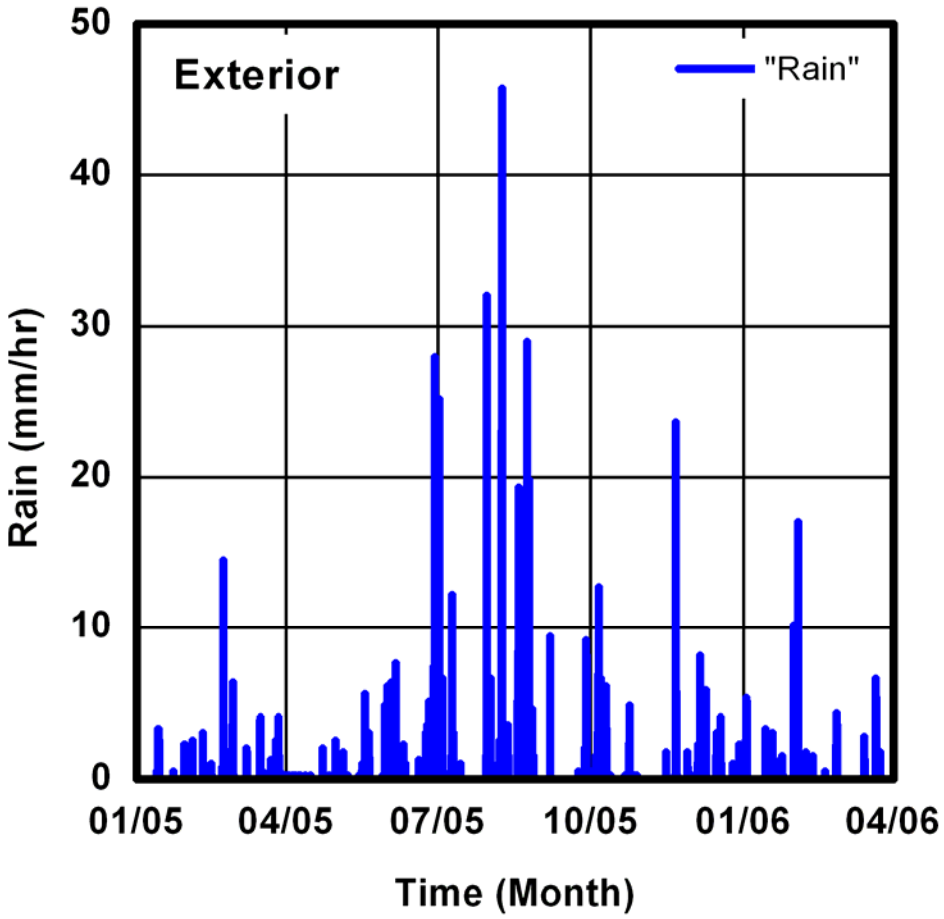

Figure 27: Rain Horizontal

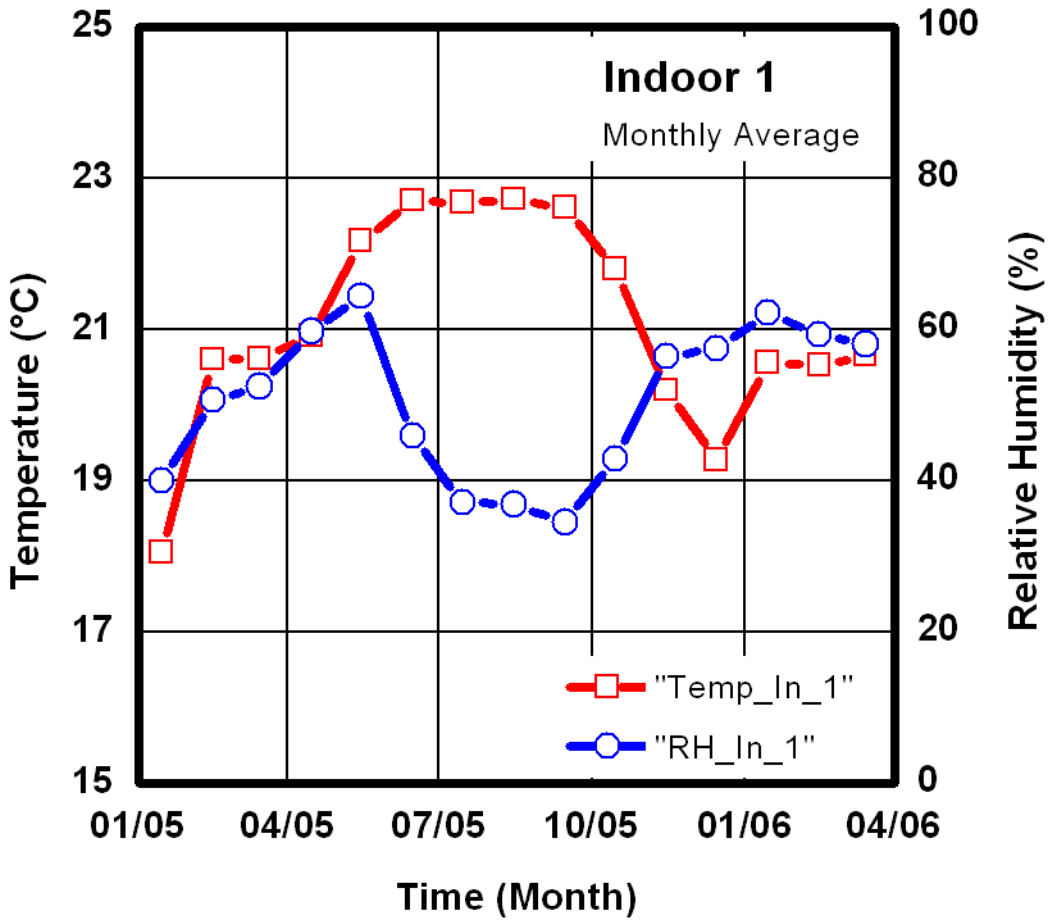

Figure 28: Interior RH for room 1 of NET Facility

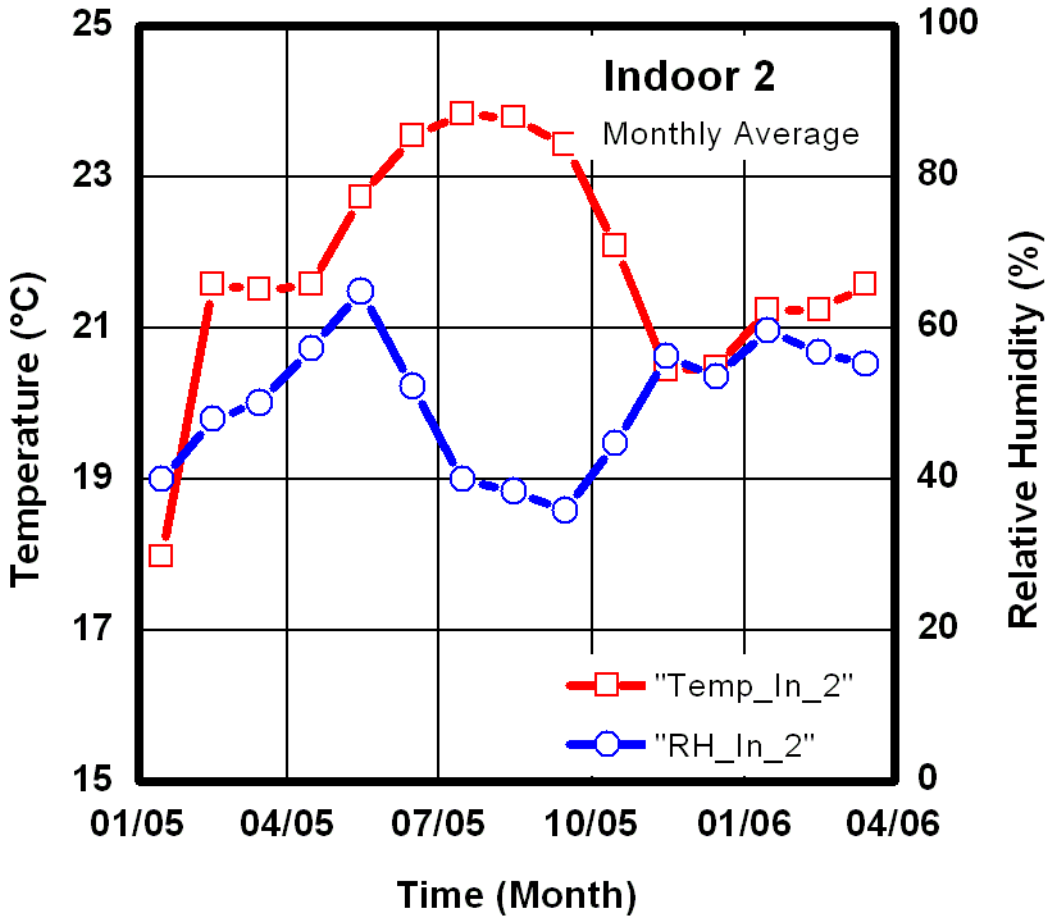

Figure 29: Interior RH for room 2 of NET Facility

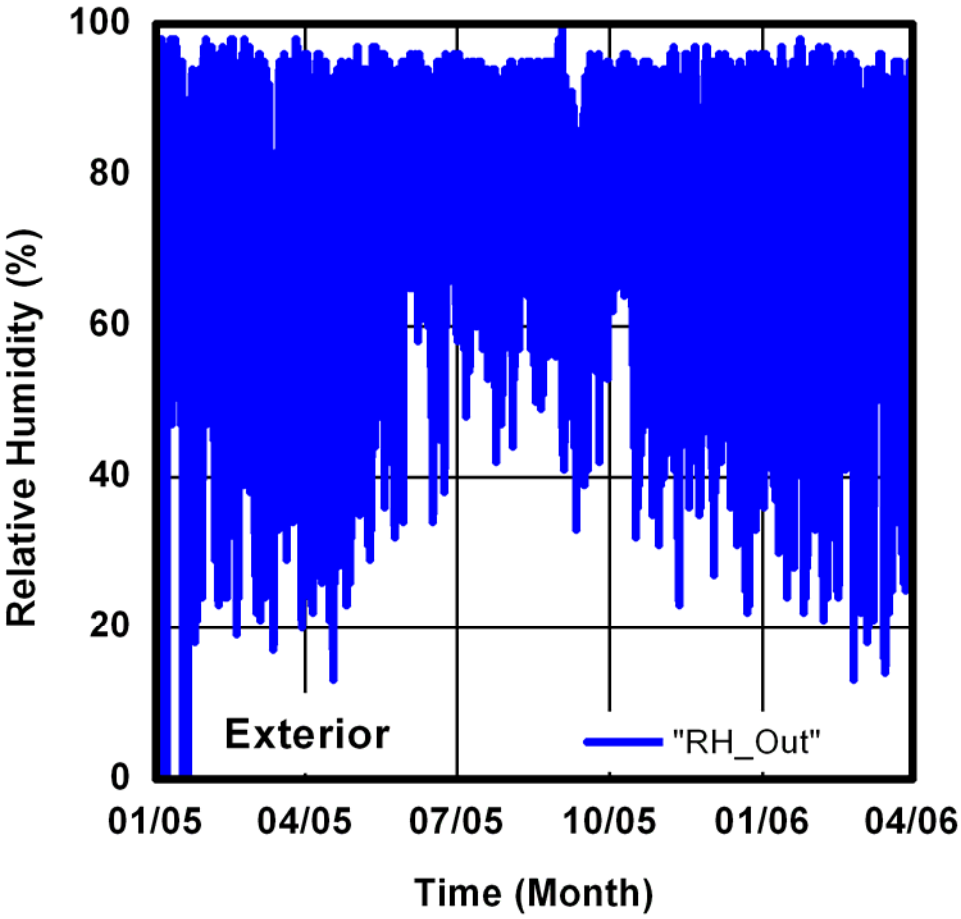

Figure 30: Exterior RH

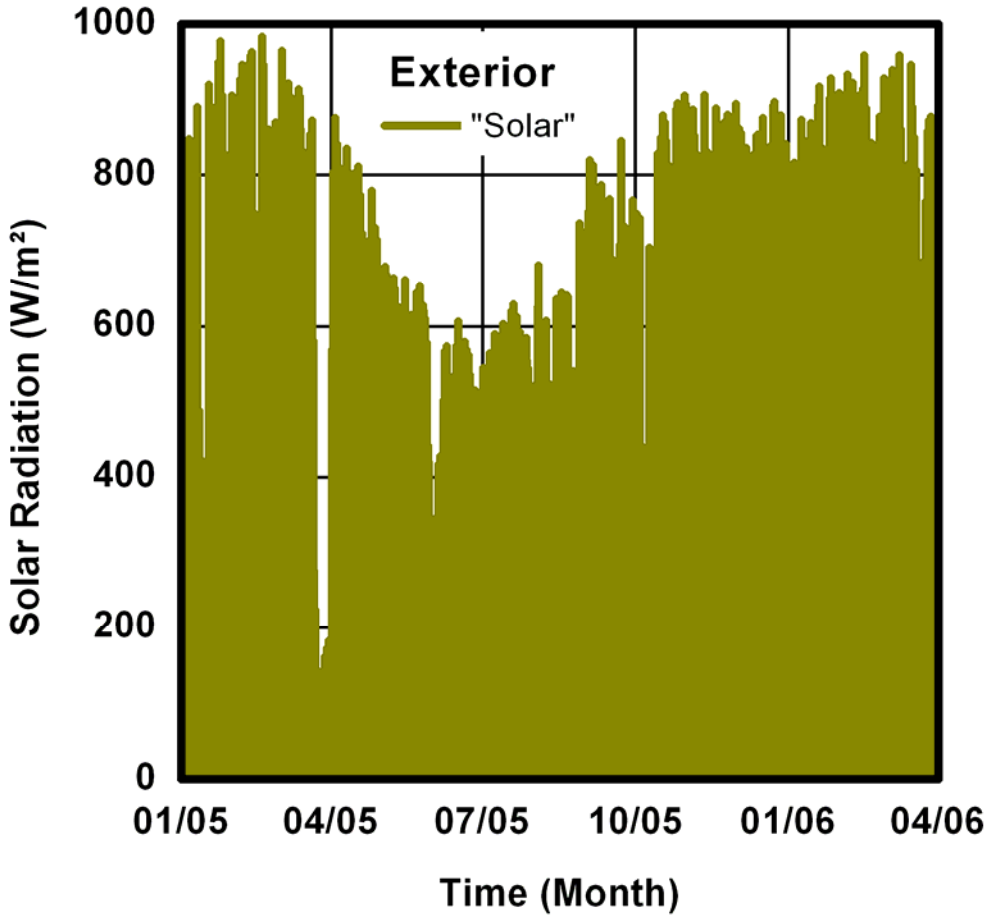

Figure 31: Measured Solar Radiation

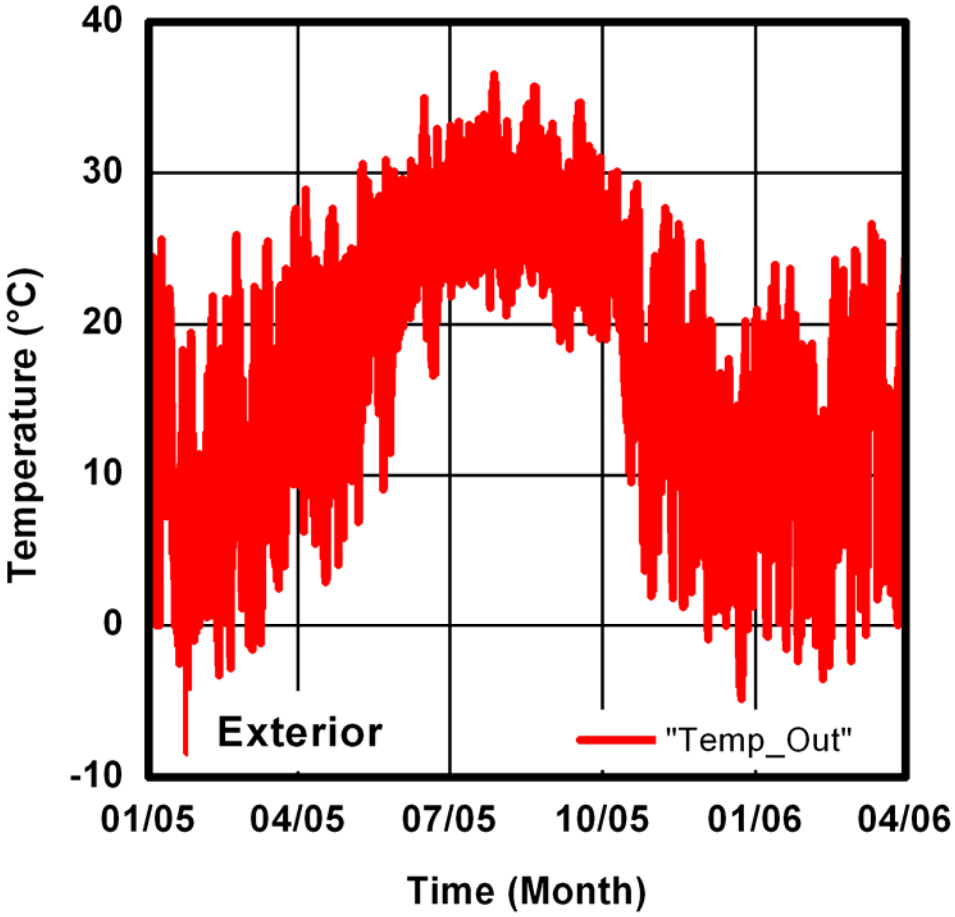

Figure 32: Measured Exterior Temperature

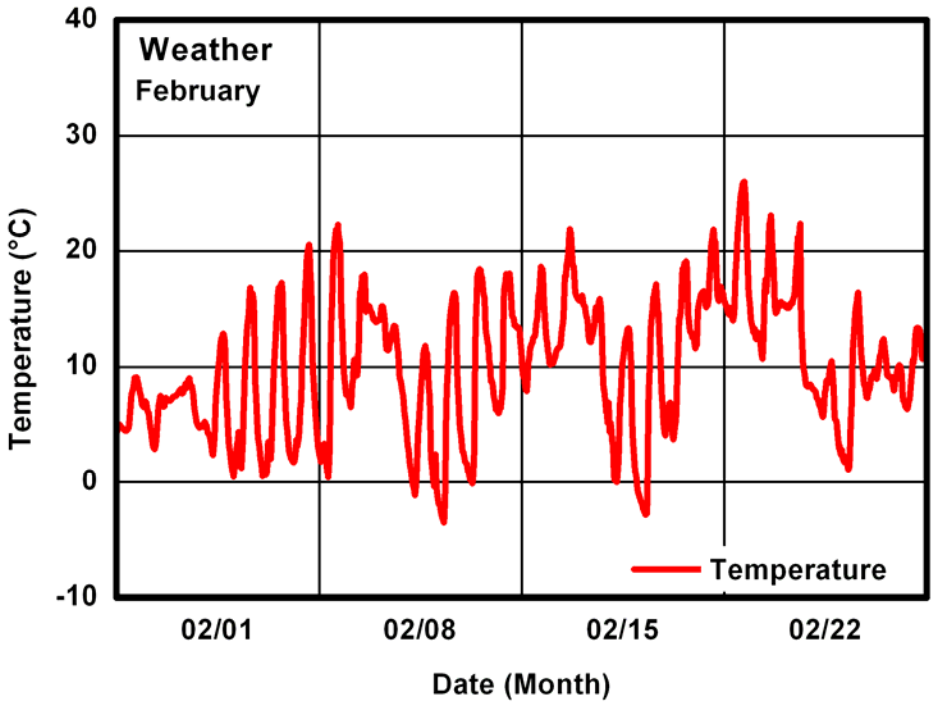

Figure 33: Measured Exterior Temperature

RESULTS: MEASURED DATA

In the following graphs the average monthly data are presented for moisture content (all locations), relative humidities (all locations) and vapor pressures (all locations). As a full year cycle is not available only the short term performance is displayed. Results are shown for the period of January 2005 to March 2006.

The sensor locations have been presented in the Wall Instrumentation Layout section in this report. Also additional information for each of the sensor used in this study is given in Report 1. The reader is encouraged to read Report 1 for information of the data analysis and collection approach.

In Figures 34 to 41 the moisture content comparison at the same designated location for all walls (panels) is shown. Results have been averaged on a monthly basis, and monthly values are plotted out. The moisture content is show in a comparative fashion for each wall system. It is important to notice that the results presented here are developed by employing calibration curves that were not developed in-house by ORNL. It is expected that these calibration curves will be adjusted as soon as in-house calibration data become available. For the current period, the moisture content results should be envisioned as temporary results.

In Figures 42 to 56 show the comparison of the relative humidity as a function the six installed locations for each of the 15 walls. Locations 1 & 2 are on both sides of the exterior insulation, or as described in the Wall Instrumentation Layout section. location 3 and 4 on both sides of the sheathing board, location 5 is at the bottom interior of the sheathing wall and location 6 coincides with the exterior most of the interior sheathing (gypsum board).

In Figures 57 to 71 show the temperatures for each of the 6 relative humidity sensors in the 15 walls.

Discussions of Results

The moisture content results show that all wall systems demonstrate cyclic performance in terms of wall wetting and drying as a function of time of year. Indeed the results show that initially the walls had high moisture loads, which was reduced during the spring and summer season to the lowest levels. During the fall these levels started creeping upwards but did not exceed 12 % with the exception of moisture pin 1 in wall 1 (concrete block). The initial moisture content of the walls was substantially different for each wall system.
The relative humidity data provide a significant amount of insight. The accuracy of these sensors is significantly higher than those due to the measurements of the moisture content. The results show that substantially differences are present among the various walls. Distinct hygrothermal responses have been found among the various wall systems. From the results the following summaries can be deducted

- The walls with polyethylene vapor retarders were found to have higher wood moisture content present. Excessive interior insulation vapor pressures (80 % and higher) were present. The results from this study clearly indicate that the use of poly as a vapor retarder is not a good strategy. It is therefore recommended that the interior vapor retarder should be vapor open and not provide a resistance to moisture drying in climates similar to Charleston, SC (hot and humid).
- EIFS wall may employ housewraps as exterior weather resistive barriers, however, moisture movement and accumulation is higher in these wall systems when compared to trowel applied weather resistive barriers. In climates such as Charleston (Hot and Humid) it becomes critical to employ open vapor retarder strategies (for example high water vapor permeance paint coatings)
- Groove insulation improves the performance of EIFS wall systems, as venting becomes possible.
- Vertical ribbons as drainage layers and air spaces contribute positively towards the hygrothermal performance of the walls.
- Steel stud systems with gypsum sheathings when compared to wood frame and wood sheathing systems, perform slightly better for interior vapor control strategies that are open (higher water vapor permeance).
- The best performing wall system was found to be the 4 inches exterior insulation wall system without any interior stud insulation (no fiberglass present). This wall outperformed all other walls in terms of moisture management.
- Walls with exterior air space ventilation (open top and bottom) provided less hygric differences and in that regard performed better than those walls with just venting. However these differences are not significant for well constructed wall systems without water penetration present.
- When comparisons between exterior claddings with building paper and EIFS with liquid applied membranes significantly better performance was provided by the EIFS systems.
- For all vapor open interior vapor retarder strategies, the worst wall in terms of hygrothermal performance was the brick system, followed by the stucco clad systems (3-coat and 1-coat), and then the cementitious cladding. It should be noted that the brick employed in the walls was not particular liquid absorptive, and would be representative of a very good quality brick for the Charleston (hot and humid) area.

Conclusions:

This report provides performance data on 15 walls systems that have been monitored for a period of 1 year and 3 months (01 January 2005 till 30 March 2006).

The monitored results are displayed in terms of monthly averaged data and provide insight on the heat and moisture performance of the walls for a 15 month period. A number of parameters have been investigated such as, the effect of weather resistive membrane systems (spun-bonded polyolefin, liquid applied membranes, 60 min building papers), the effect of cladding systems (EIFS, Brick, Stucco, Cementitious Board), the effect of ventilation type (unvented, vented and ventilation), effect of insulation placement (exterior only or exterior and interior) and the effect of interior vapor control strategies.

The results indicate that the most critical parameters found in this hygrothermal study are:

a) The type of exterior cladding (brick wall systems tend to accumulate more moisture).
b) The type of interior vapor control strategy (vapor open must be used in all walls examined in this study).
c) Insulation placement is more beneficial to be concentrated towards the exterior.
d) Trowel led applied liquid membranes outperform the spun-bonded polyolefin membranes in this study.
e) Ventilation provides a beneficial effect on the performance of the walls investigated. Vented systems are also beneficial.
f) EIFS wall with Steel stud and gypsum sheathing perform better than wood frame systems in terms of moisture management. The differences are small.

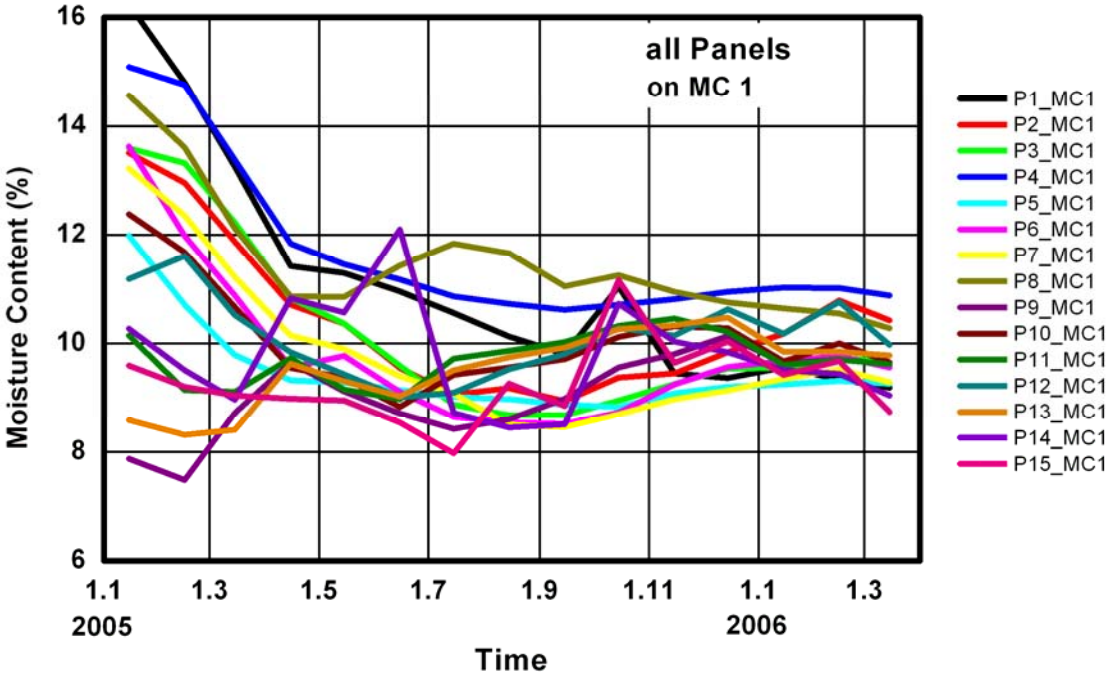

Figure 34: Measured Moisture Contents at Location 1

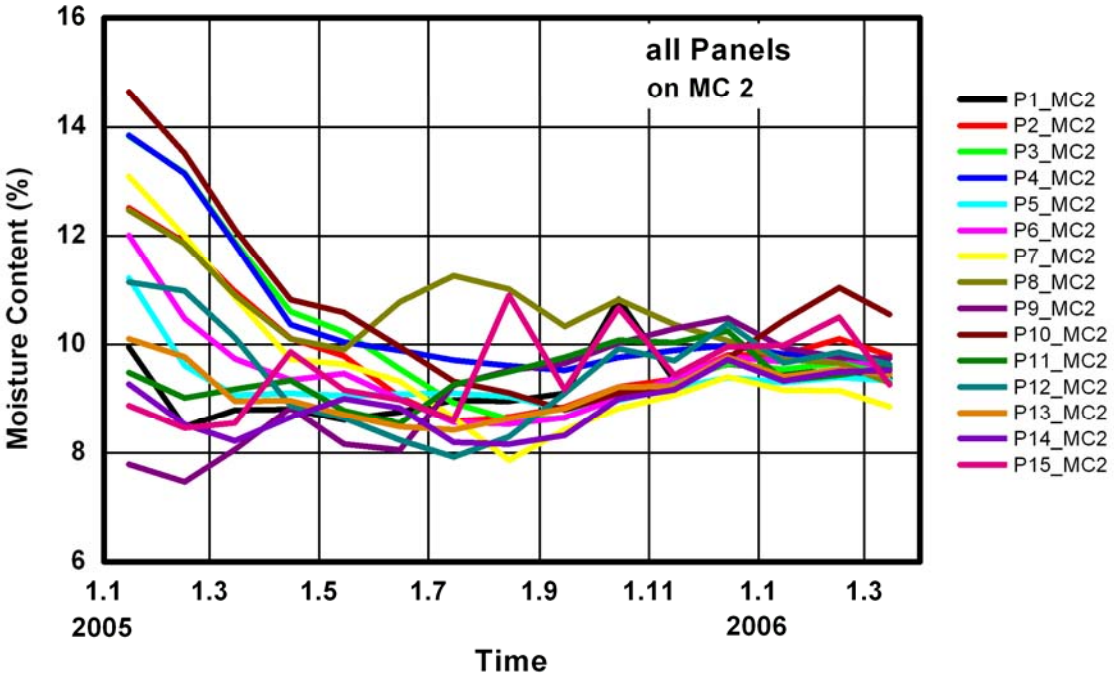

Figure 35: Measured Moisture Contents at Location 2

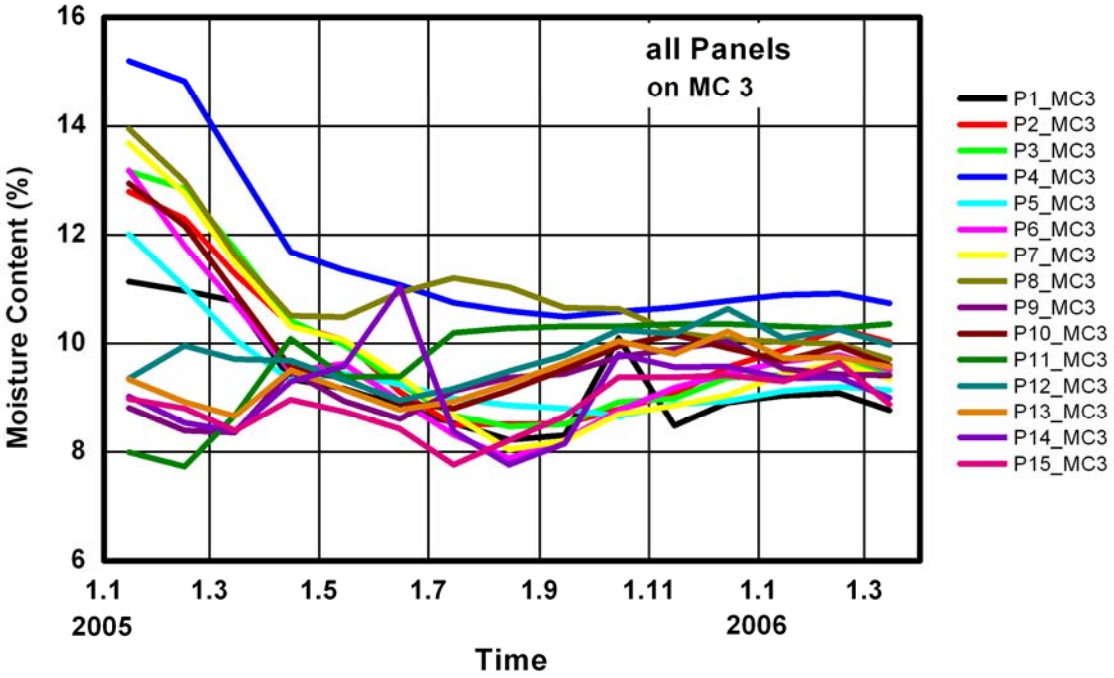

Figure 36: Measured Moisture Contents at Location 3

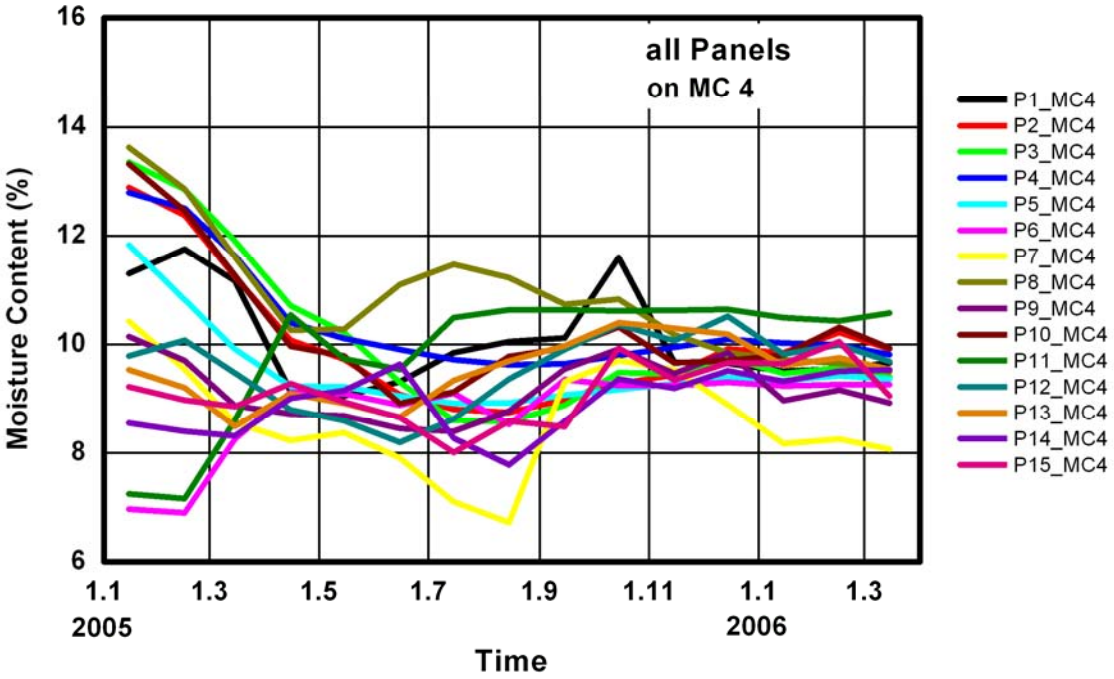

Figure 37: Measured Moisture Contents at Location 4

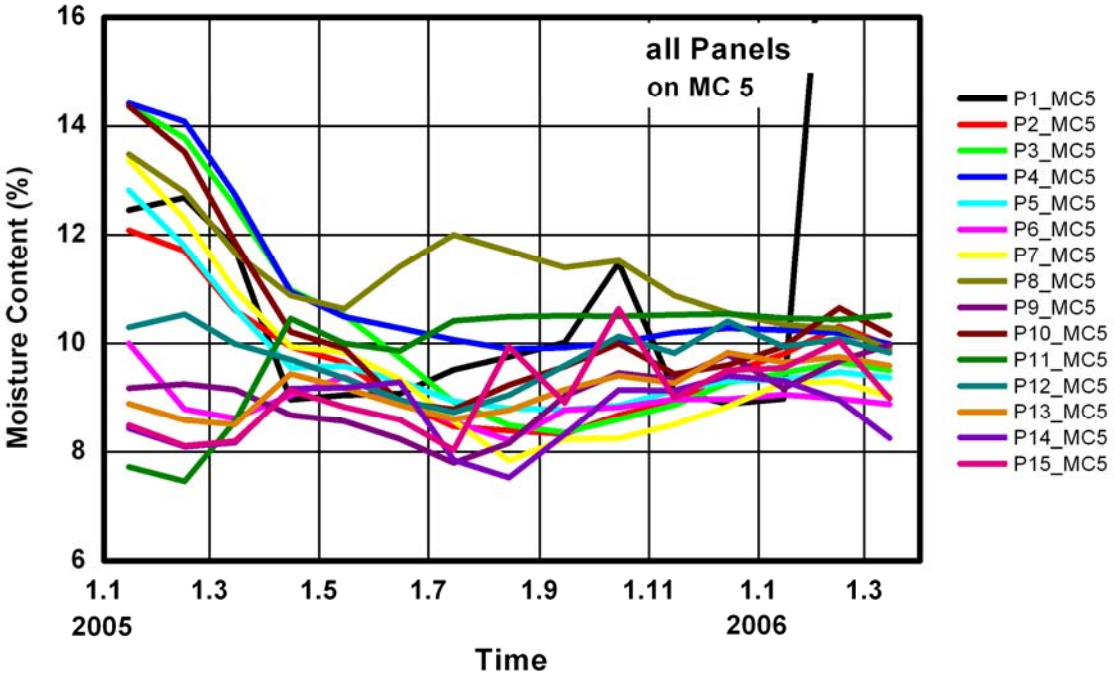

Figure 38: Measured Moisture Contents at Location 5

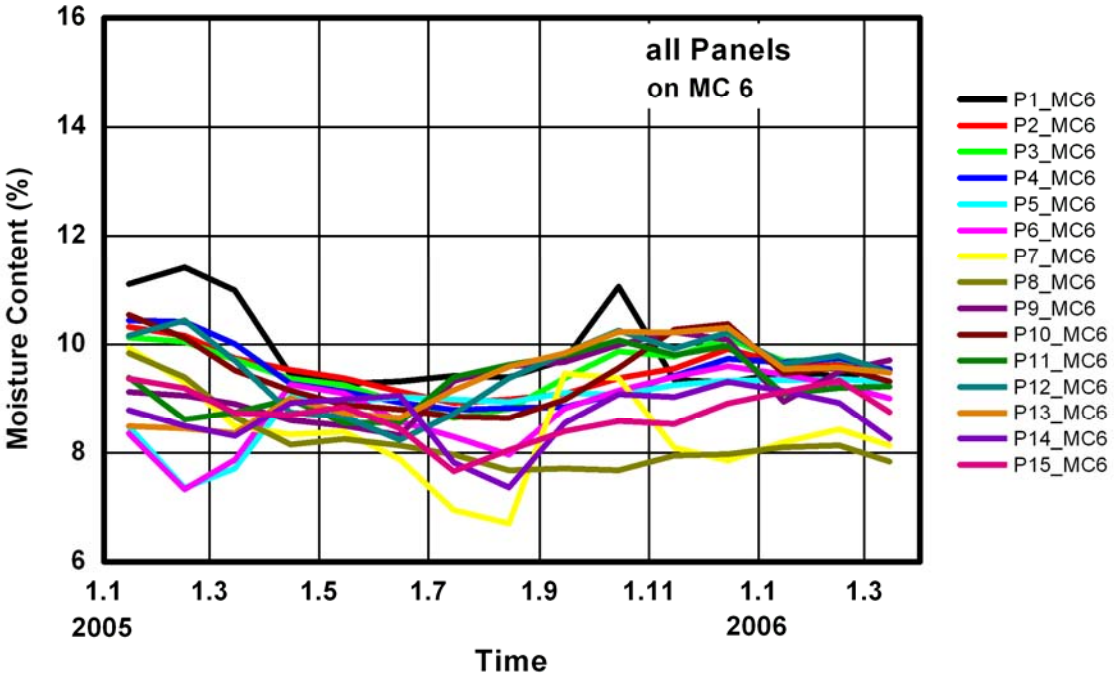

Figure 39: Measured Moisture Contents at Location 6

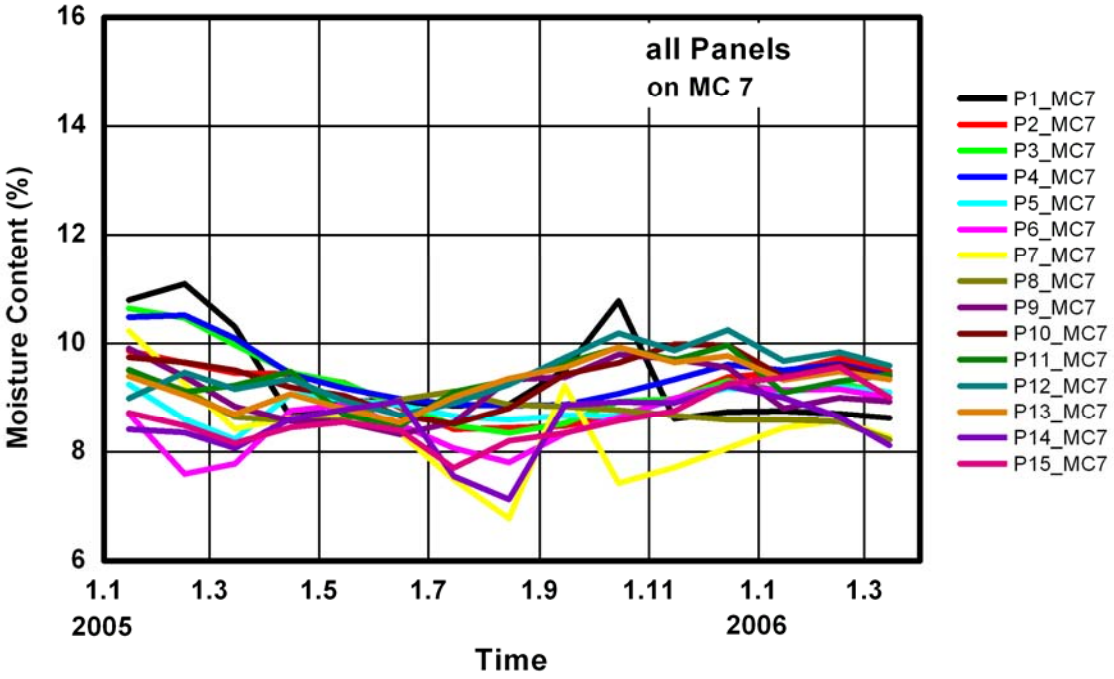

Figure 40: Measured Moisture Contents at Location 7

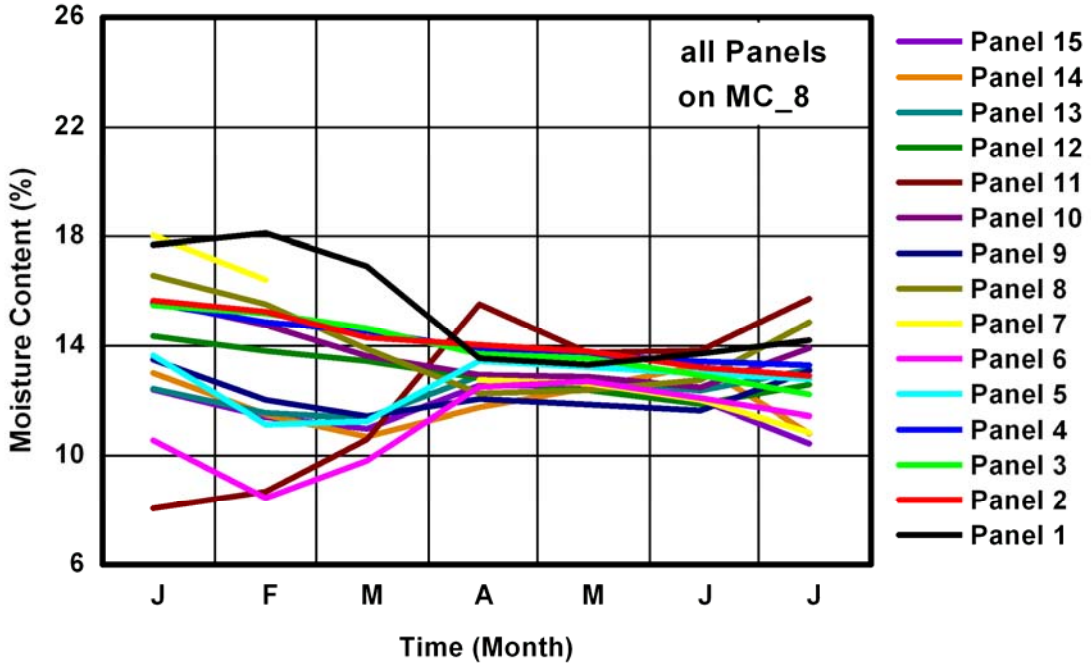

Figure 41: Measured Moisture Contents at Location 8

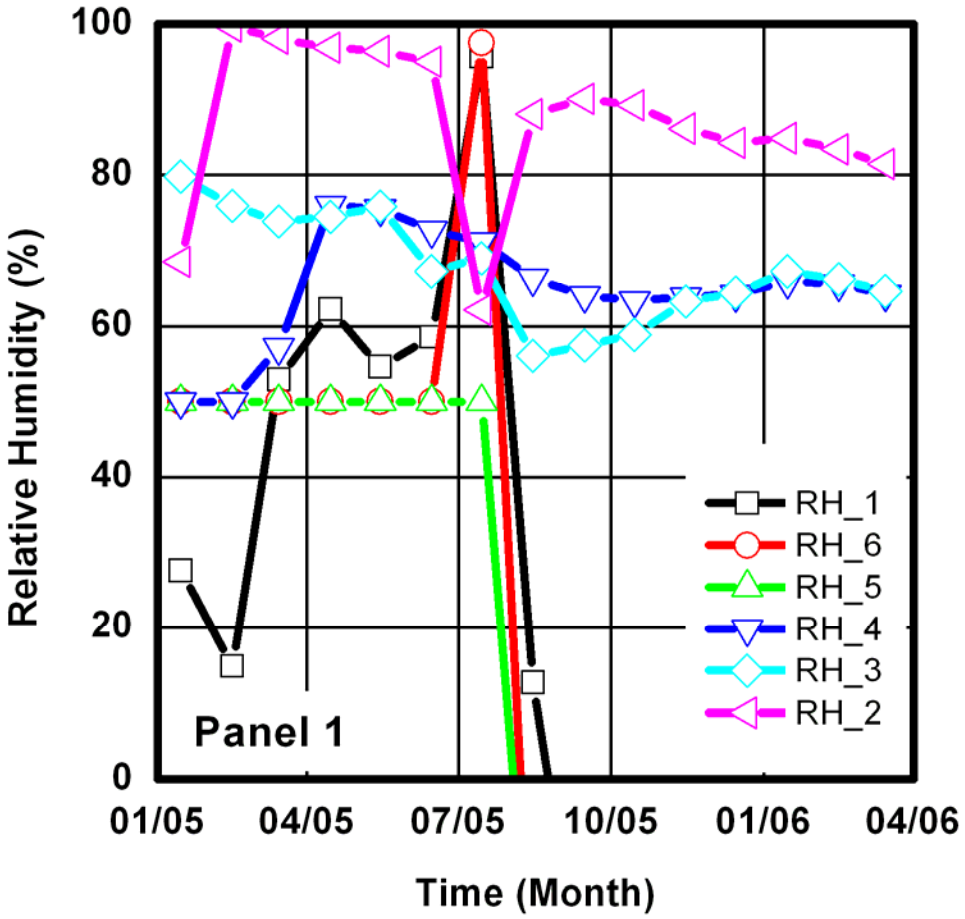

Figure 42: Measured Relative Humidity for Wall 1 (RH1, RH2 and RH3 sensors failed)

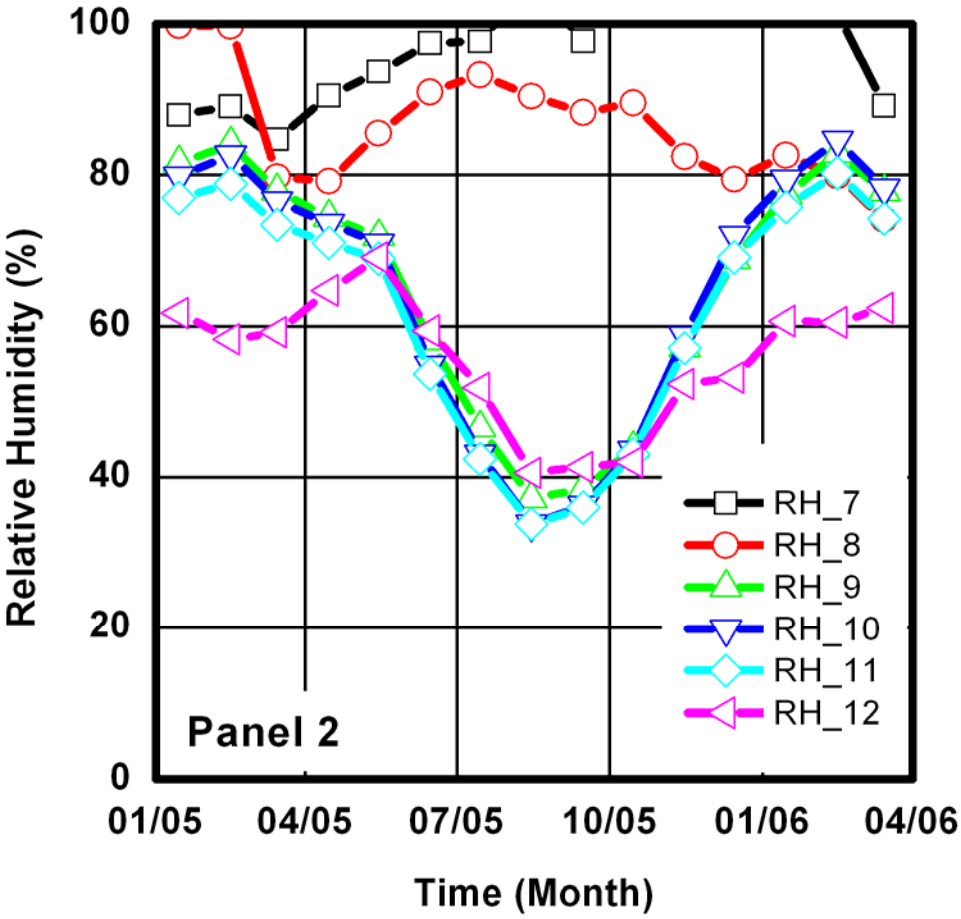

Figure 43: Measured Relative Humidity for Wall 2

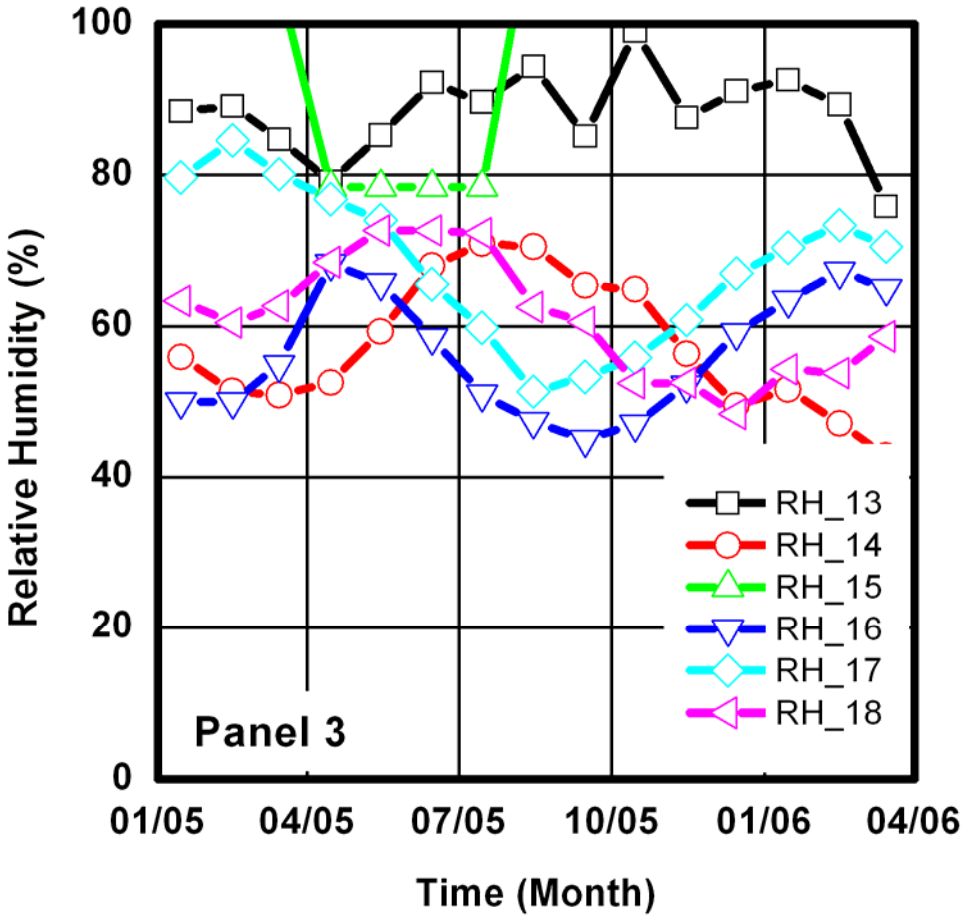

Figure 44: Measured Relative Humidity for Wall 3 (RH 15 sensors failed)

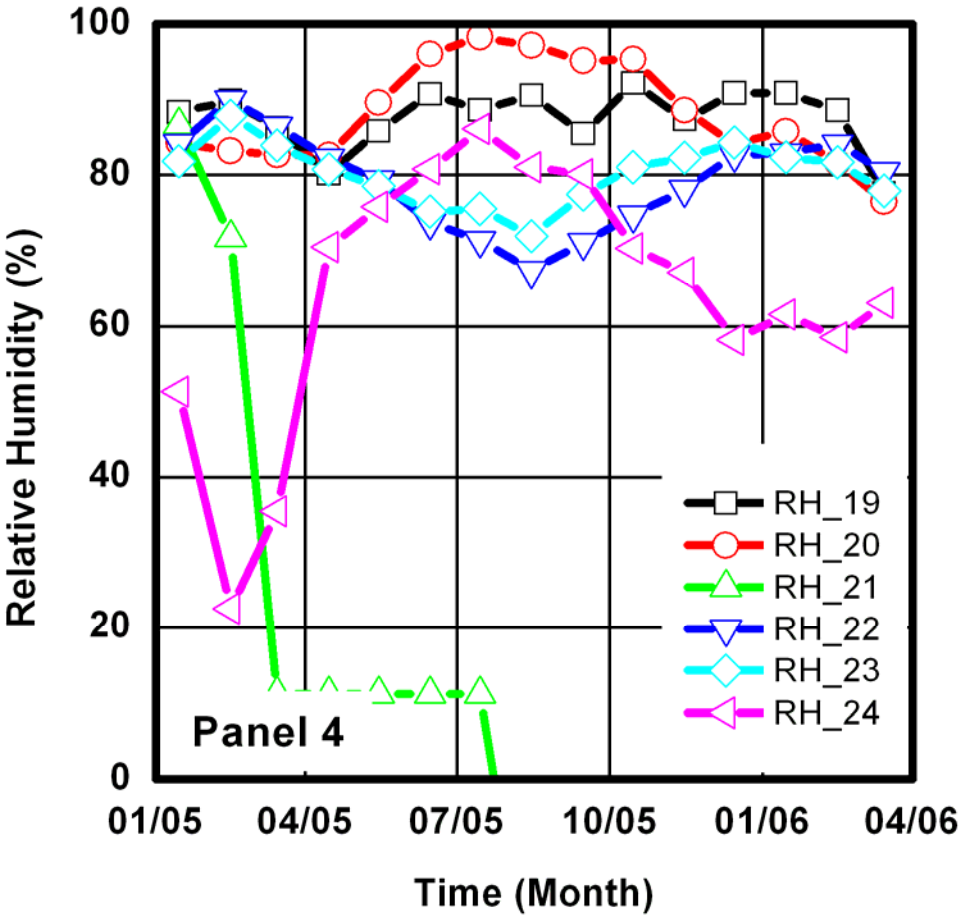

Figure 45: Measured Relative Humidity for Wall 4 (RH3 sensors failed)

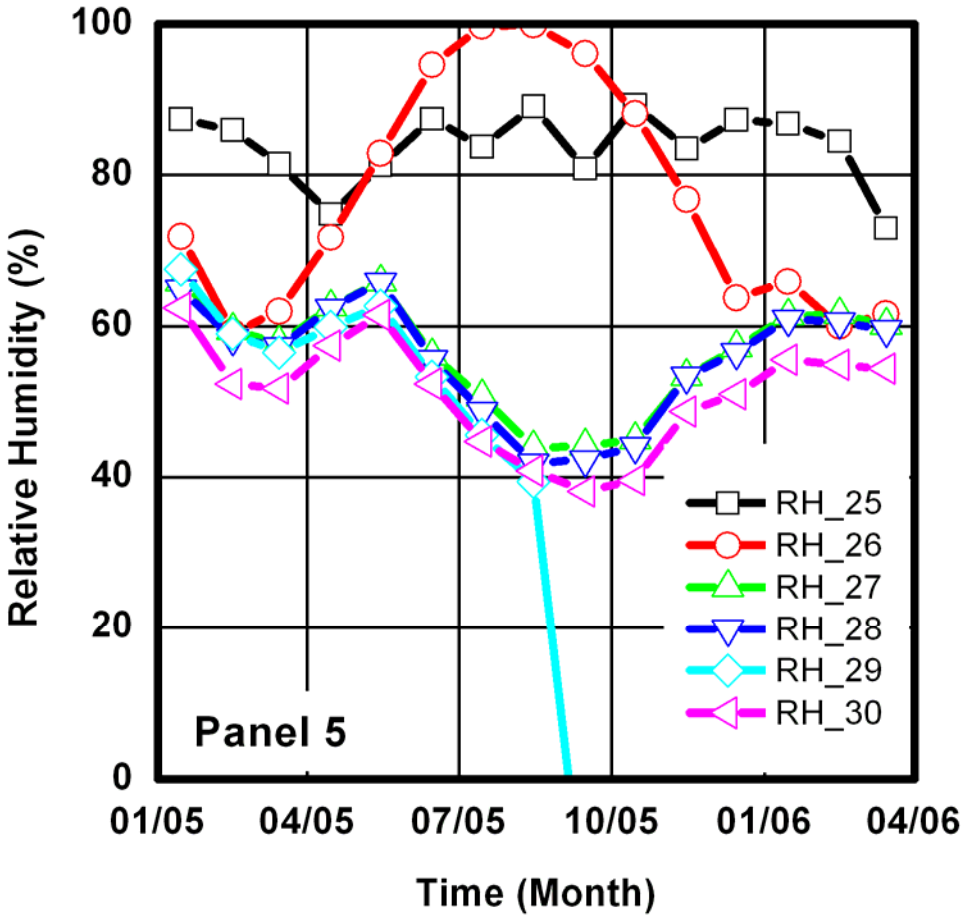

Figure 46: Measured Relative Humidity for Wall 5 (RH5 sensor failed)

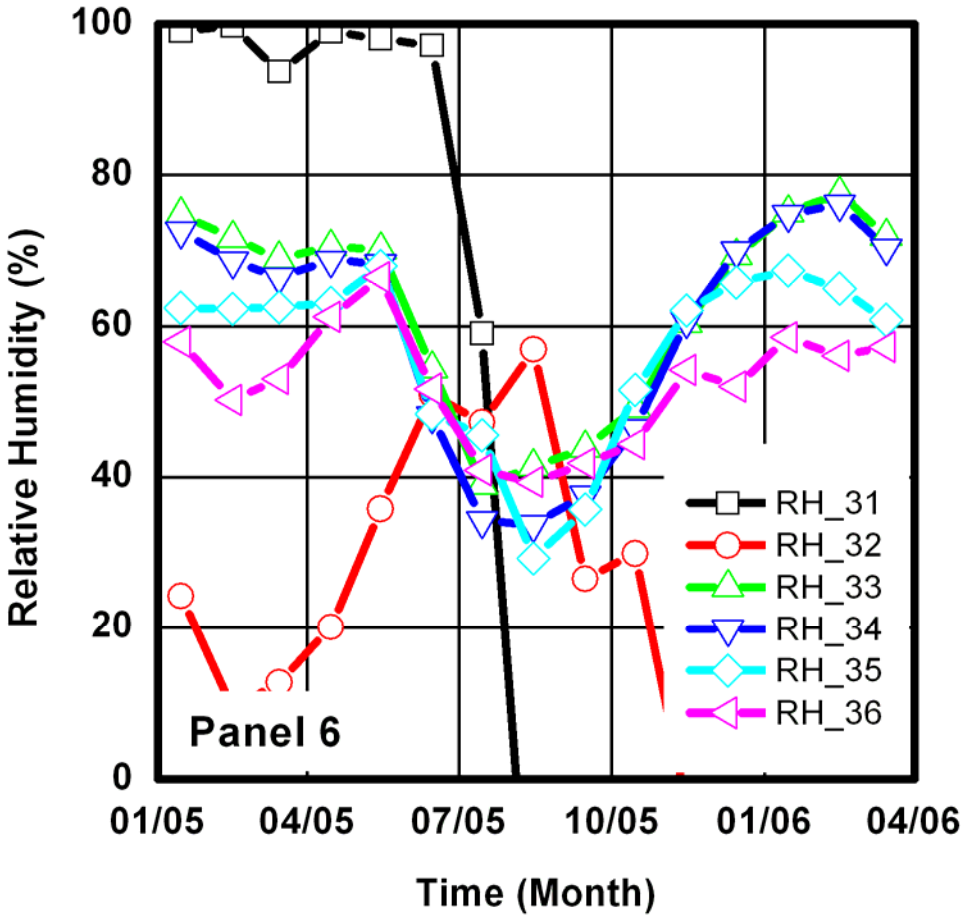

Figure 47: Measured Relative Humidity for Wall 6 (RH1 and RH2 sensors failed)

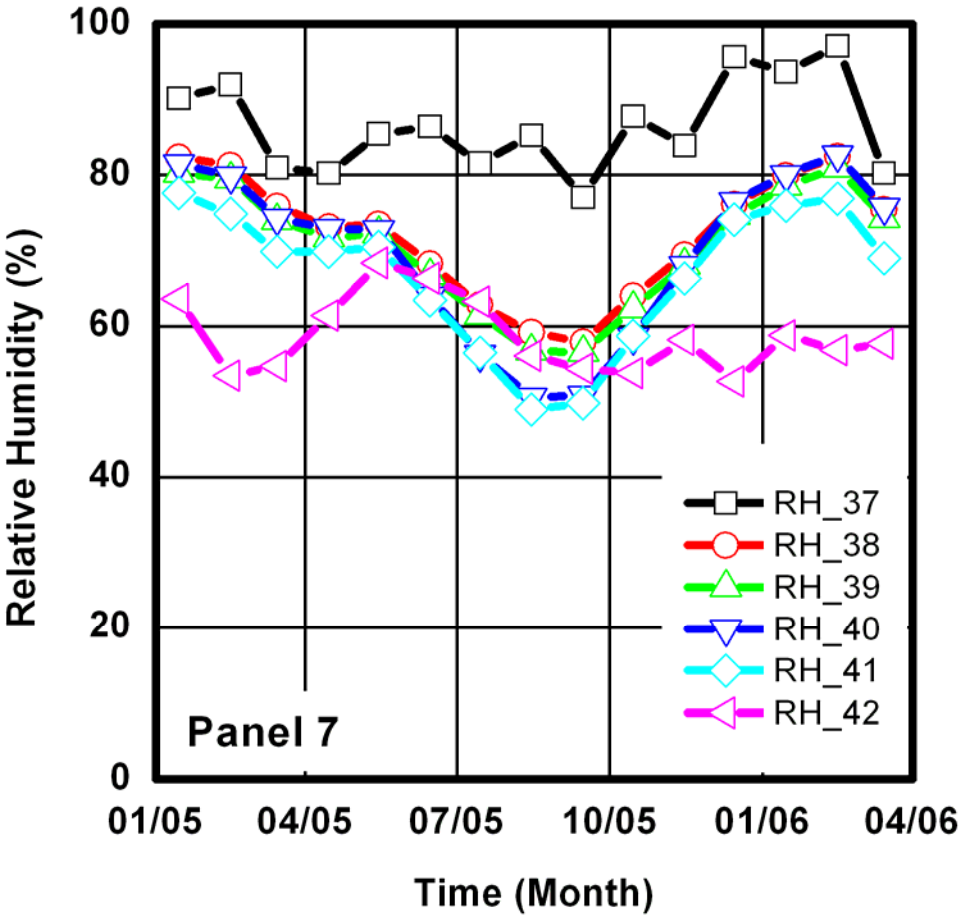

Figure 48: Measured Relative Humidity for Wall 7

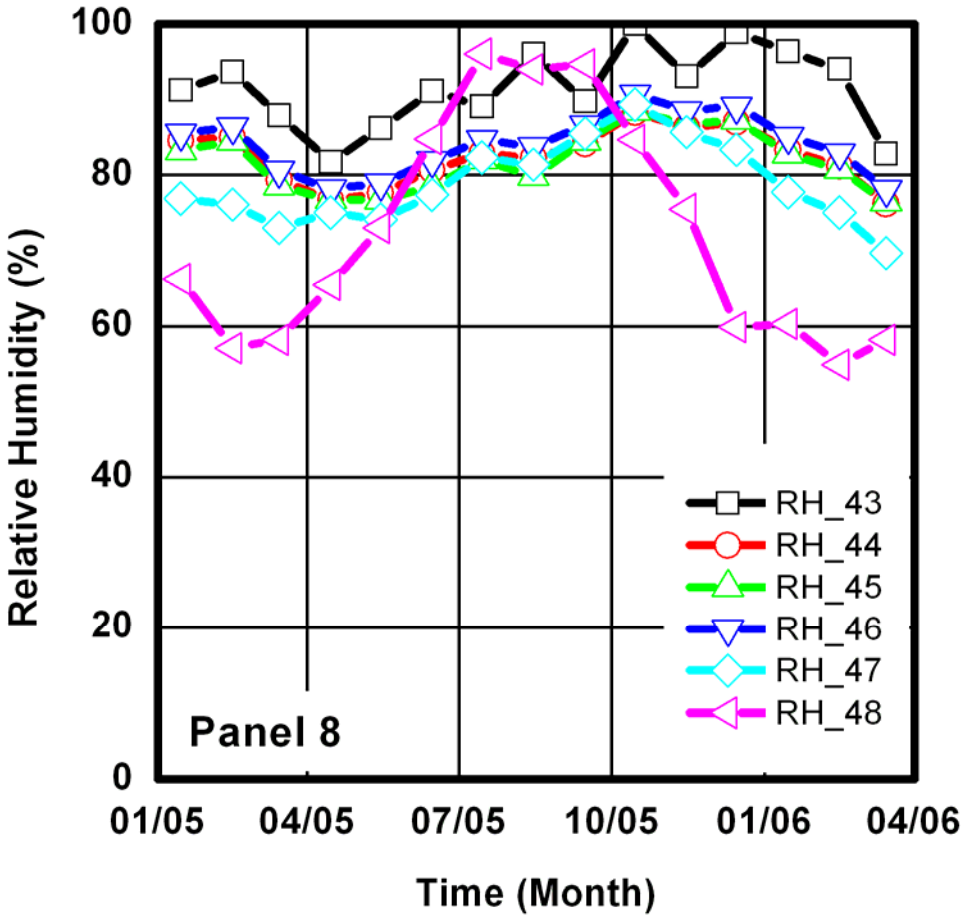

Figure 49: Measured Relative Humidity for Wall 8

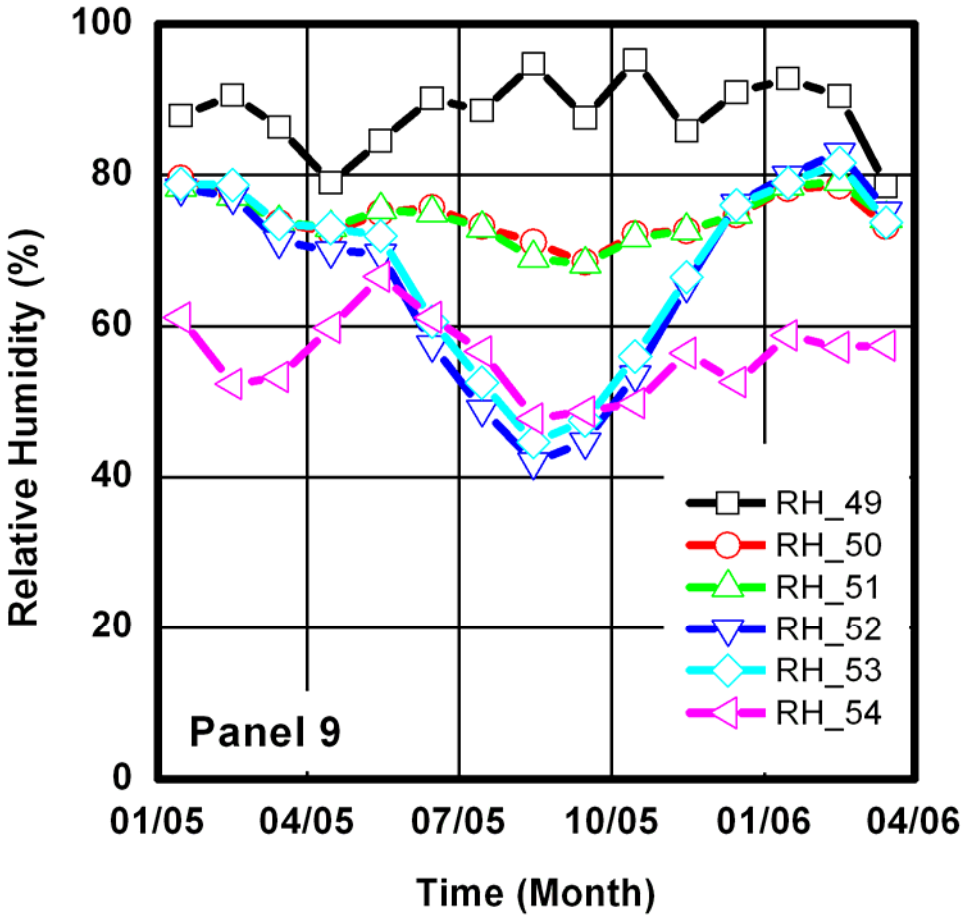

Figure 50: Measured Relative Humidity for Wall 9 (RH1, RH2 and RH3 sensors failed)

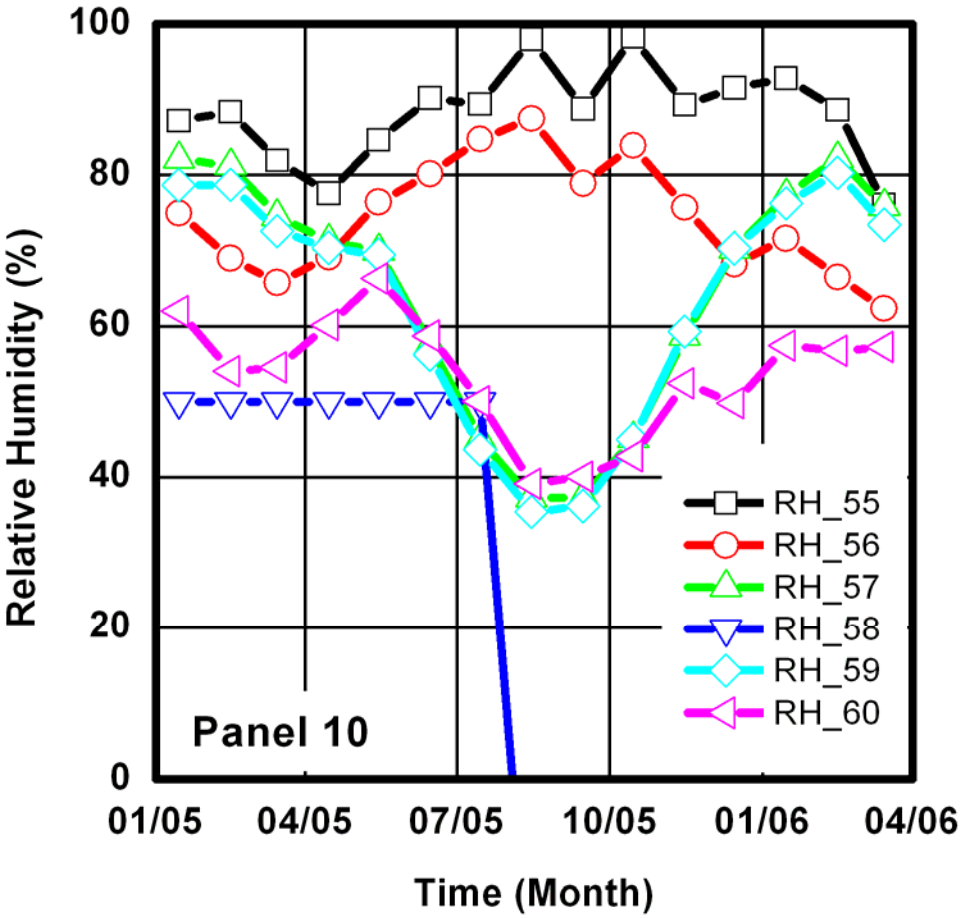

Figure 51: Measured Relative Humidity for Wall 10 (RH4 sensor failed)

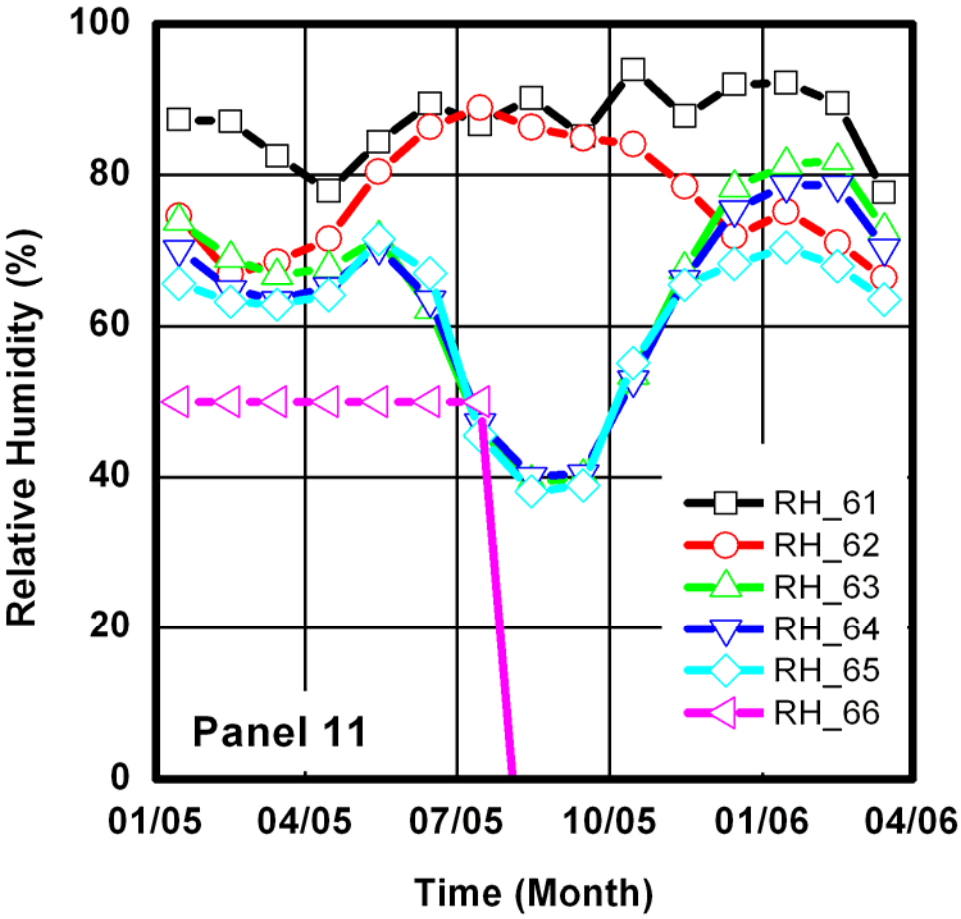

Figure 52: Measured Relative Humidity for Wall 11 (RH6 sensor failed)

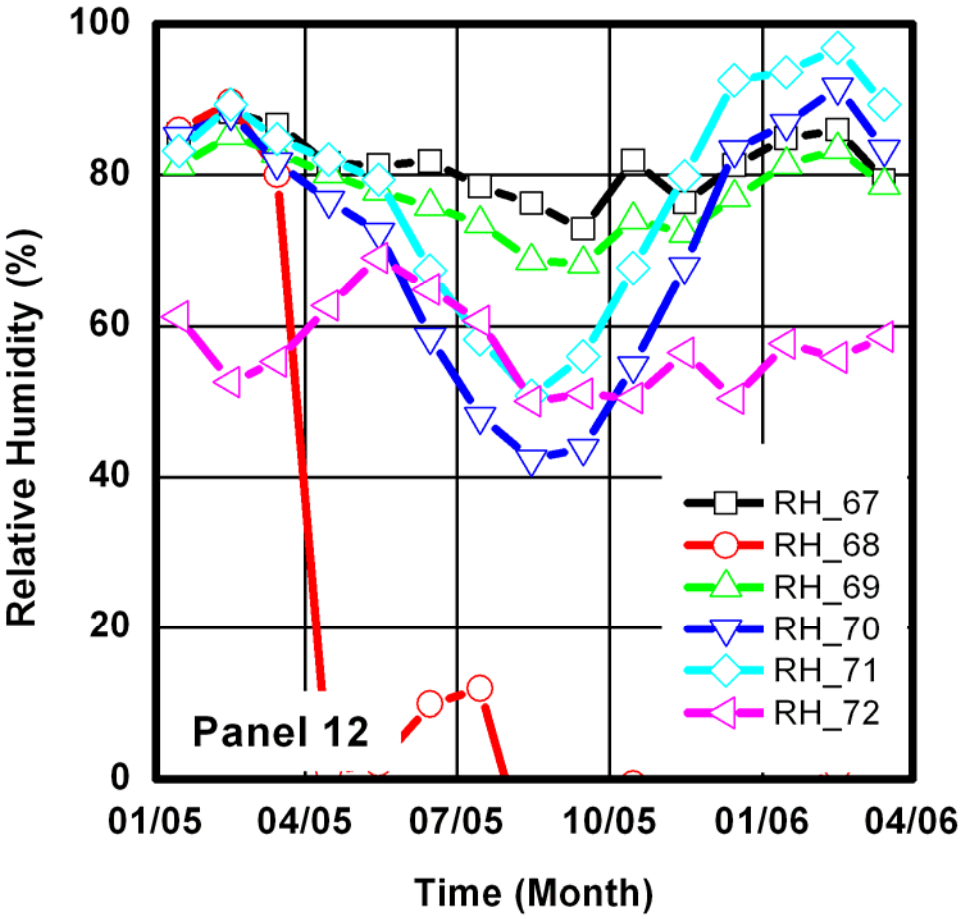

Figure 53: Measured Relative Humidity for Wall 12 (RH2 sensor failed)

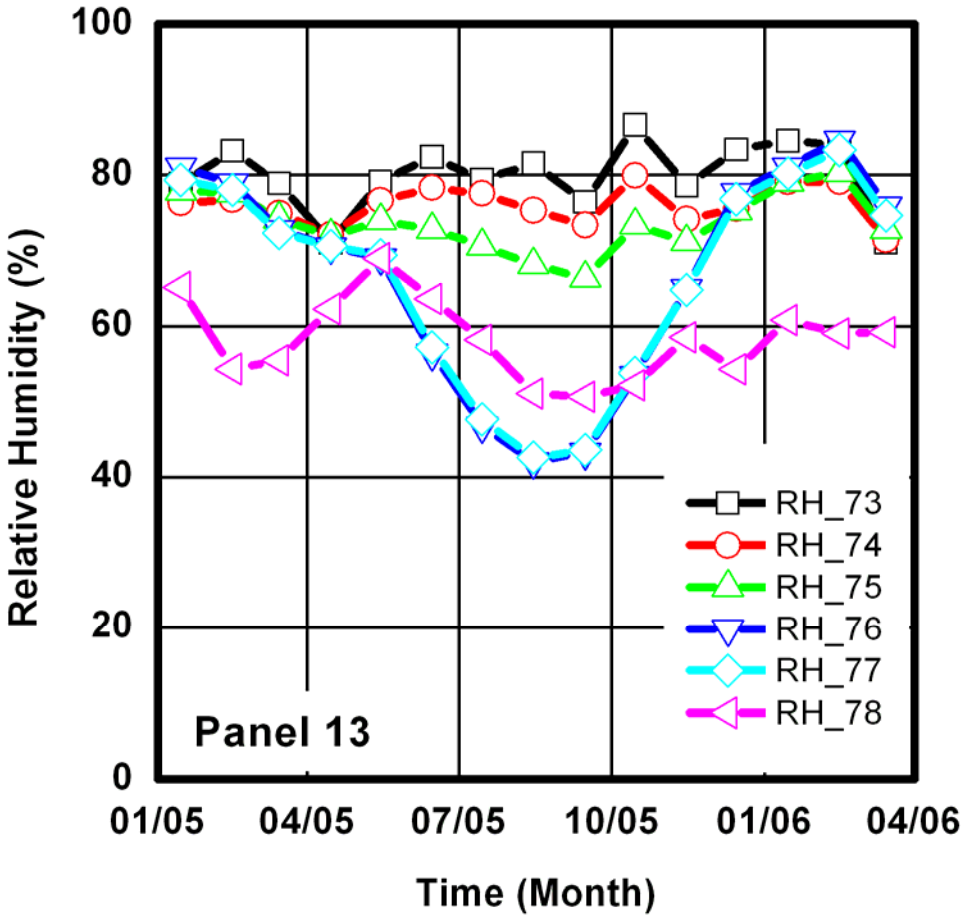

Figure 54: Measured Relative Humidity for Wall 13

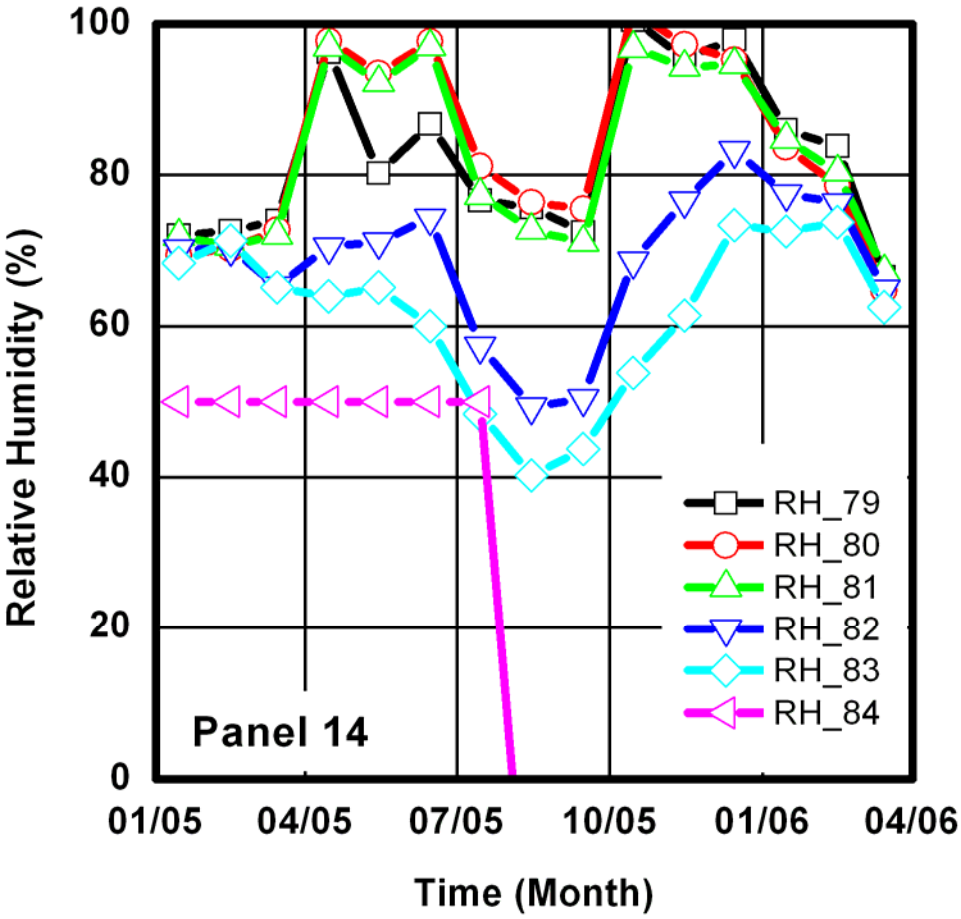

Figure 55: Measured Relative Humidity for Wall 14 (RH6 sensor failed)

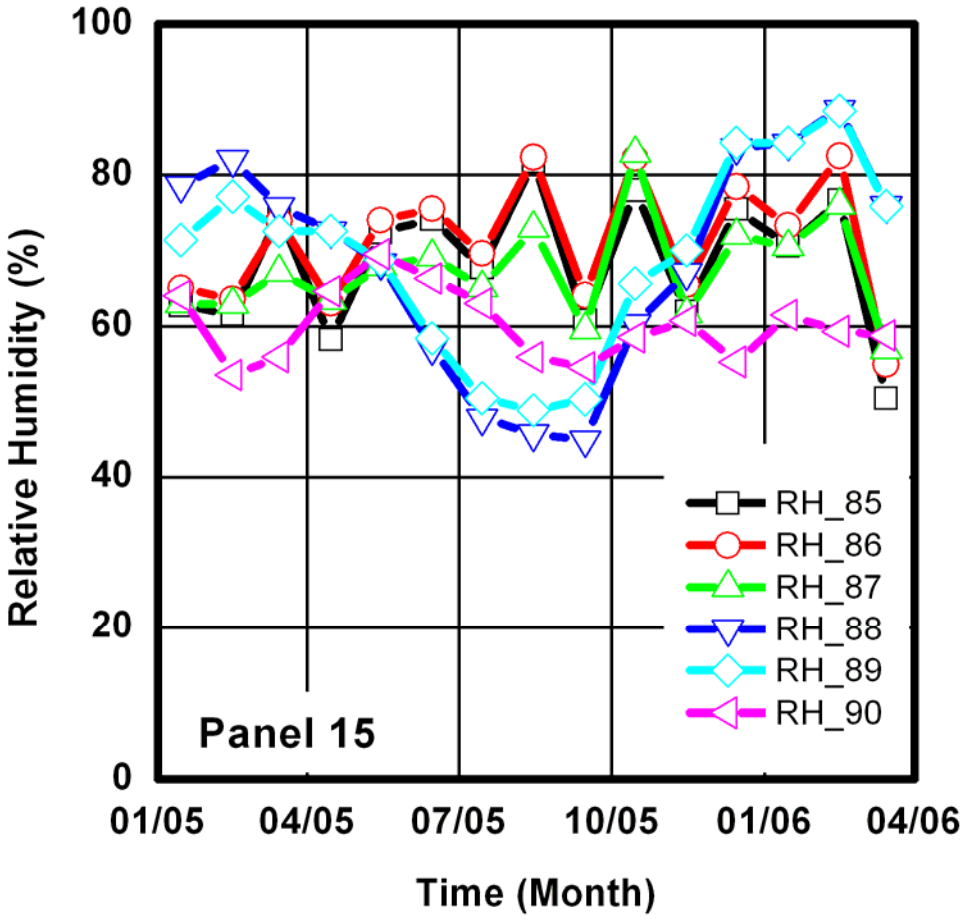

Figure 56: Measured Relative Humidity for Wall 15

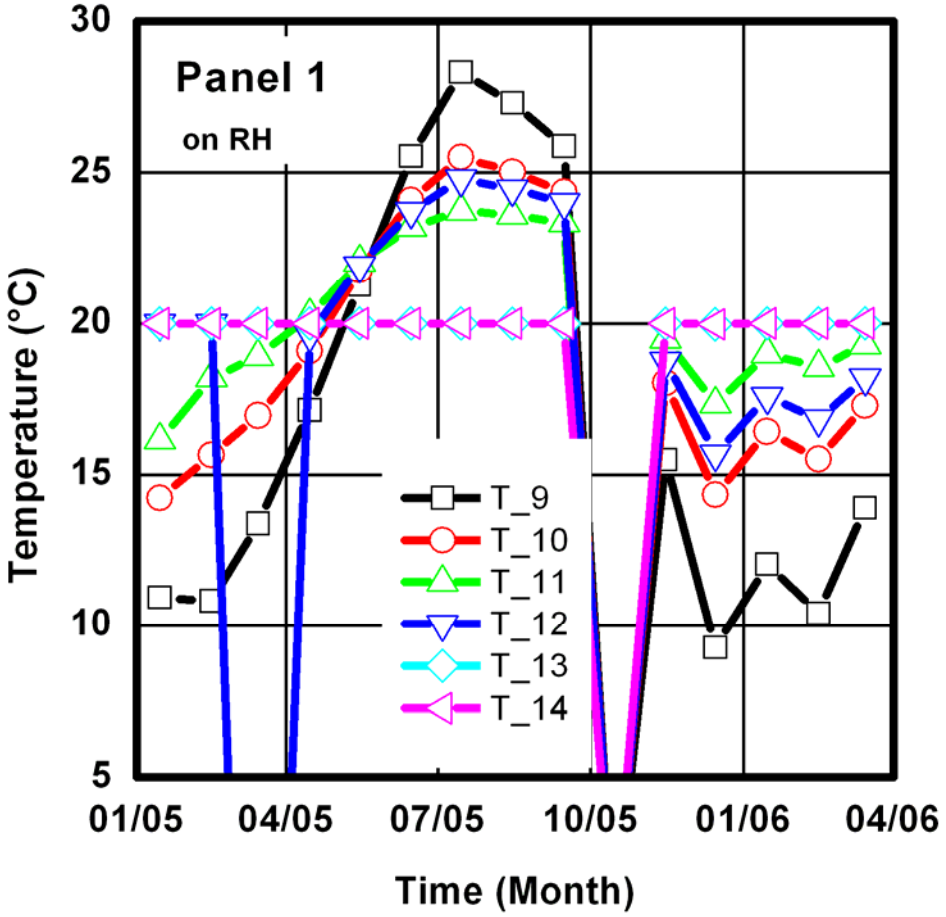

Figure 57: Measured Temperature at RH location for Wall 1 (RH1, RH2 and RH3 sensors failed)

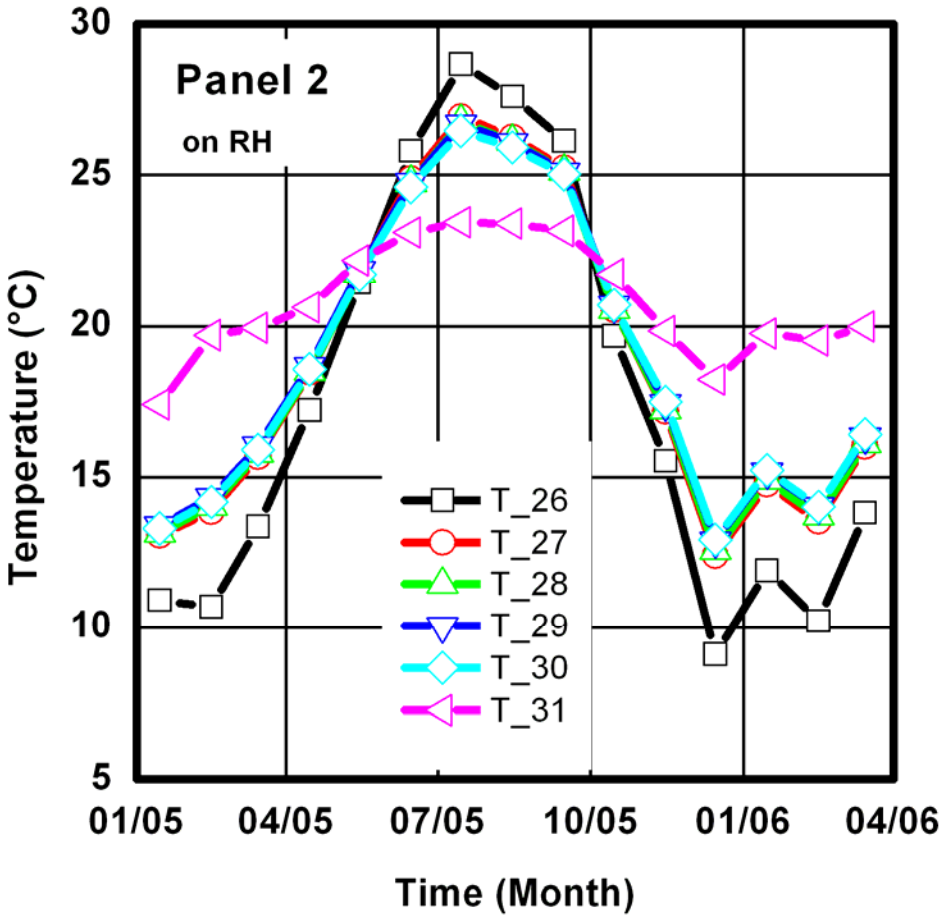

Figure 58: Measured Temperature at RH location for Wall 2

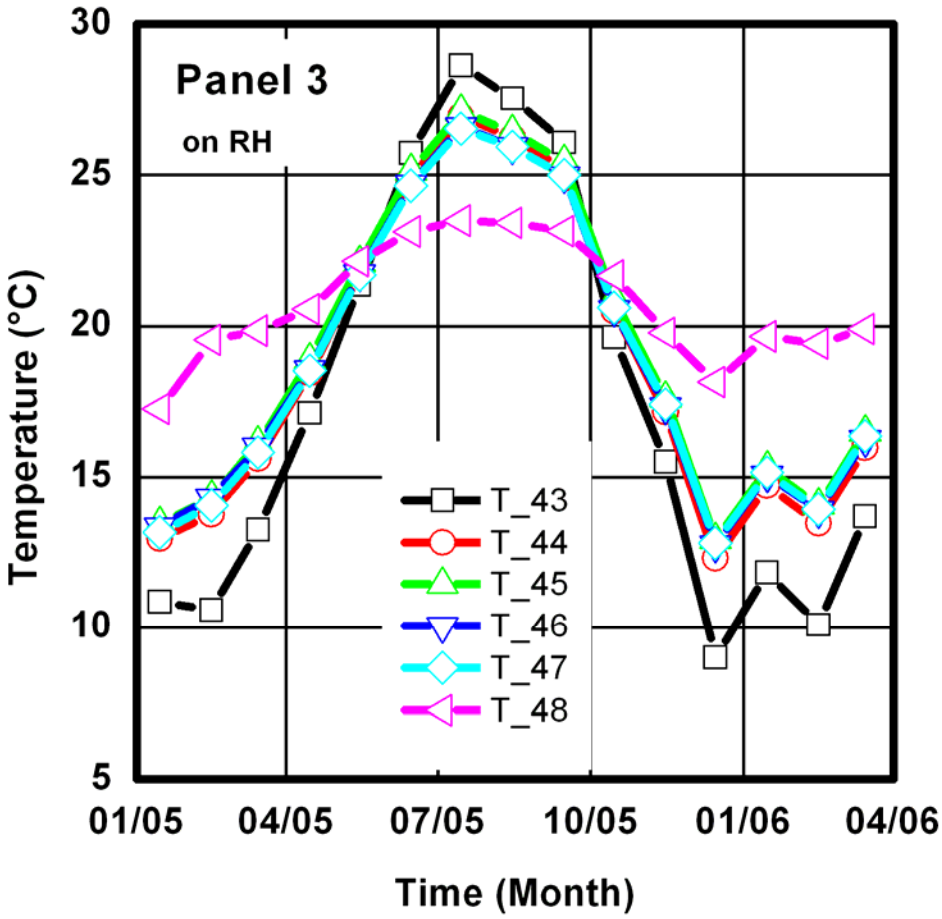

Figure 59: Measured Temperature at RH location for Wall 3 (RH 15 sensors failed)

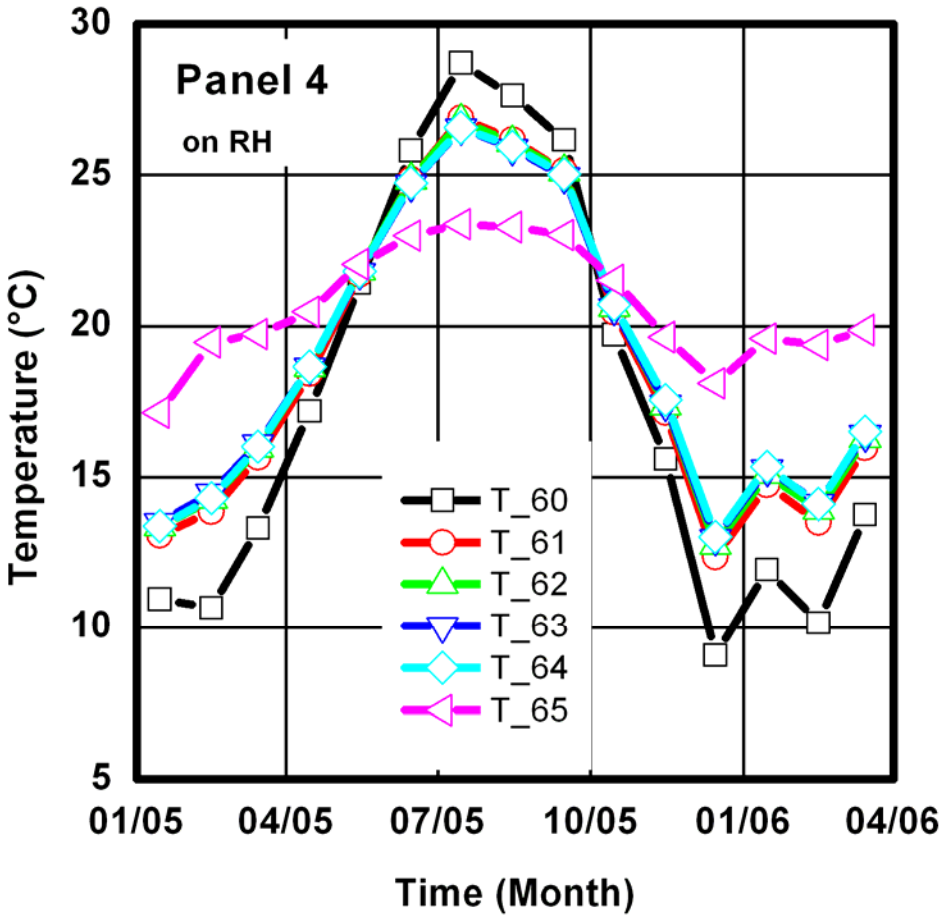

Figure 60: Measured Temperature at RH location for Wall 4 (RH3 sensors failed)

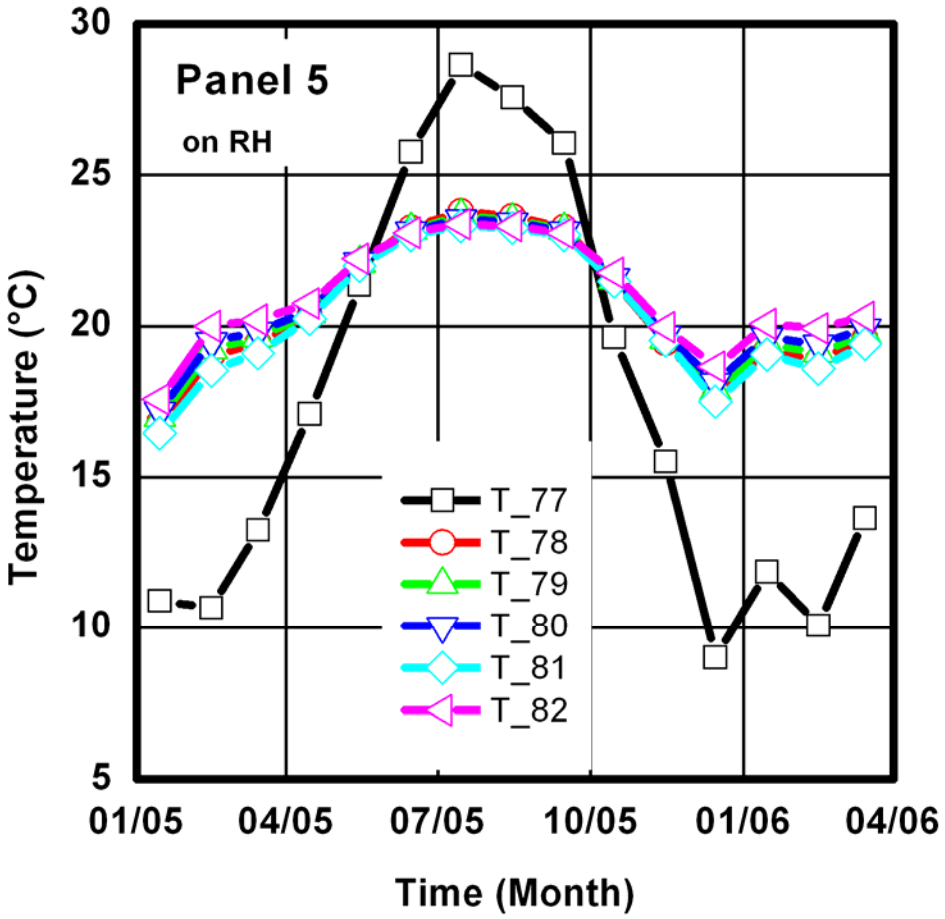

Figure 61: Measured Temperature at RH location for Wall 5 (RH5 sensor failed)

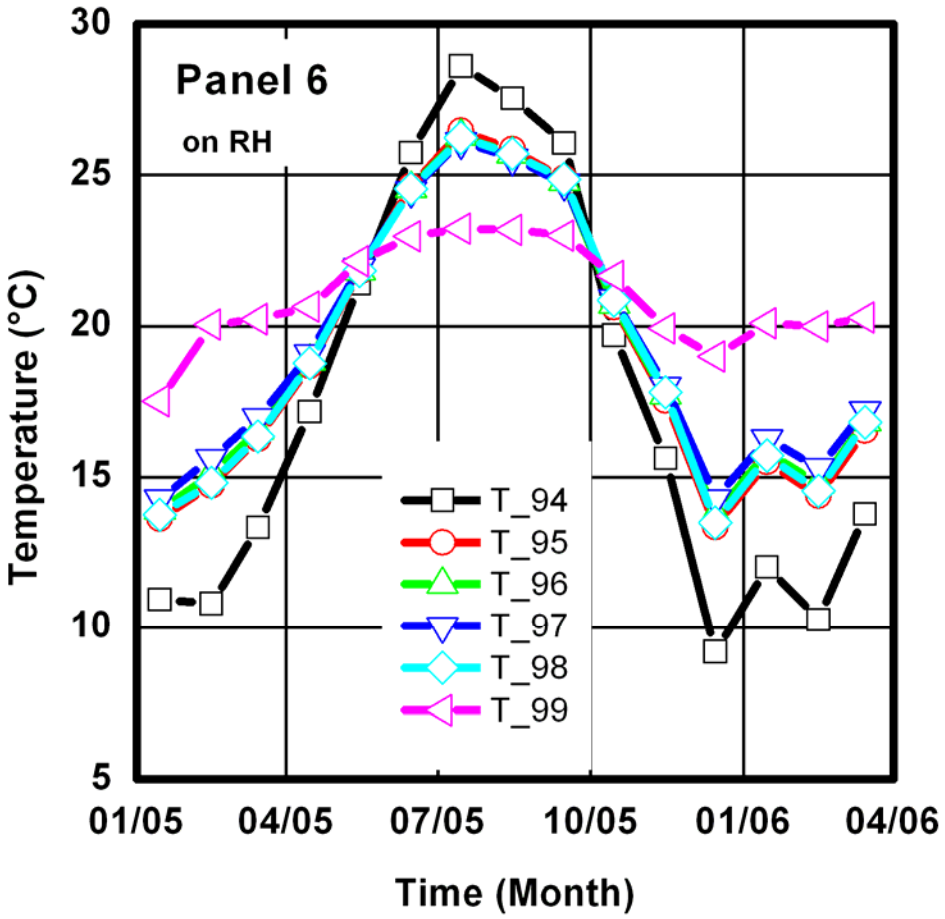

Figure 62: Measured Temperature at RH location for Wall 6 (RH1 and RH2 sensors failed)

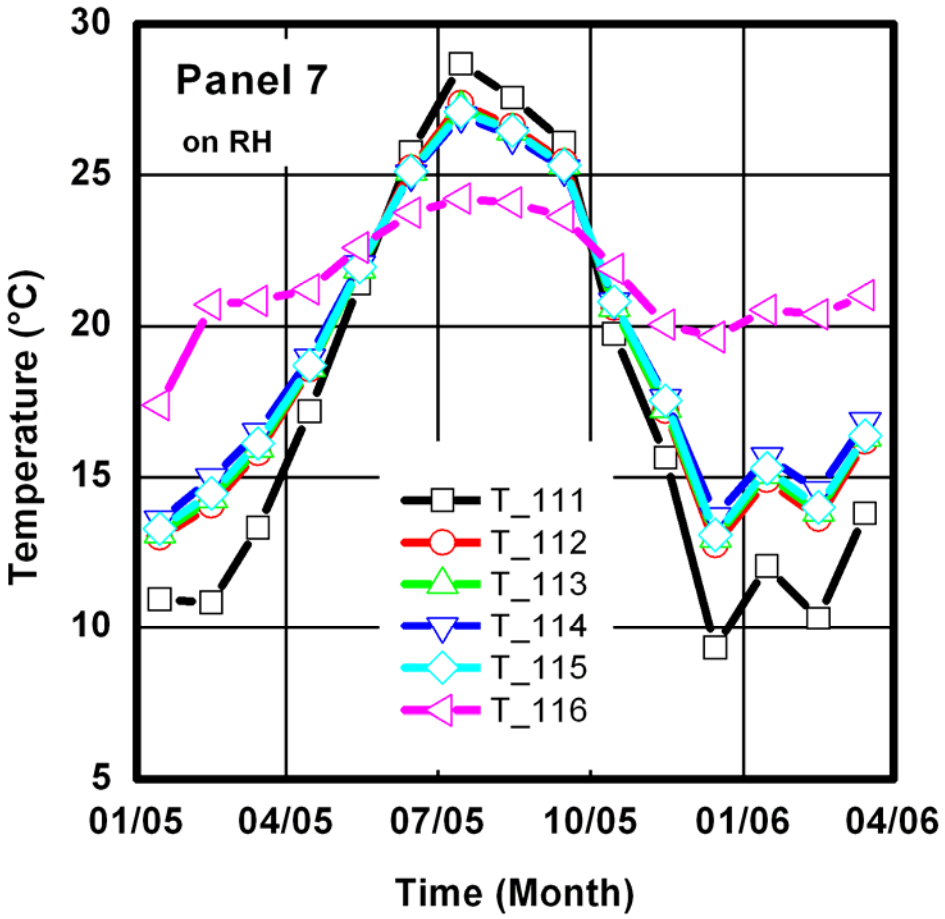

Figure 63: Measured Temperature at RH location for Wall 7

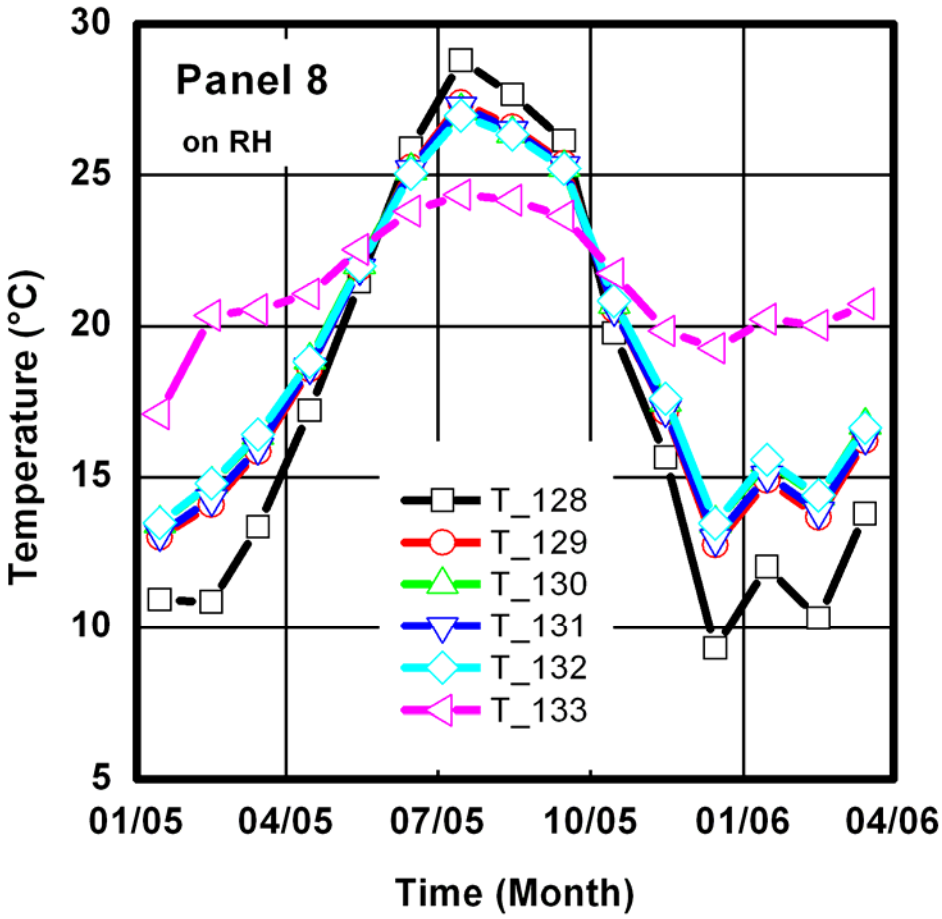

Figure 64: Measured Temperature at RH location for Wall 8

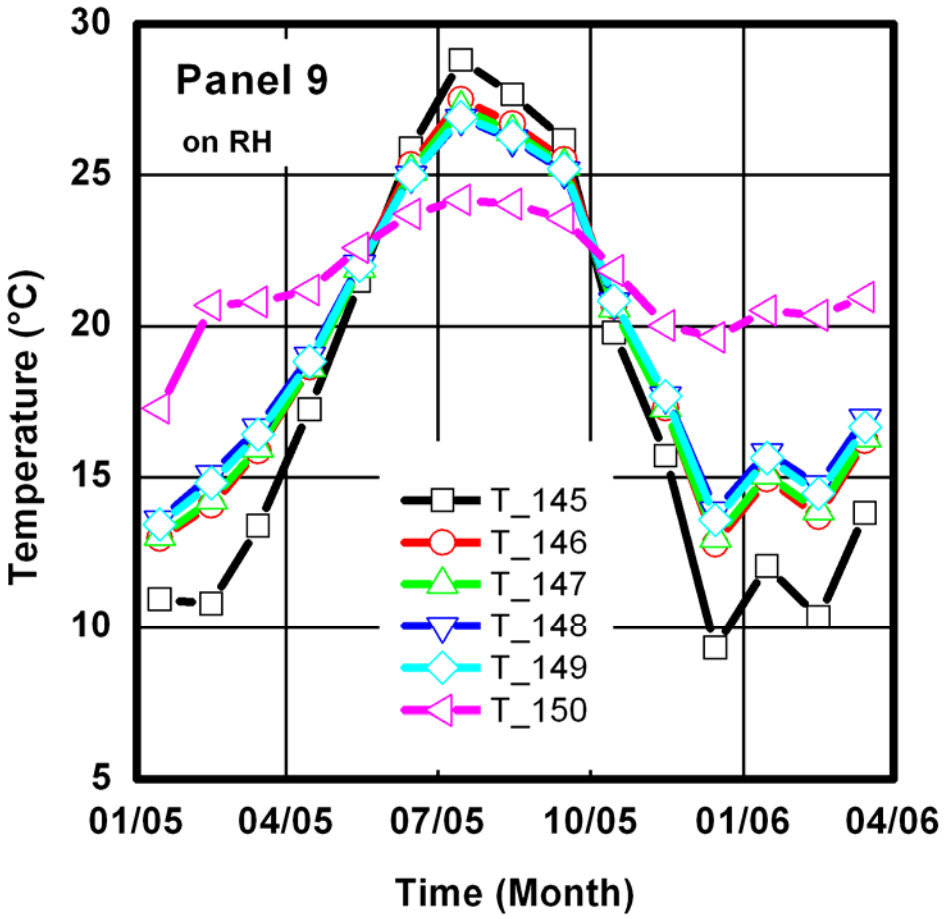

Figure 65: Measured Temperature at RH location for Wall 9 (RH1, RH2 and RH3 sensors failed)

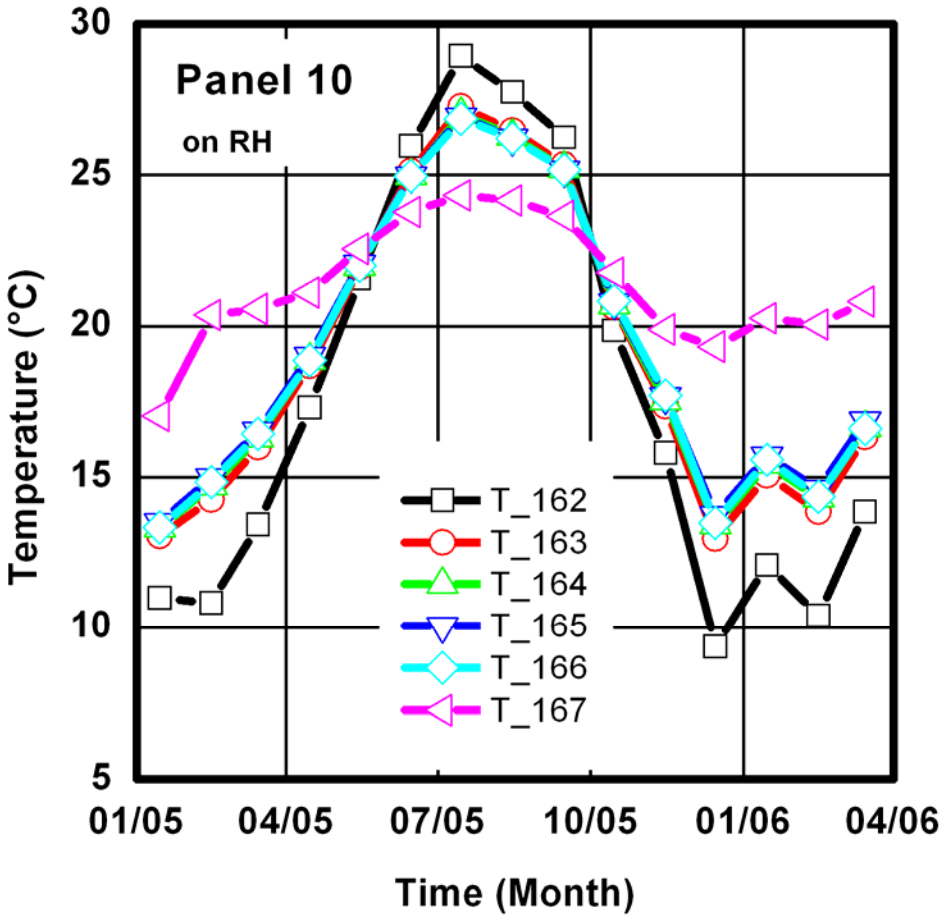

Figure 66: Measured Temperature at RH location for Wall 10 (RH4 sensor failed)

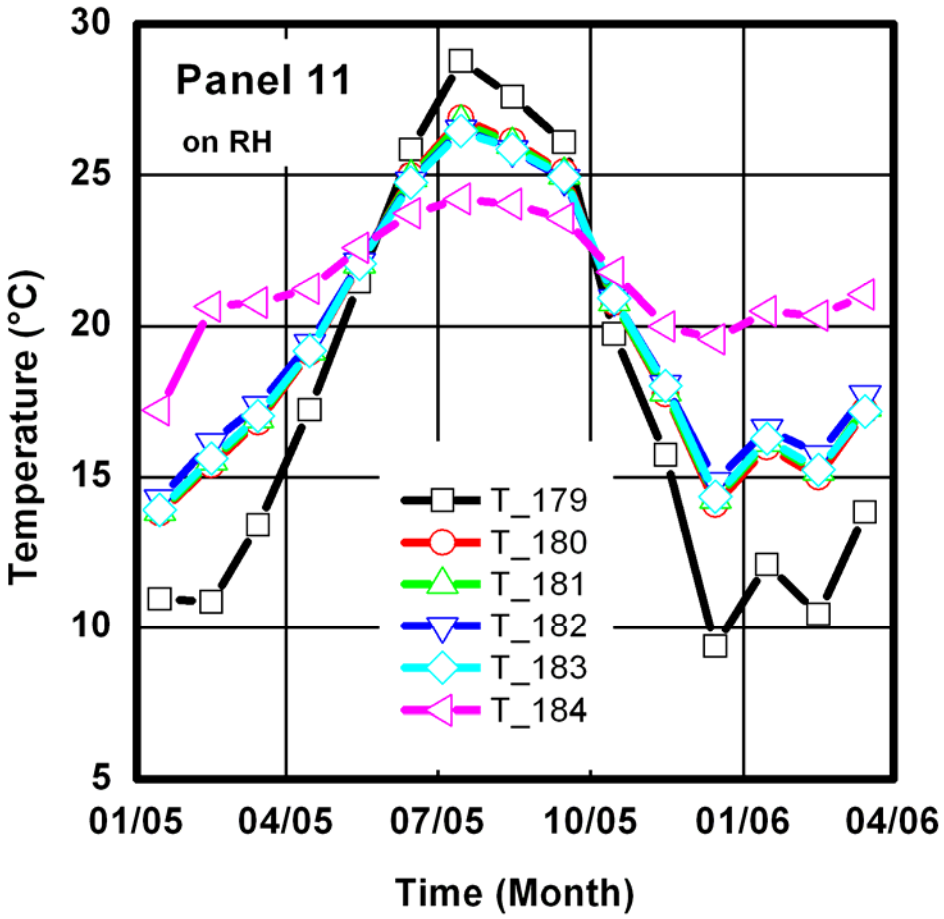

Figure 67: Measured Temperature at RH location for Wall 11 (RH6 sensor failed)

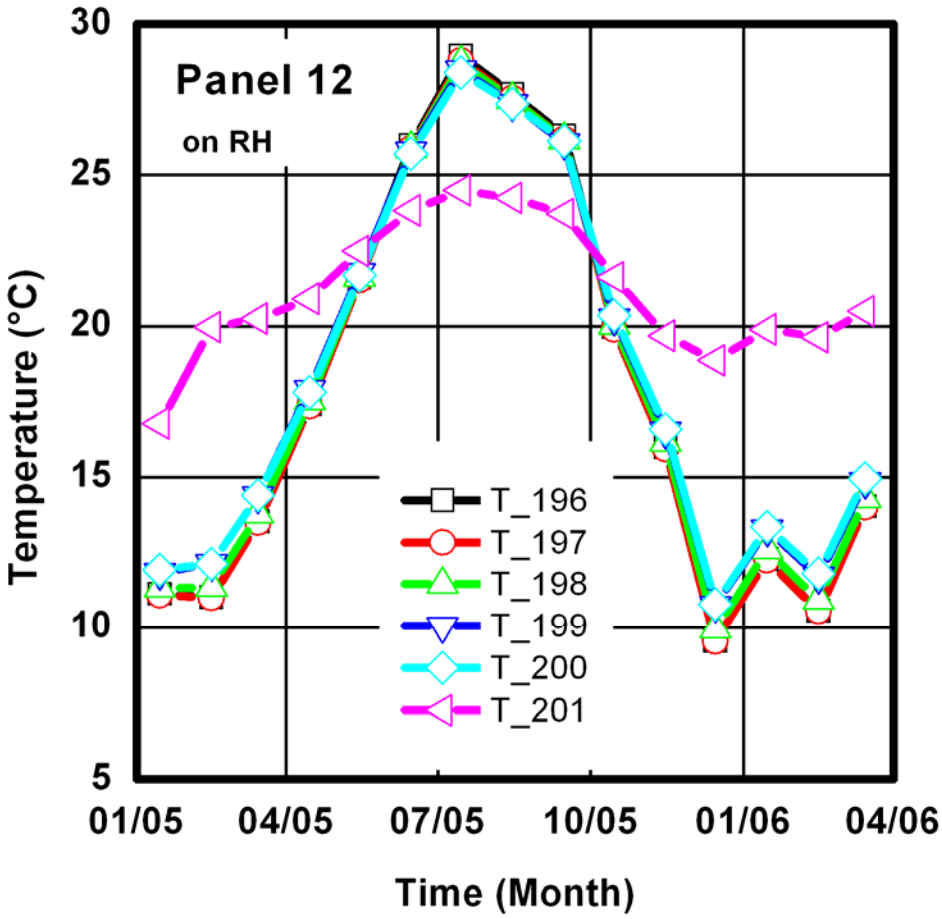

Figure 68: Measured Temperature at RH location for Wall 12 (RH2 sensor failed)

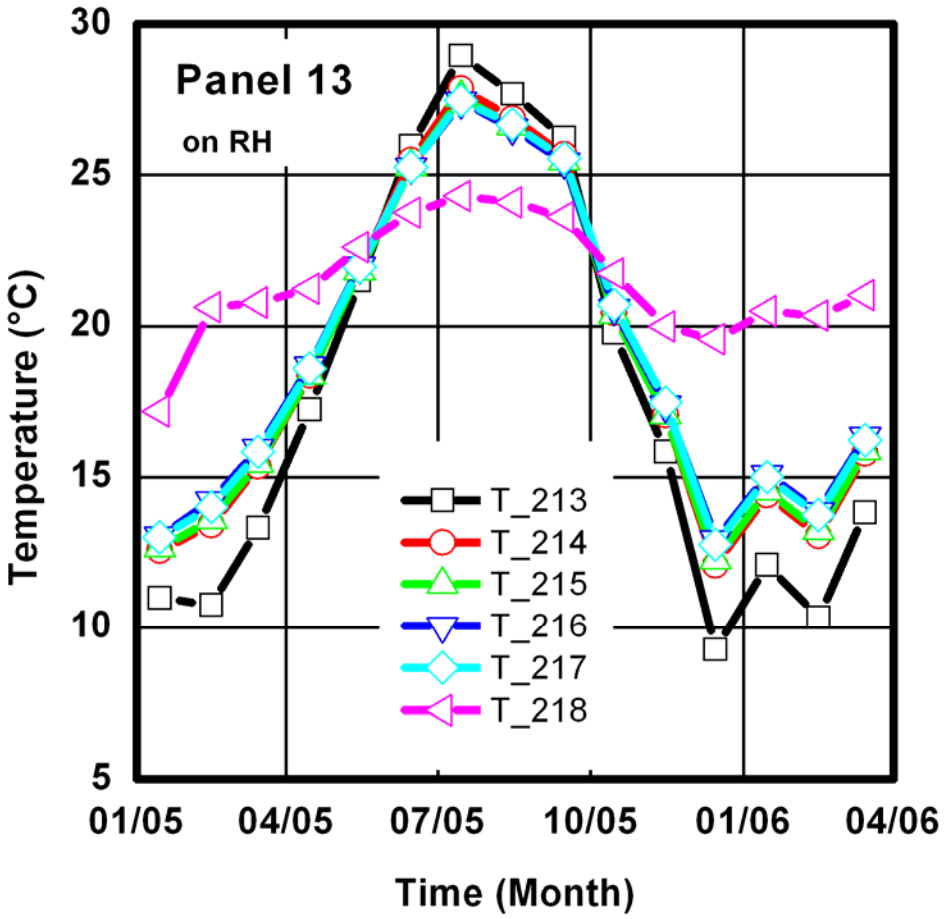

Figure 69: Measured Temperature at RH location for Wall 13

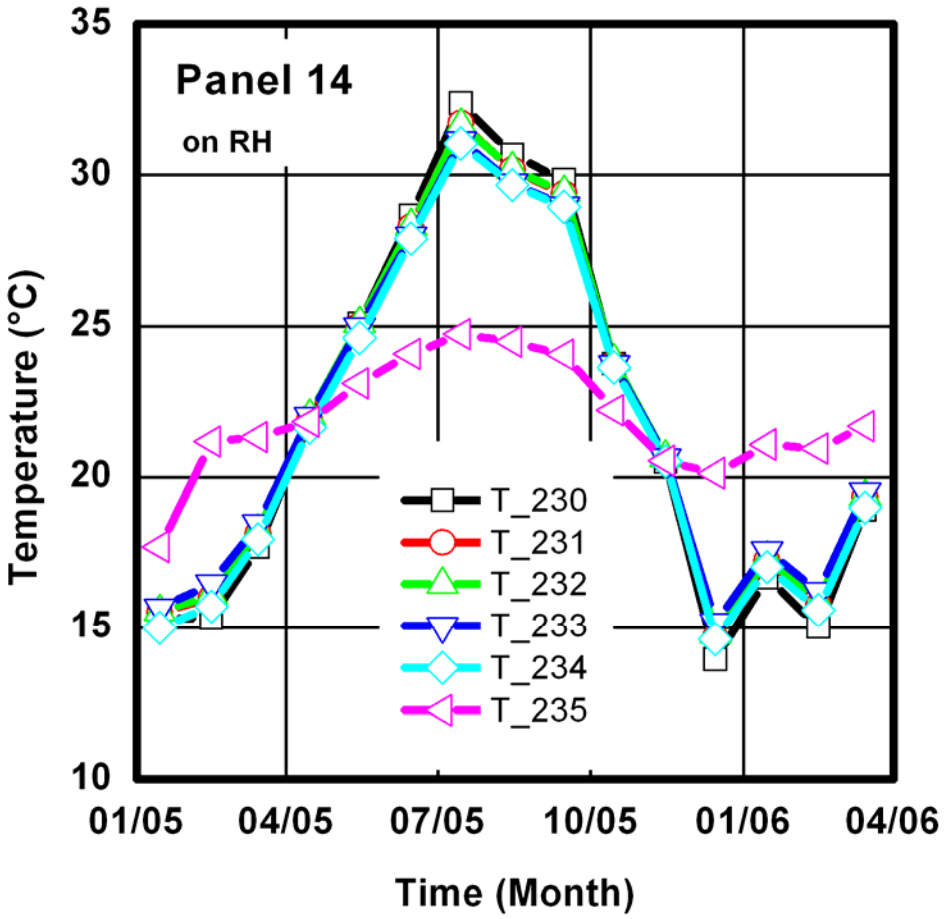

Figure 70: Measured Temperature at RH location for Wall 14 (RH6 sensor failed)

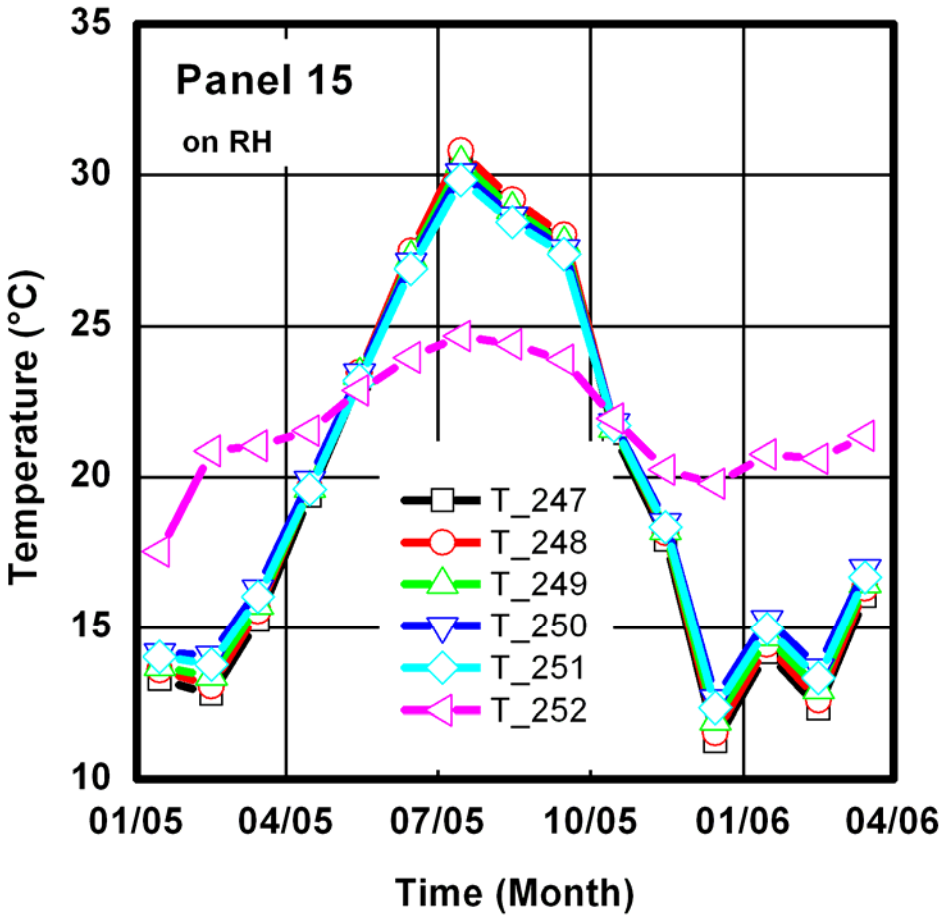

Figure 71: Measured Temperature at RH location for Wall 15